PTI
ENVIRONMENTAL SERVICES

Human Health Risk Assessment for the Clear Creek Management Area

Submitted to

Halliburton-NUS
Gaithersburg, Maryland

Prepared for

U.S. Department of the Interior
Bureau of Land Management
Hollister, California

September 1992

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ENVIRONMENTAL SERVICES
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ACRONYMS AND ABBREVIATIONS

ANOVA	analysis of variance
ATV	all-terrain-vehicle
CCMA	Clear Creek Management Area
f/cc	fibers per cm^3
EPA	U.S. Environmental Protection Agency
IRIS	Integrated Risk Information System
OSHA	Occupational Safety and Health Administration
PAT	proficiency analytical testing
PCM	phase contrast microscopy
PTI	PTI Environmental Services
QA/QC	quality assurance and quality control
RME	reasonable maximum exposure
TEM	transmission electron microscopy
TWA	time-weighted average
URF	unit risk factor
$_{u}URF$	unofficial unit risk factor

HUMAN HEALTH RISK ASSESSMENT

INTRODUCTION

This document presents the baseline human health risk assessment for the Clear Creek Management Area (CCMA). A baseline risk assessment is an analysis of the potential adverse effects on human health or environmental receptors that could result from exposure (current or future) to hazardous substances or materials (e.g., chrysotile asbestos) released from a site in the absence of any actions to control or mitigate these releases (i.e., under the no-action alternative). This assessment addresses human health concerns only and focuses on risks associated with inhalation of airborne asbestos generated during off-road vehicle use, as well as other site uses (such as hiking or camping) that generate less dust. Human health risks associated with ingestion of asbestos will not be addressed because inhalation is expected to be the primary contributor to exposure and risk. In addition, evidence for carcinogenic effects of asbestos following ingestion is inconclusive, and the U.S. Environmental Protection Agency (EPA) has not developed an asbestos toxicity value for use in risk assessment of oral exposures. This human health risk assessment will be used to:

- Evaluate potential adverse effects associated with inhalation of chrysotile asbestos present within the CCMA from naturally occurring serpentine deposits
- Develop public education materials about potential human health risks at the site
- Develop risk assessment methods that can be used to evaluate management alternatives for the CCMA.

In developing a management plan for the CCMA, the results of the human health risk assessment will be considered together with evaluations of the potential for erosion of the asbestos present at the site or for the asbestos to cause environmental impacts on ecological species (e.g., the evening primrose) or surface water.

The risk assessment follows EPA guidance provided in EPA Region IX *Risk Assessment Guidance for Superfund* (U.S. EPA 1989c) and in the EPA federal *Exposure Factors Handbook* (U.S. EPA 1989a), *Risk Assessment Guidance for Superfund* (U.S. EPA 1989b), and *Standard Default Exposure Factors* (U.S. EPA 1991b). In addition, this assessment builds on previous research conducted at the CCMA by investigators from the University of California at Berkeley (Popendorf and Wenk 1983; Cooper et al. 1979; Murchio et al. 1978), on the risk assessment conducted by EPA for the Atlas mine within the CCMA and the town of Coalinga (U.S. EPA 1990a), and on visitors' estimates of site use reported in transcripts from the Atlas Asbestos Company Superfund site community meeting (U.S. EPA 1990b).

The risk assessment is composed of four components: data analysis; exposure assessment; toxicity assessment; and risk characterization (Figure 1). In *Data Analysis*, the first section of this chapter, available asbestos air concentration data from EPA, researchers at the University of California at Berkeley, and BLM are described and a dataset is selected for use in the risk assessment. The *Exposure Assessment* section follows with a discussion of site use and estimates of exposure point concentrations for site visitors, the only population of concern for this risk assessment. The *Toxicity Assessment* section describes available dose-response data on the carcinogenicity of inhaled asbestos including a discussion of the ongoing re-evaluation of the EPA unit risk factor (URF) for asbestos. In *Risk Characterization*, the final section of this chapter, quantitative estimates of risk are derived by combining exposure and dose-response data. This section also provides a qualitative discussion of uncertainties associated with risk estimates.

DATA ANALYSIS

Several datasets were reviewed for use in this risk assessment. This section provides an overview of these datasets and a discussion of analyses conducted to evaluate 1) data quality and 2) correlations between asbestos concentrations and activity or season. The last part of this section describes data selected for use in the risk assessment.

Available Data

To select data for use in the risk assessment, the following data sources providing asbestos concentrations in ambient air in the CCMA were reviewed:

- Ambient air measurements and model estimates of asbestos concentrations in air presented in the U.S. EPA (1990a) risk assessment for the Atlas mine and the town of Coalinga
- Activity-specific ambient air data collected by BLM as part of its occupational safety and health program
- Ambient air data collected by researchers at the University of California at Berkeley (Popendorf and Wenk 1983, Cooper et al. 1979, Murchio et al. 1978).

The strengths and limitations of these datasets are discussed in the following sections.

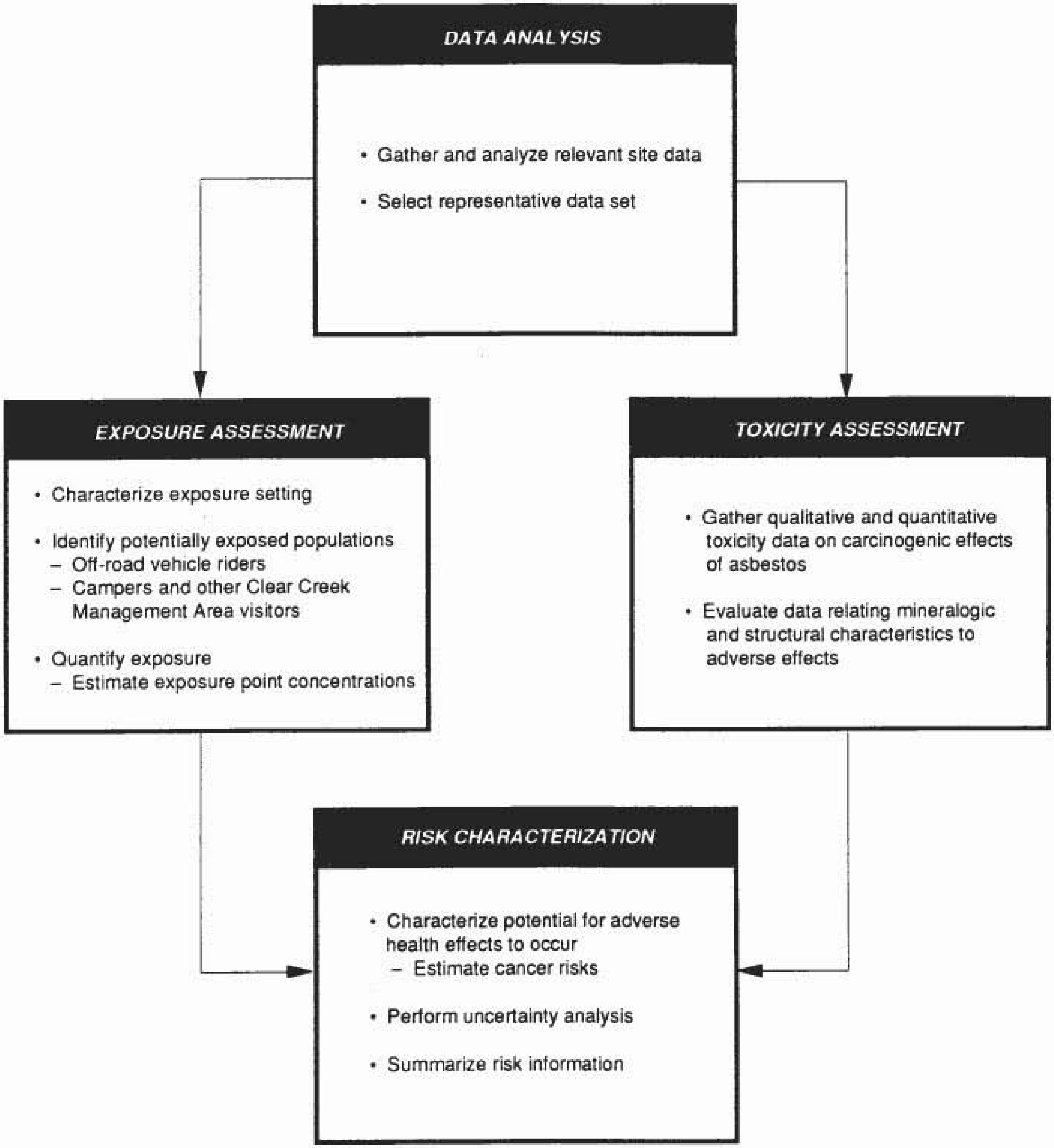


Figure 1. Major components of the baseline human health risk assessment for the Clear Creek Management Area.

Data Used in the U.S. EPA (1990a) Risk Assessment

Both air monitoring and air modeling data presented in U.S. EPA (1990a) were reviewed to determine their potential use in a risk assessment for the CCMA. However, neither of these datasets is appropriate for assessing risks at the CCMA. U.S. EPA (1990a) air monitoring data were collected from stationary samplers. Although these data can potentially be of some use in estimating ambient conditions, the data were not intended to be representative of activity-specific airborne asbestos concentrations. In addition, none of the air sampling data were collected during periods when the wind was strong enough to cause soil resuspension. For these reasons, ambient air data collected in U.S. EPA (1990a) were not used by EPA to derive quantitative risk estimates in the risk assessment for Atlas Mine and Coalinga. Instead, U.S. EPA (1990a) used ambient air concentrations estimated through modeling. These limitations, together with the placement of sampling stations at locations intended to evaluate impacts of Atlas Mine on surrounding offsite communities, preclude the use of the air monitoring data presented in U.S. EPA (1990a) in a risk assessment for the CCMA.

Limitations were also identified in the air modeling data used in the U.S. EPA (1990a) risk assessment. Therefore, these data were not suitable for use in the CCMA risk assessment. Fundamental limitations in the modeling data with respect to use in the risk assessment for the Atlas and Coalinga sites were identified in previous comments submitted by PTI Environmental Services (PTI) to BLM (PTI 1990). These limitations are likely to result in overestimation of emissions and include the following: 1) assuming in the air modeling that the entire tailings pile and mine surface areas are completely disturbed on a monthly basis, 2) failing to account for reduced erosion associated with rain that often occurs with strong winds from the southwest, and 3) omitting mitigating effects on erosion resulting from the crust that forms on the surfaces of mine waste and tailings (PTI 1990).

In addition to limitations in the assumptions used to derive model estimates, comparing the EPA model estimates for off-road vehicle riders with asbestos concentrations measured in onsite air by BLM and by researchers at the University of California at Berkeley (Popendorf and Wenk 1983) demonstrated that the modeled estimates were at least an order of magnitude higher than concentrations of asbestos measured in areas throughout the CCMA. Furthermore, EPA maximum model estimates were 3 orders of magnitude higher than the maximum concentration measured by BLM and 4 orders of magnitude higher than the 95-percent confidence limit on the average concentration from the BLM dataset. Thus, use of EPA model estimates is likely to overestimate exposure and potential cancer risks associated with activities within the CCMA.

BLM Data

As part of its ongoing occupational safety and health program for workers in the CCMA, BLM collected 157 activity-specific ambient air samples from November 1988 to April 1991. The BLM data were collected by BLM employees who wore personal samplers during their normal activities within the CCMA and during tests run in the CCMA to simulate exposures that motorcyclists and all-terrain-vehicle (ATV) riders might experience while riding in the area. Additional samples were collected by volunteers riding in motorcycle races in the CCMA. Activities included in the BLM database are listed in Table 1. Although the distribution of sampling events was not statistically random throughout the 18-month period, the events were spread over the entire time period and covered all seasons. All of the BLM samples were collected using a personal air sampling pump (typically running at 2 L per minute) with standard open-face cassettes (25 mm or 37 mm in diameter) containing a 0.8-μm pore size mixed-cellulose ester filter. Samplers were located near the breathing zone and away from obstructions that could influence wind patterns.

The BLM data are useful for a risk assessment because they compose an activity-specific dataset for the entire CCMA. However, the BLM samples were analyzed by phase contrast microscopy (PCM), which has some recognized technical limitations. Using PCM, asbestos concentrations are measured by counting the number of fibers in a defined volume of air. Although the PCM method has traditionally been used to measure asbestos concentrations in the workplace, PCM uses relatively low magnification (typically 450×) and does not allow exact identification of asbestos fibers. Instead, in the PCM method, particles that are 1) longer than 5 μm, 2) greater than 0.4 μm in width, and 3) have a length:width ratio greater than or equal to 3:1 are defined as PCM fibers (ATSDR 1989). Thus, depending on the composition and size distribution of asbestos and other fibers being measured, the PCM method may underestimate total asbestos fiber counts by missing fibers shorter or narrower than can be seen with the PCM magnification. In addition, when the fiber to dust ratio in samples is low, dust particles may obscure measurement of fibers, resulting in underestimation of fiber counts. PCM also may overestimate the counts by counting nonasbestos fibers.

The BLM PCM samples were analyzed by the R.J. Lee Group, Inc., laboratory following procedures outlined in NIOSH (1989), which include use of a magnification of 400× and standard criteria for identification of PCM fibers described above. Both single fibers and fibers contained within clusters were counted by the R.J. Lee Group, Inc. A cluster is defined as a random grouping of several intermixed fibers, with no single fiber isolated from the group and with a minimum of three intersections per cluster. To the extent possible, individual fibers contained in a cluster were counted separately. Alternatively, clusters meeting the PCM fiber size definitions described above were counted as an individual PCM fiber. The asbestos analysts (counters) of the R.J. Lee Group, Inc., verify their analytical counting methods through regular participation in the EPA-sponsored proficiency analytical testing (PAT) program.

The PCM asbestos concentrations discussed in this analysis are reported in fibers per cm^3 (f/cc) corrected for the sample volume, not as time-weighted 8-hour average (TWA) concentrations. The algorithm used to calculate the asbestos concentration from counts of fibers on filters is shown in the following example, which represents the PCM limit of reliable quantification applicable in analysis of the BLM samples:

TABLE 1. ACTIVITY CODES, ACTIVITIES, AND NUMBER OF SAMPLES IN THE BLM DATABASE

Activity Code	Activity		Number of Samples
0	No activity information		1
1	Motorcycle operation		31
2	On foot, walking, etc.		13
3	Riding in open vehicle		22
4	Riding in closed vehicle		16
5	Light maintenance		1
6	Heavy maintenance		5
7	Equipment operation		4
8	Nonpersonal special use		11
9	Ambient sample		3
10	All-terrain-vehicle operation		10
		Total	117

$$\text{Quantification Limit} = \frac{QL \times CA}{SV \times FV \times CF}$$

$$= 0.002 \text{ f/cc}$$

where:

QL = the limit of reliable quantification for the NIOSH (1989) method (10 fibers/100 fields)

CA = the collection area of a filter within a 25-mm cassette (385 mm^2)

SV = sample volume (3,000 L)

FV = field of view for a PCM microscope. This value will vary for different microscopes; BLM data were analyzed with a 0.007854 mm^2 field of view.

CF = conversion factor of 1,000 cc/L.

Concentrations of asbestos in ambient air measured by BLM using the PCM method ranged from nondetected (0.002 f/cc) to 0.49 f/cc. Further analyses of the BLM dataset are provided in the section entitled *Quality Assurance of the BLM Dataset.*

Data Gathered by Researchers at the University of California, Berkeley

Concentrations of asbestos in ambient air at the CCMA were measured in several studies conducted by groups led by researchers at the University of California in Berkeley (Popendorf and Wenk 1983; Cooper et al. 1979; Murchio et al. 1978). Popendorf and Wenk (1983) describe collection of asbestos air samples from 5 or 6 motorcycle riders on each of 11 test runs conducted at the CCMA, including data from runs reported by Cooper et al. (1979). Runs were conducted on two circuits. In Run A, cyclists stayed single file on a 8-km circuit on a well-traveled dirt road. Run A generally took about 15–18 minutes. In Run B, cyclists had more latitude to vary their group sequence and path; a loop of 19-22 km was generally traversed in 50–70 minutes. Like the BLM researchers, these investigators collected samples using a personal air sampling pump (1.7 to 2 L/min) with a 25- or 37-mm open-face cassette and a 0.8-μm pore size filter. In addition, analyses were conducted by PCM with 450× magnification. In contrast to the BLM work, asbestos concentrations measured in personal monitors on motorcycle riders were much higher, ranging from 0.05 to 7.1 f/cc, with 95-percent upper confidence limits on mean concentrations of 3.37 f/cc for Run A and 1.5 f/cc for Run B. Exposures were generally greater in Run A than Run B. Popendorf and Wenk (1983) attributed this difference to the greater degree of latitude available to riders on Run B to vary their intergroup spacing and position, thereby avoiding some visible dust clouds.

Asbestos air concentrations reported by Popendorf and Wenk (1983) are much higher than concentrations reported in the BLM dataset for comparable activities. The reasons for the discrepancies between the BLM and the Popendorf and Wenk (1983) data could not be fully clarified. The University of California at Berkeley measurements were performed in 1978. The authors have been unable or unavailable to answer questions concerning the specific quantities that are necessary inputs to the above algorithm. The major variable influencing calculation of f/cc is the total fiber counts per filter. This variable could only be verified through reanalysis of archived samples (preferably by the R.J. Lee Group, Inc.). The document referenced by Popendorf and Wenk (1983) for quantifying the airborne asbestos fiber concentrations is NIOSH (1977). The NIOSH (1977) methods differ from the NIOSH (1989) methods predominantly in the recommended fiber fixation methods and in the counting techniques; these discrepancies may partially account for the differences between results obtained by BLM and the University of California researchers. However, differences in the following variables may have a greater influence on the observed discrepancies between the two datasets: 1) meteorologic conditions (i.e., wind, ambient humidity, or precipitation), 2) the protocols for spacing or speed of the offroad vehicles, and 3) the size of the offroad vehicles used.

Popendorf and Wenk (1983) also reported analysis of some sample filters by both PCM and transmission electron microscopy (TEM). The TEM method more reliably identifies asbestos fibers in ambient air. However, the subset of PCM samples reanalyzed by TEM was too small to provide a statistical basis for comparing the obtained results. In addition, no data are available on the results of laboratory quality assurance and quality control (QA/QC) samples (i.e., replicate or duplicate samples). In the absence of such verifying data, the data reported by Popendorf and Wenk (1983) are judged as not as reliable as the BLM dataset for use in a risk assessment for the CCMA. However, because these concentrations are significantly elevated over BLM measurements for off-road vehicle riders, the *Uncertainty Assessment* section of this report presents risk estimates for off-road vehicle riders derived from the Popendorf and Wenk (1983) data.

Quality Assurance of the BLM Dataset

Because the BLM data are the most viable for use in a risk assessment for the CCMA, several additional analyses of this dataset were conducted to evaluate data quality. Concerns about the precision of the PCM method and the potential unpredictability (i.e., over- or under-reporting) of PCM asbestos air concentrations were addressed through the following evaluations of the PCM data:

- Comparison of results from 10 archived BLM samples for which both PCM and TEM analyses were conducted
- Evaluation of the laboratory replicate and duplicate samples from R.J. Lee Group, Inc.

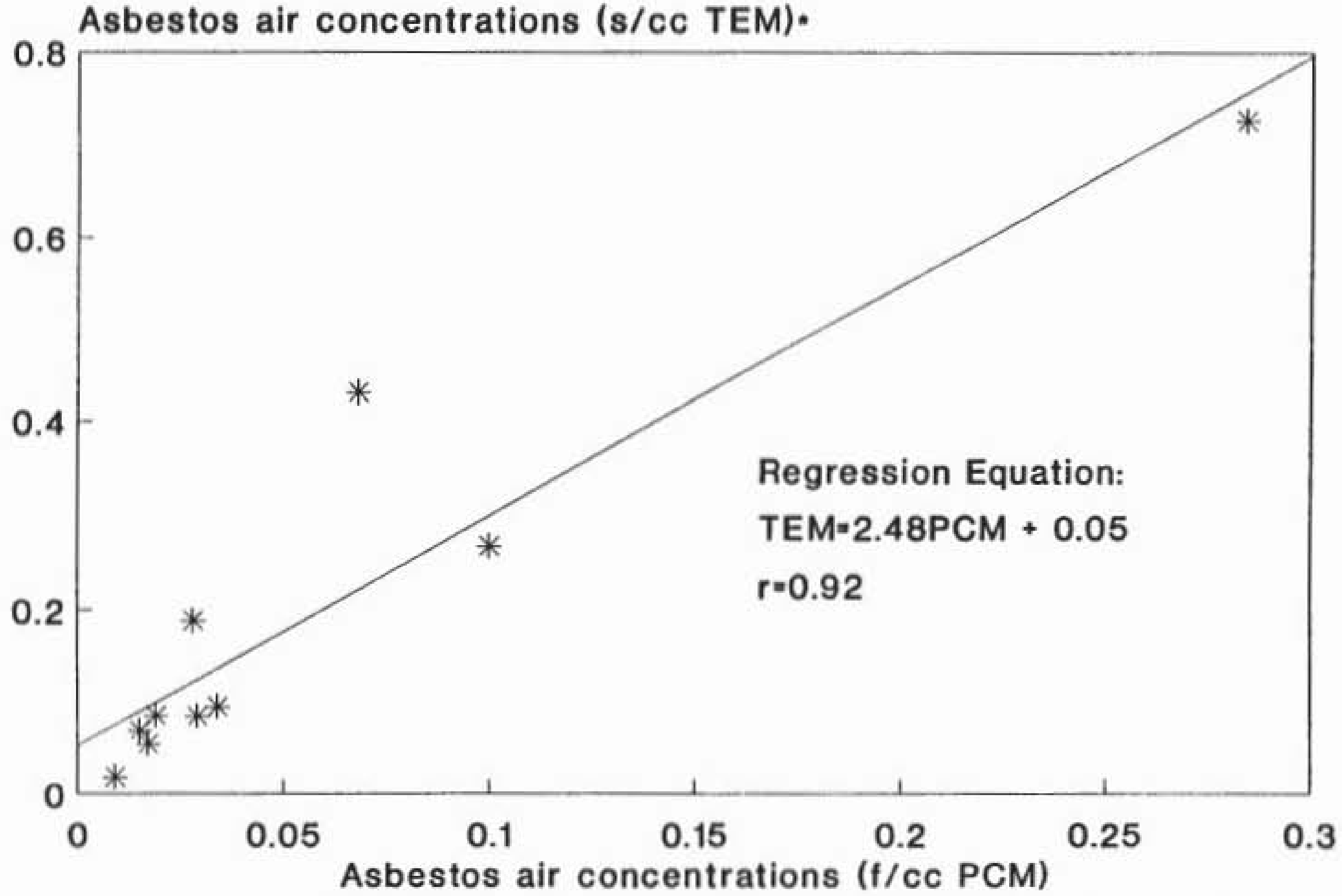
The findings of these evaluations are discussed below. In addition, statistical analyses were conducted to evaluate a possible association between air concentrations and seasons or activities. These analyses are outlined in the section entitled *Analysis of Variance with Season and Activity*. As described in the section entitled *Selection of Data for the Risk Estimates*, the analyses of data quality resulted in selection of the BLM data for use in a risk assessment for the CCMA.

In contrast with the limitations of the PCM method described above, TEM, which uses a magnification of 6,000× or greater, can measure much smaller fibers and can distinguish between asbestos fibers and other fibers (such as cellulose, fiberglass, or hair) that might be counted using the PCM method. Because of the recognized advantages of TEM, a statistical comparison was conducted of 10 BLM asbestos air samples that were originally analyzed by PCM and subsequently reanalyzed by TEM. The samples chosen to be reanalyzed by TEM were selected from similar activity groups (motorcycle and ATV operation only) and provided maximum coverage of the concentration range observed in samples at the CCMA. In addition, the motorcycle and off-road vehicle data were collected from a variety of areas throughout the CCMA and, thus, should be representative of potential differences in asbestos composition and mineralogy.

The BLM samples were reanalyzed by TEM by the R.J. Lee Group, Inc., using the Yamate Method (40 CFR § 763, Appendix A to Subpart E). This method reports asbestos structures, which include single fibers, bundles, clusters, and matrices. Each structure reported must contain at least one asbestos fiber having a minimum length ≥ 0.5 μm and an aspect ratio (length:width) of 5:1. Bundles are defined as three or more parallel fibers less than one fiber diameter in separation. As with PCM measurements, clusters are defined as structures in a random arrangement such that all fibers are intermixed and no single fiber is isolated from the group. Matrices are defined as structures with a fiber or fibers embedded in or covered by a particulate. Only those structures that are identified as, or are suspected to be, either chrysotile or one of the amphibole minerals are reported. Other materials, such as gypsum, cellulose fibers, and filter artifacts (e.g., undissolved filter strands), are not included in the structure count. All samples were prepared using a direct preparation method.

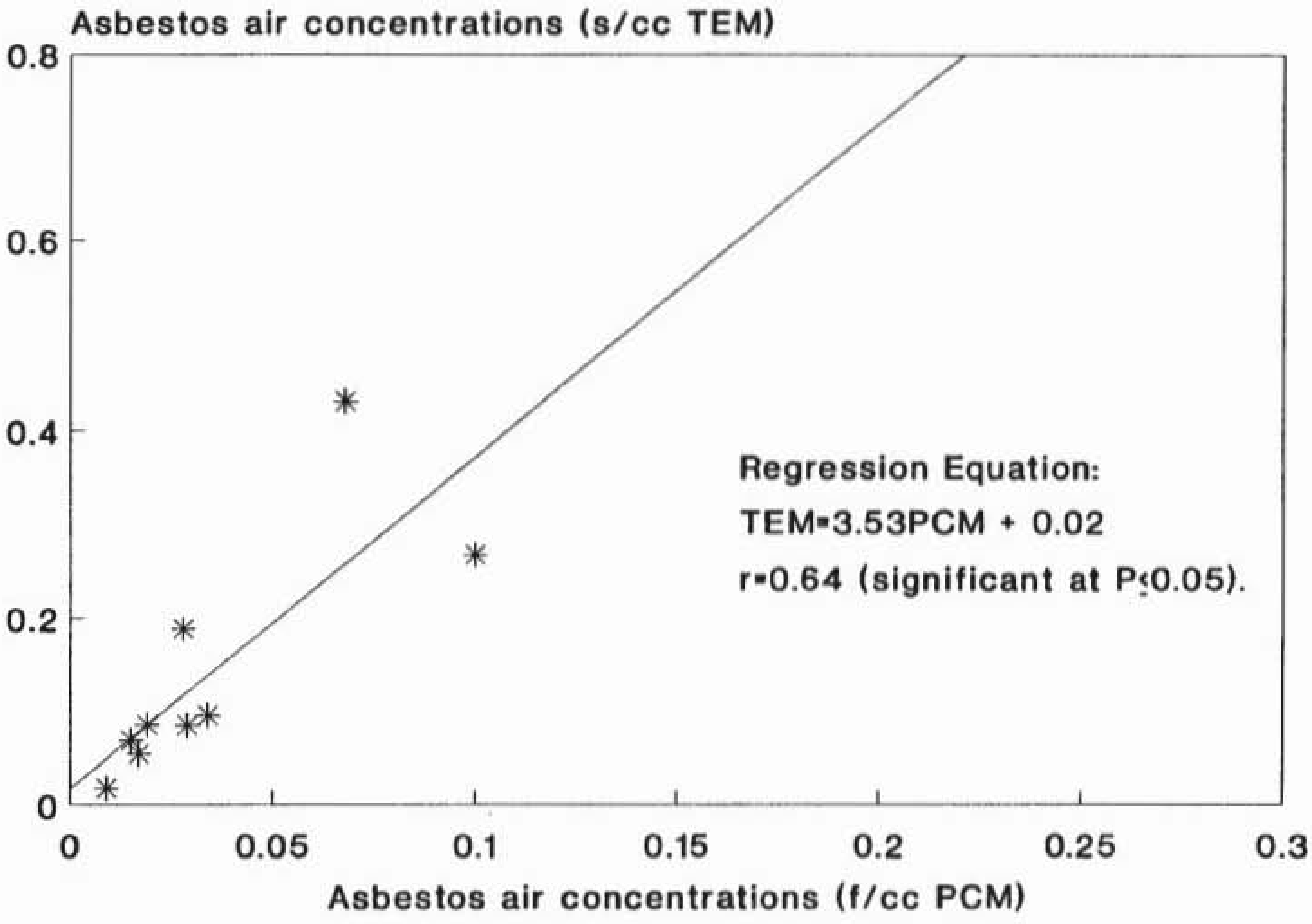
The 10 BLM samples analyzed by TEM provide a paired data set for comparing asbestos concentrations determined with PCM and TEM methods. A plot of TEM versus PCM data is shown in Figure 2. This evaluation was based on concentrations of TEM structures per $\text{cm}^3 > 5$ μm in length. The data are significantly correlated, with a Pearson correlation coefficient of 0.92 (significant at $P<0.01$). The regression equation that is provided in Figure 2 can be used to predict TEM concentrations from PCM concentrations using a slope factor of approximately 2.48 and an intercept of 0.05. Even if the highest single point is excluded from the analysis, the correlation between PCM and TEM analyses of the remaining 9 samples is still statistically significant ($P<0.05$), with a Pearson correlation coefficient of 0.64 (Figure 3).

These results indicate that within the BLM dataset in general and particularly within the motorcycle rider data, statistical evidence supports using the linear equation: $\text{TEM} = 2.48 \times \text{PCM} + 0.05$ to convert PCM f/cc into TEM structures per cm^3. The correlation suggests that there may be little interference from other fibers in CCMA ambient air



*TEM analyses are reported in structures per cubic centimeter (s/cc); PCM analyses are reported in fibers per cubic centimeter (f/cc).

Figure 2. PCM and TEM correlation.



Regression Equation:
TEM=3.53PCM + 0.02
r=0.64 (significant at $P < 0.05$).

Correlation excludes values greater than 3 standard deviations away from the mean.

Figure 3. PCM and TEM correlation excluding outlying values.

samples in this dataset and that the size and shape distributions of fibers apparently remain constant with increasing concentrations. The correlation is likely to be due to site-specific characteristics and, therefore, should not be applied to PCM and TEM data from other sites where environmental conditions differ from those at the CCMA. However, because the TEM method provides a more precise measurement of asbestos in air, the correlation between PCM and TEM data reduces the uncertainty surrounding the relationship between PCM measurements and asbestos concentrations in air at the CCMA.

As an additional step in the evaluation of data quality, PTI also reviewed the quality assurance data for the BLM data, which were provided by R.J. Lee Group, Inc., the lab that analyzed the BLM sampling data. R.J. Lee Group, Inc., supplied two repeated analyses, one replicate and one duplicate, for each of seven samples analyzed by PCM (i.e., a total of 14 quality assurance data points were provided). For each sample, one of the repeated analyses was a duplicate (i.e., the same sample was analyzed by the same analyst) and the second repeated analysis was a replicate (i.e., the same sample was analyzed by a different analyst). The coefficients of variation for the 14 repeated analyses among all seven analyzed samples ranged from 5.97 to 32.3 percent. This variability is relatively low when compared with results of chemical analyses and is well within the NIOSH requirements that duplicate and replicate PCM samples fall within 1.5 standard deviations from the original sample value.

Although these repeated analyses only address variability due to the analytical technique, and not sampling variability, this reproducibility is similar to that demonstrated in a set of samples collected in an EPA-sponsored study of asbestos at a Superfund site, the South Bay Asbestos Site near San Jose, California. These samples were analyzed by TEM, and the coefficient of variation ranged from 0.0 to 82 with an average of 34.6 percent (Black et al., unpublished). Thus, the PCM data analyzed for BLM are well within method standards and appear to compare favorably with TEM samples collected in the same region.

Analysis of Variance with Season and Activity

Possible correlations between asbestos air concentrations (determined by PCM in f/cc) and activities, or between air concentrations and season (as determined by date), were statistically evaluated. All analyses excluded one outlier that was greater than 3 standard deviations away from the mean of the total dataset. In comparing air concentrations and activities, asbestos data in the BLM database were included when the activity was performed during at least 80 percent of the sampling periods. This approach provided the greatest number of data points without sacrificing representative air concentrations associated with a given activity. Using this approach, 117 activity-specific PCM data points were available for analysis. Table 1 presents the 10 activity categories and the number of data points available for each category. The BLM database also included data on the position of the riders in the motorcycle and ATV tests: riders were designated as lead, mid, or tail riders and remained in those positions throughout the test.

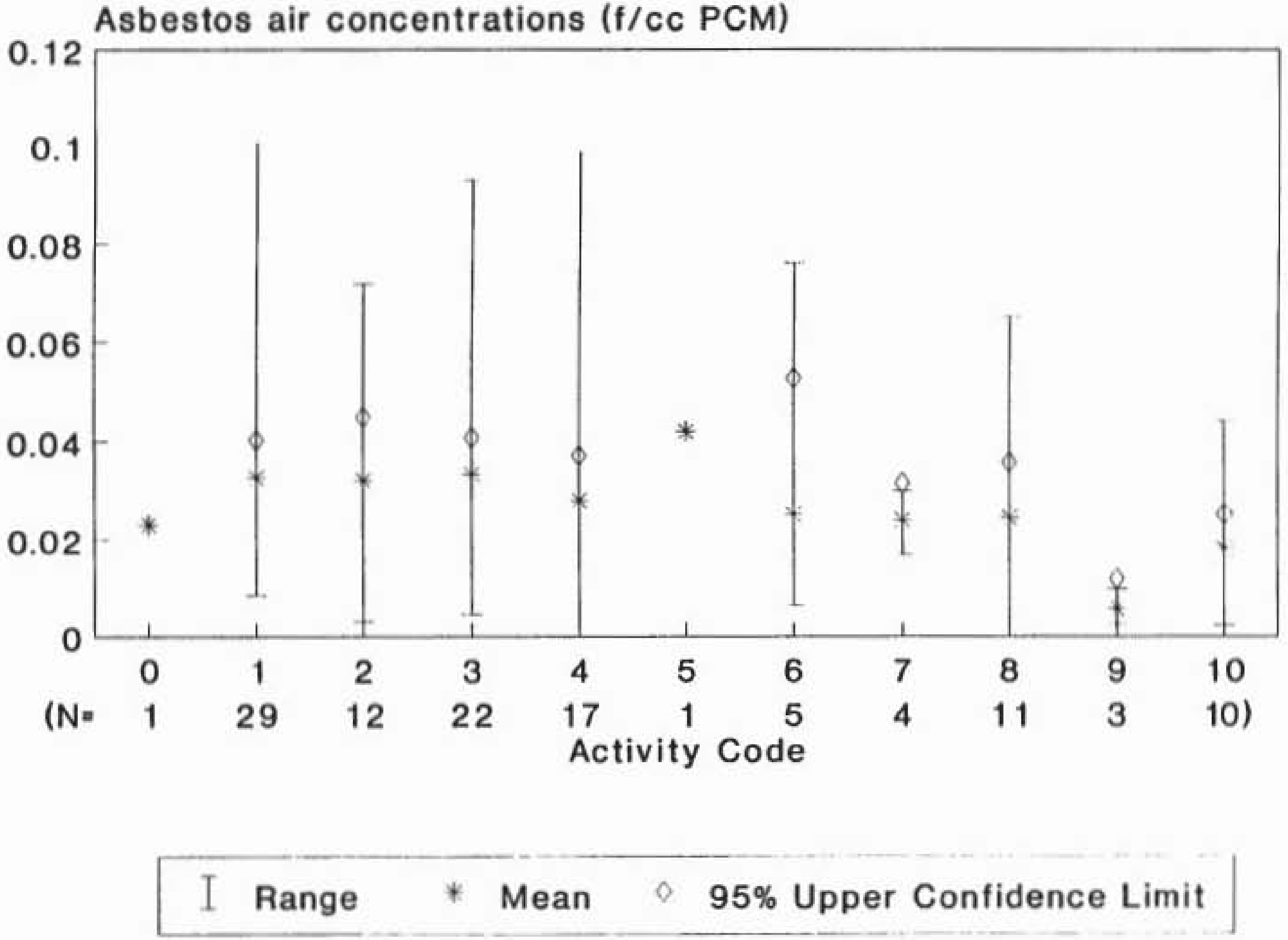
These data were used to evaluate possible correlations between air concentrations and rider position.

Using the statistics package SPSS/PC+, parametric and nonparametric analysis of variance (ANOVA) tests were performed to assess statistical differences in air asbestos concentrations between activity groups (Table 1). These two broad categories of statistical analyses differ in their underlying assumptions about the data distribution. The parametric ANOVA assumes that the actual variability in the values of interest (e.g., air concentrations) is constant for the population and does not vary between groups. A non-parametric (Kruskal-Wallis) ANOVA was used for datasets failing the Cochran's test for homogeneity of variances. All possible pairwise comparisons were conducted using these two tests (i.e., each activity was compared with each other activity). The following statistically significant relationships between activity and air asbestos concentrations were identified:

- Ambient concentrations (activity 9) were significantly lower ($P<0.05$) than concentrations measured for the following six activities (Figure 4):
    - Motorcycle riding (activity 1)
    - Walking (activity 2)
    - Riding in an open vehicle (activity 3)
    - Riding in a closed vehicle (activity 4)
    - Equipment operation (activity 7)
    - Nonpersonal special use (activity 8)
- Concentrations measured during motorcycle riding (activity 1), riding in an open vehicle (activity 3), and riding in a closed vehicle (activity 4) were significantly higher ($P<0.05$) than those measured during ATV operation (activity 10) (Figure 4)
- Concentrations measured for lead riders were significantly lower in comparison with the group of mid and tail riders in the motorcycle and ATV tests ($P<0.05$ for the non-parametric ANOVA) (Figures 5 and 6).

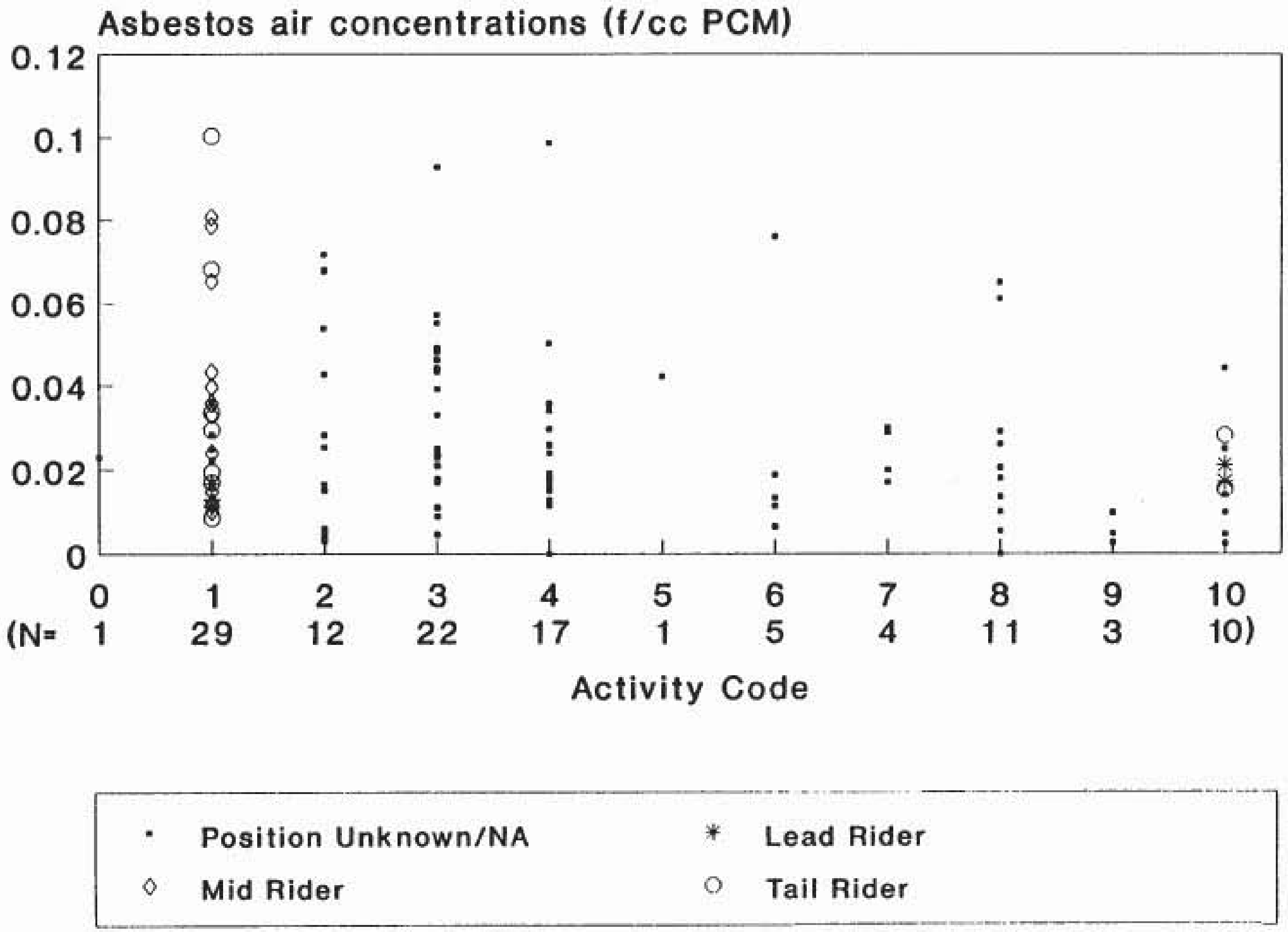
The findings were generally consistent with the findings of Popendorf and Wenk (1983) and with the expectation that increasing asbestos concentrations would be experienced by mid and tail riders compared with lead riders.

Pairwise comparisons were also conducted between motorcycle riders and all other activities pooled (Figure 4) and between ATV operators and all other activities pooled (Figure 4) (non-personal, special use was excluded when activities were pooled because of the lack of information on this activity). No statistically significant differences were identified in these comparisons.



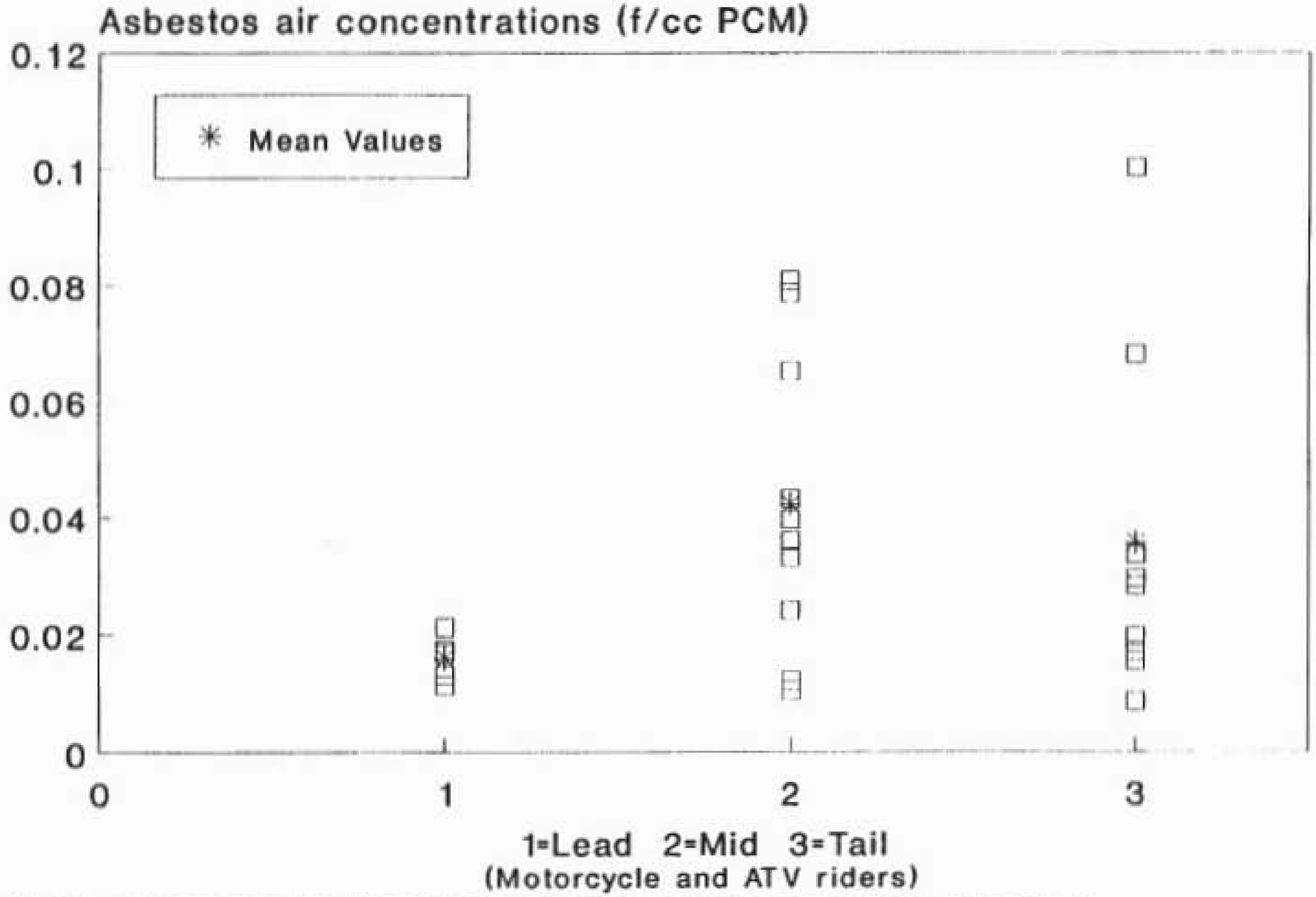
Excludes values greater than 3 standard deviations away from the mean.
Only data points where activities were conducted 80% of the time were included.

Figure 4. Summary of asbestos concentrations for selected activities.



Excludes values greater than 3 standard deviations away from the mean.

Figure 5. Asbestos concentrations by activity with rider position.



Excludes values greater than 3 standard deviations away from the mean.

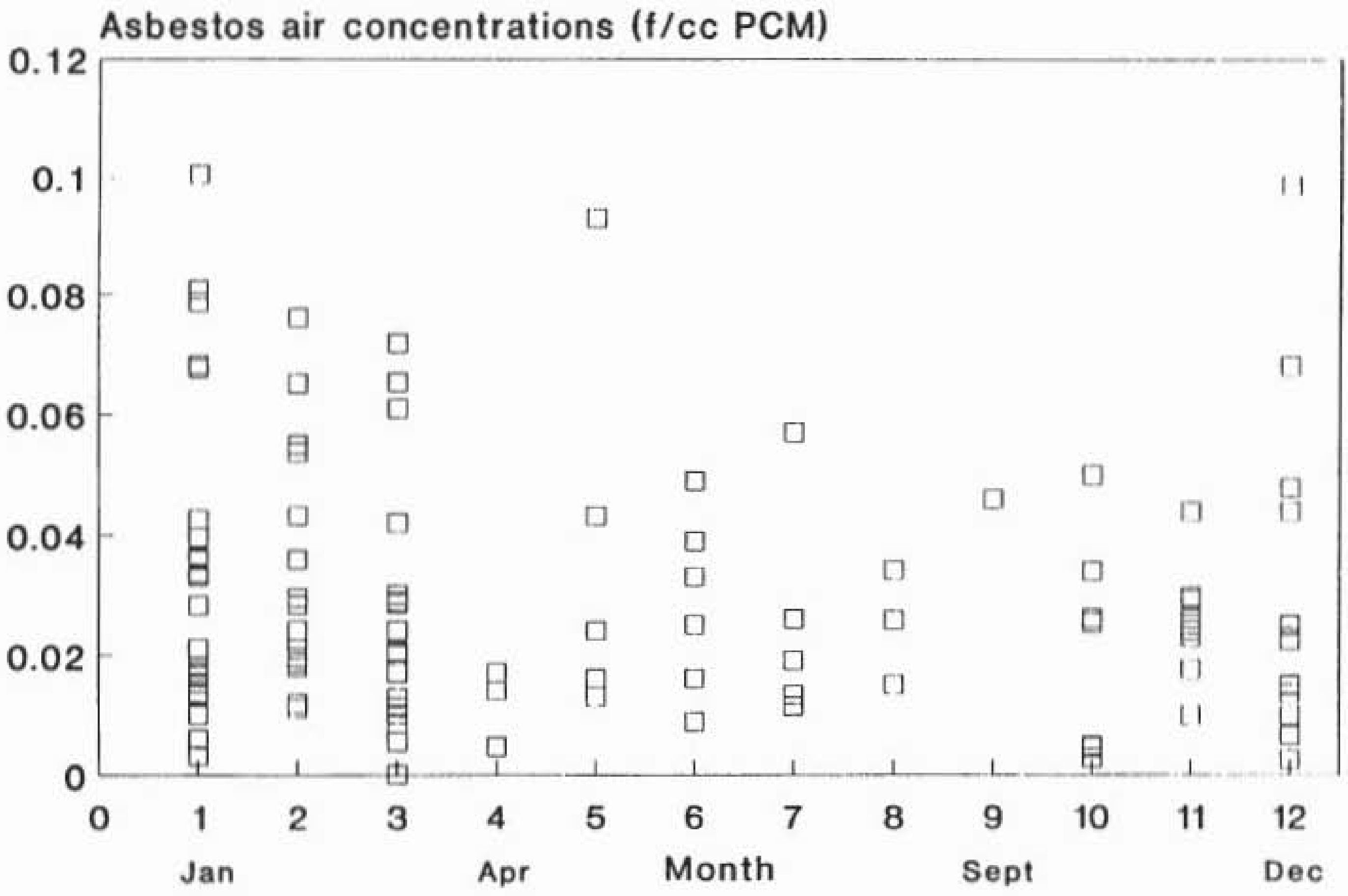
Figure 6. Asbestos concentrations by rider position.

Although significant differences were seen between air concentrations measured during six activities and ambient concentrations and between lead and following motorcycle riders, fewer differences were seen between activity groups than expected. For example, there were no differences in asbestos air concentrations between motorcycle riding and hiking. Several factors may account for the lack of statistical differences between activities and asbestos concentrations measured in air. Data points were only included where a given activity was conducted 80 percent of the time period that data were collected. However, because workers were engaged in additional activities for up to 20 percent of the sampling period, asbestos exposures during the 20 percent period may interfere with the ability to detect a difference between activities accounting for 80 percent of the sampling time. In addition, because most of the BLM employees' activities at the CCMA also involve riding in a vehicle, differences in exposure concentrations between activities may be reduced by the influence of dust generated from vehicles. This is particularly true where the vehicles are driven on unpaved roads.

Seasonal differences in asbestos concentrations were evaluated for the entire BLM dataset. While the spring and summer months appear to have lower asbestos concentrations than the winter months, the ANOVA performed on monthly data did not detect any statistically significant differences at the $P=0.05$ level (Figure 7). Asbestos concentrations for motorcycle riders by month were also compared using ANOVA techniques, and no significant differences were identified at the $P=0.05$ level (Figure 8). The lack of correlation between asbestos concentration and season probably results from variability within a given month of critical factors (i.e., soil moisture, wind speed, and the presence or absence of precipitation) that would influence asbestos concentrations in air. Thus, it appears that season (i.e., month) alone cannot be used as a predictor of ambient asbestos concentrations in site management.

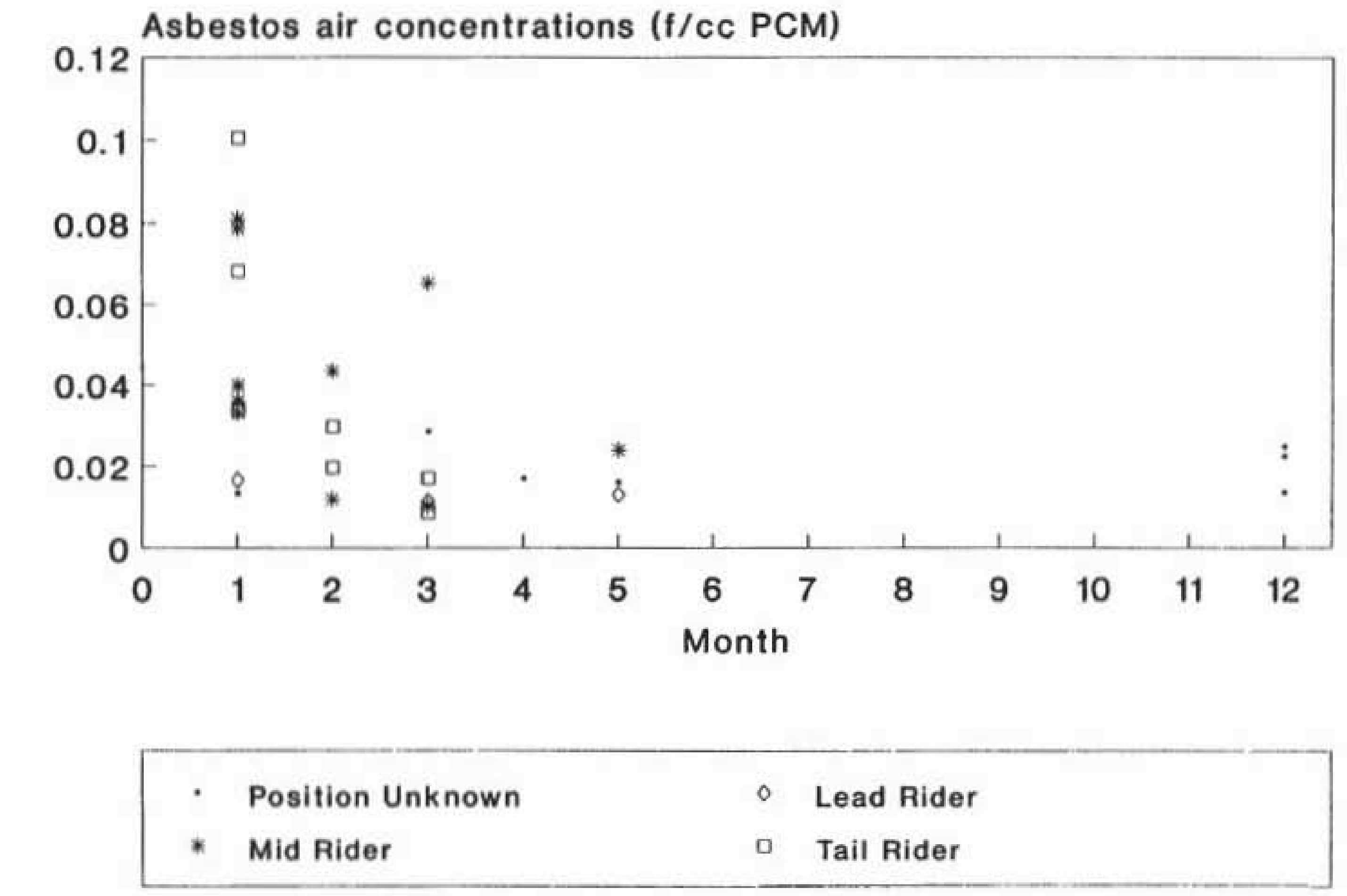
Selection of Data for Risk Estimates

Although no correlations were found between BLM air asbestos concentrations and season or activity, statistically significant elevations were seen in concentration data from the lead motorcycle group when compared with pooled data from mid and tail riders and in concentration data from five of the activity groups in comparison with BLM ambient data. In addition, the BLM database is likely to be representative of potential exposures experienced by site visitors because the data were collected throughout the CCMA during onsite activities similar to those undertaken by onsite visitors. Samples were collected in the breathing zone, which also increases the representativeness of the data. In addition, the BLM database covers all seasons and comprises 117 activity-specific data points. The limitations of the PCM method, including the inability to count fibers shorter than 5 μm or narrower than 0.4 μm and the potential for including nonasbestos fibers in counts, have been evaluated in light of the current risk assessment methods and through comparison with data from PCM samples reanalyzed by TEM. The linear correlation between TEM and PCM analyses of selected BLM samples and the high degree of reproducibility of the PCM data (demonstrated by PCM duplicate and replicate



Excludes values greater than 3 standard deviations away from the mean.

Figure 7. Asbestos concentrations by month.



Excludes values greater than 3 standard deviations away from the mean.

Figure 8. Asbestos concentrations for motorcycle riders by month.

analyses of samples) tend to support the validity of the PCM data collected by BLM at the CCMA.

Although PCM measurements are not as precise as TEM measurements, the current EPA URF for asbestos is based on PCM measurements (and on earlier measurements made with a different measuring device). Therefore, uncertainties associated with the use of PCM data are inherent in the current URF and will remain regardless of the environmental monitoring data used for a specific risk analysis.[1] EPA's Integrated Risk Information System (IRIS), which is an EPA database containing verified toxicity values and up-to-date health risk and EPA regulatory information, indicates that "the correlation between TEM and PCM is very uncertain" (U.S. EPA 1991a). According to Steven Bayard, the EPA risk assessment guidance contact for asbestos, the PCM method is generally selected for use in risk assessment because of cost considerations and comparability with the current URF (Bayard 1991, pers. comm.). For these reasons, the BLM database was used in the risk assessment for the CCMA.

Following EPA guidance for risk assessment (U.S. EPA 1989b), the 95-percent upper confidence limits on the mean from the BLM data were used in the risk calculations. Although there was no statistically significant difference between concentration data for off-road vehicles (motorcycles and all-terrain-vehicles [ATVs]) and other activity groups, the upper 95-percent confidence limit on the mean concentration for off-road riders was somewhat higher than that for all other groups combined (i.e., 0.066 f/cc and 0.04 f/cc, respectively). For this reason, the concentration data for these two groups have been used separately in the risk assessment. However, because the concentrations are so similar, pooling all data would make very little difference in final risk estimates. Although there were statistically significant differences between lead and following motorcycle riders, a given individual is likely to shift between rider positions. Therefore, concentration data from all offroad riders have been pooled for use in the risk assessment.

In contrast with the approach used to compare asbestos concentrations and seasons or activities, no samples were excluded in deriving the 95-percent upper confidence limits on mean concentration (i.e., the outlier that was greater than 3 standard deviations away from the mean was included). The outlier was included in these calculations to provide a more conservative approach to the risk assessment. For example, excluding outliers produces 95-percent upper confidence limits for off-road vehicles and other uses of 0.035 and 0.033 f/cc, respectively. As discussed above, only data for activities that took place for 80 percent of the time were included in the calculations.

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[1] A discussion of an ongoing EPA evaluation of the methods of analysis for asbestos in air is presented in the *Toxicity Assessment* section of this risk assessment.

As indicated above, the data from Popendorf and Wenk (1983) will also be included in a risk evaluation presented in the *Uncertainty Assessment* section of this report. The 95-percent upper confidence limit on the average concentrations for all data points in Run A was 3.37 f/cc and for all data in Run B was 1.5 f/cc.

EXPOSURE ASSESSMENT

Exposure assessment is the process of identifying human populations that could potentially come into contact with site-related chemicals and estimating the magnitude, frequency, duration, and route(s) of potential exposure. The exposure assessment phase of the risk assessment includes the following steps: characterizing the exposure setting and identifying potentially exposed populations, identifying exposure pathways, and quantifying exposure. Each of these steps is described below.

The first step in exposure assessment is to characterize the site in terms of its physical setting, land use, and associated human populations that may be exposed to site-related contaminants. This information is used to identify possible exposure pathways for each potentially exposed population and to determine appropriate exposure intake variables to quantify exposure. A general description of the physical setting of the management area, including climate, soil type, and surface water hydrology, was provided in previous sections of this chapter. The local demographics, land use, and human populations potentially exposed to site-related contaminants under current and possible future land-use conditions are discussed below.

Current Land Use and Populations

The CCMA is within a 250-km^2 area of federally owned land managed by the BLM for recreational uses. There are no permanent residences within the management area. The nearest town is Idria, California, which lies to the north of the management area. Land use is expected to remain recreational for the foreseeable future (i.e., residences or businesses will not be allowed to locate within this area). Thus, there are two populations of people who are of concern for the human health risk assessment:

- **Current Occupational**—BLM employees with potential for exposure to asbestos during work in the CCMA
- **Current and Future Recreational**—Site visitors who may enter the CCMA and be exposed to asbestos in ambient air.

BLM employees are covered under Occupational Safety and Health Administration (OSHA) regulations and, thus, the potential for exposure to asbestos is limited or eliminated through adherence to the health and safety practices required under OSHA. Therefore, site visitors are the focus of this risk assessment.

Although the CCMA is located in a relatively unpopulated area, the unique characteristics of the area (i.e., sparsely vegetated, erosion-resistent slopes) draw visitors from population centers such as San Jose and San Francisco (Popendorf and Wenk 1983; U.S. EPA 1990b). In particular, visitors who spoke at a public meeting on the CCMA indicated that this is one of a few remaining large public areas allowing off-road vehicle use (U.S. EPA 1990b). Other site uses include camping, hiking, hunting, and rock collecting (U.S. EPA 1990a; Popendorf and Wenk 1983). Although exact counts are not available, the BLM has estimated the annual number of visitors to the CCMA for the years 1977 to 1990 (BLM unpublished). Visitor use appears to have peaked in 1988, when BLM estimated 80,000 visitor-days were spent in the area. This estimate was extrapolated from vehicle counts taken by BLM rangers assuming that each vehicle has 2.5 visitors and that visitors spend about three and one-half, 12-hour "days" per visit. BLM also derived estimates of off-road vehicle use in the area by assuming the following: 1) 70 percent of all vehicles entering the CCMA are support vehicles for off-road vehicles and 2) each support vehicle includes two off-road vehicles. Using this approach, BLM estimated that off-road vehicle riding peaked at 14,000 vehicles in 1988. The 1990 estimate for off-road vehicles was 9,000 (BLM unpublished).

Quantification of Exposure

Site visitors could be exposed to asbestos through inhalation and ingestion. However, as discussed in the toxicity assessment section, the inhalation pathway is likely to be the most important pathway for evaluating human health risk. In addition, existing data on asbestos concentrations in soil are inadequate for use in risk assessment. Therefore, only the inhalation pathway will be included in the risk assessment for the site. Exclusion of potential risks associated with ingestion of asbestos may underestimate overall risks associated with exposure to asbestos at the CCMA. Although the degree of underestimation cannot be precisely quantified, experimental data indicate that ingested asbestos is either not carcinogenic or is less carcinogenic than inhaled asbestos.

Estimates of the extent of use by site visitors were described in the previous section. In risk assessment, the exposure estimates are based on the reasonable maximum exposure (RME) case. *Risk Assessment Guidance for Superfund* (U.S. EPA 1989) describes the RME case as the highest exposure that is reasonably expected to occur at a site. In this evaluation, RME estimates were derived for the site based on the following:

- EPA guidance for risk assessment (U.S. EPA 1989a,b, 1991b)
- Site use estimates derived by U.S. EPA (1990a) in the risk assessment for the Atlas and Coalinga sites
- Statements about site use made by site visitors as reported in transcripts from the Atlas Asbestos Company Superfund site community meeting (U.S. EPA 1990b).

Appendix A and Tables A-1 and A-2 provide a detailed comparison of exposure estimates derived using data from these three sources. Although the estimates derived from information from these three sources are fairly similar, the detailed comparison described in Appendix A suggests that the exposure variables derived from the EPA guidance documents for risk assessment (*Exposure Factors Handbook* [U.S. EPA 1989a] and the U.S. EPA *Standard Default Exposure Factors* [U.S. EPA 1991a]) are the most appropriate for use in a risk assessment for the CCMA. Assumptions used in estimating exposure for off-road vehicle riders and for other site users derived using these guidance documents (U.S. EPA 1989a, 1991a) are described here and presented in Table 2. In addition, a combined exposure scenario is shown in Table 2 because CCMA visitors may engage in more than one activity during a given visit. For example, off-road vehicle riders often camp in the area, thus increasing their overall exposure to asbestos in ambient air. Estimates of asbestos inhalation levels resulting from such combined exposures are also described in this section.

The last part of this section presents the method used to derive exposure point concentrations for inhalation of asbestos in ambient air during activities at the CCMA. The exposure estimates provided here are intended as best-estimates and should not be considered to be exact because of variability in exposure frequency between individuals and the imprecision in the sampling methods used to measure asbestos in ambient air. To facilitate evaluation of various exposure frequencies, exposure estimates are derived that range from a 1-day exposure to the highest exposure estimate based on statements made by site visitors.

Off-road Vehicles

Although no national or regional data are available on the amount of time people spend riding off-road vehicles, U.S. EPA (1989a) reported the results of a national survey indicating that men spend 0.52 hours/week in the following activities: motorcycling, biking, walking, hiking, jogging, running, and horseback riding. Because motorcycling is just one of these activities, it seems reasonable that only one-half of that time might be spent riding off-road vehicles for the average case, with 0.52 hours/week as an RME. U.S. EPA (1991) recommends using an exposure duration of 30 years for the RME estimate for the recreational scenario (i.e., recreational fishing) included in that guidance document. The 30-year exposure duration and the exposure frequencies derived using U.S. EPA (1989a) guidelines are generally consistent with estimates made by site visitors who spoke at the public meeting (Table A-1). In addition, the maximum estimate of total hours of exposure over the lifetime, derived through use of values in U.S. EPA (1989a), is essentially the same as that derived in U.S. EPA (1990a).

Use of the above variables results in an RME estimate of 27 hours riding off-road vehicles per year for 30 years, or about five rides of approximately 5.4 hours in duration per year. Because at least one site visitor indicated that they ride even more frequently and for longer periods of time (i.e., approximately 84 hours per year) (Table A-1 and U.S. EPA 1990b), a "high estimate" of exposure of 12 rides of 7 hours duration per year

TABLE 2. INHALATION EXPOSURE ALGORITHM

$$\text{Chronic Daily Exposure Concentration (EC)} = \frac{C_a \times ET \times EF \times ED}{AT}$$

where:

C_a = asbestos concentration in fibers per cubic cm (f/cc) (95-percent upper confidence limit on the average concentration)
ET = exposure time in hours/day
EF = exposure frequency in days/year
ED = exposure duration in years
AT = averaging time of 24 hours × 365 days × 70 years.

Exposure Assumptions[a]

	Off-Road Riding Scenario			Other Activities Scenario		Combined Scenario			
						1-Day		RME	
Parameter	1-day	RME[b]	High Estimate[c]	1-day	RME	Riding	Other	Riding	Other
C_a	0.066	0.066	0.066	0.04	0.04	0.066	0.04	0.066	0.04
ET	5.4	5.4	7	24	24	5.4	24	5.4	24
EF	1	5	12	1	3.2	1	1	5	3.2
ED	30	30	30	30	30	30	30	30	30
EC	1.7×10^{-5}	8.7×10^{-5}	2.7×10^{-4}	4.7×10^{-5}	1.5×10^{-4}	Combined CDI: 6.4×10^{-5}		Combined CDI: 2.4×10^{-4}	

[a] All exposure estimates are based on U.S. EPA (1989a, 1991a) documents, except as indicated. Exposure concentrations are 95-percent upper confidence limits of average concentrations for off-road riders, or for all other activities combined.

[b] RME - reasonable maximum exposure.

[c] Exposure estimate derived from statements at the Atlas Asbestos Company Superfund site community meeting recorded in U.S. EPA (1990b).

was also calculated to provide a range of exposure estimates for off-road vehicle riders. In addition, an exposure estimate for a single 5.4-hour ride per year for 30 years was calculated to assist in evaluating a range of exposures (Table 2).

Other CCMA Uses

U.S. EPA (1989a) presents results from a national survey indicating that men spend 1.49 hours/week outdoors in the following activities: hunting, fishing, boating, sailing, canoeing, camping at the beach, and other activities. This estimate was used to derive an RME of 77 hours/year, or about 3.2 days per year at the CCMA (Table A-2). Application of the 30-year duration of exposure recommended in U.S. EPA (1989a), as described in the discussion for off-road vehicle riders, results in an estimate of 2,310 hours over the lifetime for the RME case (Table A-2). Use of these exposure assumptions is likely to overestimate exposures for most site visitors because this estimate incorporates the assumption that people spend all of their time in these activities at the CCMA (i.e., they would not camp or hunt elsewhere) over a 30-year period. Therefore, to evaluate a range of exposures, an exposure estimate for visitors who spend 1 day each year at the CCMA for 30 years also was calculated (Table 2).

Combined Activities

RME estimates for off-road vehicle riding and for other site uses were combined to evaluate exposures for individuals who engage in more than one activity at the CCMA during a year (Table 2). This combined exposure scenario is based on the assumption that people who ride off-road vehicles in the area may also camp in the CCMA. However, because both estimates include a number of conservative assumptions, the combined exposure estimate is expected to be much higher than lifetime exposures for most people who visit the CCMA. For example, exposure estimates for off-road vehicle riding and other site uses are both based on national estimates of time spent in a broader range of outdoor activities than are available at the CCMA. The RME estimates are also based on the assumption that all of the time spent in these activities takes place within the CCMA. In addition, the RME estimates incorporate the assumption that visitors would continue this high level of use of the CCMA over a 30-year exposure duration.

Derivation of Chronic Daily Exposure Concentrations

Chronic daily exposure concentrations were calculated for the RME and 1-day estimates for off-road vehicle riding and for other activities at the CCMA based on the algorithm presented in Table 2. Consistent with EPA guidance for risk assessment (U.S. EPA 1989a), all exposure estimates were derived using the 95-percent upper confidence limit on the mean ambient air concentrations in the BLM database. The toxicity value for asbestos is a unit risk value, which incorporates an adult's body weight of 70 kg and an inhalation rate of 20 m^3/day. Because the risk assessment for the CCMA is based on adults using the area for recreation, these variables do not need to be adjusted.

TOXICITY ASSESSMENT

As indicated above, this risk assessment focuses on adverse effects associated with asbestos inhalation. This section includes a definition of asbestiform minerals, brief discussions of available dose-response data for carcinogenic and noncarcinogenic effects of asbestos, a discussion of the relationship between fiber characteristics and adverse health effects, and a discussion of the ongoing EPA re-evaluation of the URF for asbestos.

Asbestos is the name given to a group of six different minerals that occur naturally in the environment and are mined for use in various industries. The class of asbestos is subdivided into serpentine fibers, which are characterized as being curly, and amphibole fibers, which are shaped like rods. The asbestos found at the CCMA is predominantly chrysotile (Popendorf and Wenk 1983), which is the most common of the serpentines.

Carcinogenicity

This section includes a discussion of the characteristics of asbestos influencing toxicity and the evidence for carcinogenic effects of asbestos following inhalation or ingestion.

Fiber Characteristics and Adverse Effects

The various types of asbestos fibers differ widely in their chemical composition, morphology, and durability. These differences may account for divergent effects seen in biological systems. Indeed, studies show that many factors, including fiber type, fiber size, deposition, dissolution, and migration, affect the carcinogenic potential of asbestos fibers. However, these factors are interrelated, and fiber size appears to be the most definitive in predicting carcinogenic potential of fibers in the lungs (Davis 1989). Studies in which asbestos fibers were injected into the lungs of animals form the basis for the "Stanton Hypothesis" on the relationship between fiber size and carcinogenicity. The hypothesis states that fibers greater than 8 μm in length and less than 0.25 μm in diameter have the most marked carcinogenic potential (Stanton 1981). This hypothesis is also supported by inhalation studies in rats, showing that short amphibole and chrysotile fibers (≤ 5 μm) were less carcinogenic than long fibers (Mossman et al. 1990). Some studies, however, show that fibers less than 5 μm in length appear to be capable of producing mesothelioma (a cancer of the thin membrane that surrounds the lung) in animals.

Because fiber type and levels of fiber deposition and dissolution in the lung tissue are interrelated, they are often addressed together in scientific research. Several studies have shown that deposited amphibole fibers penetrate the peripheral lung more readily than chrysotile fibers and are more persistent in the lungs (Davis 1989; Mossman et al. 1990). Mossman (1990) postulates that chrysotile fibers do not penetrate deep into the lungs because of their hindering shape and the fact that they often occur in bulky bundles. Another possible explanation for the lower persistence of chrysotile fibers is that they are rapidly removed from lung tissue by macrophages (a type of white blood cell that engulfs dead cells and foreign particles in the blood or lymph), presumably because these fibers undergo chemical dissolution in tissue, which render them fragile and susceptible to macrophage attack (Davis 1989; Mossman et al. 1990).

Several studies indicate that the risk of pleural mesothelioma is lower where chrysotile is used without concurrent use of amphiboles (Davis 1989; Mossman et al. 1990). Epidemiological studies also show that mesothelioma patients, or workers chronically exposed to asbestos, have far more amphibole than chrysotile fibers in their lungs (Mossman et al. 1990). Although controversy exists about the relative potency of chrysotile and amphiboles in causing lung cancer, several studies suggest that chrysotile may also be less potent than amphiboles in inducing lung cancer. For example, mortality rates are lower in chrysotile miners and workers who manufacture friction materials made solely of chrysotile, as compared with rates seen in amphibole miners and workers (McDonald and McDonald 1986). The strength of this apparent association is reduced by the limited data available on exposure to amphibole fibers in mining and milling operations and the lack of data on exclusive exposure to amphiboles in the manufacture of friction products. However, evaluation of asbestos fibers retained in the lungs also supports reduced potency of chrysotile as compared with amphiboles in causing lung cancer. The severity of asbestosis and incidence of lung cancer observed in asbestos factory workers in London correlated with the lung burden of crocidolite and amosite asbestos (amphiboles), while the proportions of chrysotile and nonasbestos fibers were decreased in comparison to matched control patients (Wagner et al. 1988). The results of these studies, as well as the deposition and dissolution properties of chrysotile, indicate that exposure to amphibole fibers is associated with a greater risk of developing mesothelioma than exposure to chrysotile fibers. Some data also suggests that lung cancer risks may also be greater following exposure to amphiboles than to chrysotile, particularly where exposures to chrysotile occur in mining or milling.

However, the animal studies forming the basis for the Stanton Hypothesis showed that long chrysotile fibers were as carcinogenic as long amphibole fibers when administered by intrapleural and intraperitoneal injection. Other animal experiments support the view that chrysotile fibers can be at least as hazardous as amphibole fibers. In fact, chrysotile has been found in some studies to be more fibrogenic and carcinogenic than either amosite or crocidolite (although route of administration of these amphibole fibers was not specified in the report) (Davis 1989). These results suggest that the shape and dissolution characteristics of chrysotile fibers, rather than an inherent absence of carcinogenicity, account for the apparent lack of association between inhalation of chrysotile fibers and development of mesothelioma in humans (Mossman et al. 1990; Stanton 1981).

Inhalation Exposures

Both animal and human studies have demonstrated the carcinogenicity of a variety of types of asbestos following inhalation exposures. Although there are considerable differences in carcinogenic potency of various types of asbestos, the entire class of asbestos is classified as a Group A human carcinogen based on increased incidence of lung cancer, mesotheliomas, and gastrointestinal cancer observed in occupationally exposed workers. Lung cancers and mesothelioma have been observed consistently in workers in the asbestos mining, insulation, textile, cement, and friction products industries. However, considerable differences in excess cancer rates have been observed in different industries using the same type of asbestos (i.e., exposure to chrysotile asbestos in textile mills is associated with a higher cancer risk than mining and milling) (IARC 1987). Some evidence of an association with excess cancers has also been seen in persons living in neighborhoods with asbestos factories and/or with asbestos workers. Laryngeal cancer has been associated with asbestos exposure in some groups of exposed workers. While lung cancer and mesothelioma are typically associated with chronic inhalation of asbestos, several studies in humans and animals show that short-term exposure to asbestos may also produce cancer. For example, some groups of workers exposed to asbestos for 1-12 months have shown an increased risk of lung cancer several years later. In addition, some rats inhaling asbestos for 1 day developed mesothelioma. The overall data on the subject, however, are not extensive enough to reach a definite conclusion about the association between short-term exposure to asbestos and cancer development (ATSDR 1990).

Evidence from data in human populations indicate that concomitant exposure to asbestos and tobacco smoking results in a synergistic effect to multiply the risk of developing lung cancer. For example, a study by Hammond et al. (1979) reported an age-standardized mortality ratio of 5.17 for workers who were exposed to asbestos, but did not smoke, 10.85 for smokers not exposed to asbestos, and 53.2 for asbestos-exposed smokers. Other studies have reported that risks from combined exposures are greater than those predicted by an additive model, but less than that predicted by a multiplication model (ATSDR 1990). In contrast, the risk of developing mesothelioma appears to be independent of smoking (IARC 1987).

EPA derived an inhalation URF of 0.23 $(f/cc)^{-1}$ for asbestos using data on the rates of lung cancer and mesothelioma in several occupational studies (U.S EPA 1991a). The URF for asbestos is a quantitative estimate of excess cancer risks per f/cc breathed and can be combined with an estimate of the asbestos exposure in f/cc to derive a quantitative risk estimate. This URF was derived without consideration of smoking habits in control or exposed populations. Thus, use of the URF may result in over- or underestimates of risks to individuals whose smoking habits differ from those of populations in studies used to derive the URF.

The URF is based on studies of workers exposed to a variety of asbestos types in diverse occupational settings. However, the URF does not include cancer incidence data from occupational populations exposed to chrysotile asbestos in mining and milling (U.S. EPA

1991a), and these studies may be most relevant to the exposure to chrysotile asbestos at the site. Unofficial *URFs* ($_u$*URFs*) ranging from 0.0013 $(\mathrm{f/cc})^{-1}$ to 0.0047 $(\mathrm{f/cc})^{-1}$ can be derived from data on lung cancer reported in three studies of workers exposed to chrysotile in mining and milling [McDonald et al. (1980); Rubino et al. (1979); Nicholson et al. (1979)]. These $_u$*URFs* were derived by PTI by converting an occupational exposure period of 5 days a week and an inhalation rate of 10 m^3/8 hour work day to a continuous exposure period. The lowest $_u$*URF* derived in this way is nearly 200 times less (182 times) than the current URF for asbestos and the highest value is nearly 50 times less than the current URF. Similarly, the $_u$*URF* derived from data on mesothelioma incidence in a population exposed to chrysotile asbestos in a mining setting is 0.031 $(\mathrm{f/cc})^{-1}$ (McDonald et al. 1980; Berman 1992, pers. comm.), which is 7 times lower than the current URF for asbestos. Thus, use of the current URF may result in a 7 to 200-fold overestimate of risks for exposures to chrysotile asbestos at the CCMA.

EPA Evaluation of Asbestos Analytical Methods—Although the evidence for carcinogenicity of asbestos following inhalation is conclusive, there are several uncertainties associated with its quantification. These uncertainties have prompted EPA to evaluate the methods for measurement of asbestos in air in an attempt to better correlate asbestos measurements with potential health risks. This evaluation may result in a revision of the URF for asbestos inhalation. Several issues relating to the measurement of asbestos contribute uncertainties to the URF. First, early occupational studies only provide a limited degree of quantitative data for estimating exposure. Second, the current inhalation URF for asbestos is based solely on fiber counts made by PCM and, due to limitations in the PCM method described in the *Data Analysis* section, PCM measurements may have over- or underestimated the total asbestos fibers present in the work environments where adverse effects were seen. Thus, because of uncertainty associated with the PCM method, the URF for asbestos may over- or underestimate risks for populations exposed to asbestos.

An additional uncertainty concerning the URF for asbestos is related to the active fraction of asbestos fibers (i.e., the subset of all fibers that causes adverse effects). The current URF is based on fibers that can be measured by PCM or earlier, less precise methods, (i.e., fibers greater than 5 μm, wider than 0.4 μm, and having a length:width ratio of 3:1). This approach is consistent with a body of data from experimental animals indicating that carcinogenicity generally increases with fiber length and decreases with width. However, because shorter and narrower fibers that may also have carcinogenic potential could not be accurately measured in studies used to derive the URF, the relative contribution of these fibers to risk cannot be quantified. Thus, use of this URF may under- or overestimate risks associated with asbestos exposure in a given environment.

Oral Exposures

Evidence for the carcinogenicity of asbestos following oral exposures is inconclusive. Most animal studies attempting to demonstrate carcinogenicity through ingestion have been limited in both design and number of animals. One study showed a statistically significant increased incidence of benign intestinal polyps in rats fed 1-percent asbestos in their diets. Although many studies have been conducted, only one epidemiological study showed a positive association between ingestion of asbestos and cancer. This study, which involved exposure to asbestos in drinking water, was considered inadequate for providing direct evidence about causality because of a lack of information on individual behavior that may influence risk. Despite the inadequacies of these animal and human studies, both ATSDR (1990) and DHHS (1987), who wrote a comprehensive review on literature pertaining to cancer risks associated with asbestos ingestion, concluded that it would be prudent to not disregard the possibility of asbestos being a human carcinogen by the oral route. However, the frequent negative findings of such an association leads to the belief that whatever risks do exist, they are probably low relative to background cancer rates and are significantly less than risks associated with inhalation of asbestos.

The potential for asbestos to cause adverse effects following ingestion will not be quantitatively addressed in this risk assessment. Although the majority of the evidence indicates that asbestos is not carcinogenic via ingestion, exclusion of oral exposures from the risk calculations may underestimate risks.

Noncarcinogenic Effects

A significant noncarcinogenic effect resulting from chronic inhalation of asbestos is a lung disease known as asbestosis, characterized by abnormal breathing due to the development of scar tissue in the lungs. Over time, this condition results in substantial loss in pulmonary function and increased resistance to blood flow through the lungs (ATSDR 1990). Studies in workers who developed asbestosis demonstrate that these persons are at an increased risk for lung cancer (IARC 1987). Although asbestosis has been reported in workers exposed to high concentrations of asbestos in industry during the period from the latter 1900s and through World War II, this effect occurs following relatively high exposures and would not be expected to occur following exposure to asbestos in the environment. EPA has not developed a reference dose for the noncarcinogenic effects of asbestos.

RISK CHARACTERIZATION

In this section, upper-bound lifetime excess cancer risks are estimated for the various levels of exposure derived in the *Exposure Assessment* section. A qualitative uncertainty assessment is also included in this section and is intended to help risk managers interpret the risk assessment findings.

Risk Calculations

The upper-bound lifetime excess cancer risk estimates are calculated using the following general equation described in EPA risk assessment guidance documents (U.S. EPA 1989b,c) and used in the risk assessment for the Atlas and Coalinga sites (U.S. EPA 1990a):

$$\text{Excess Lifetime Cancer Risk} = EC \times URF$$

where:

EC = Chronic daily exposure to asbestos in air averaged over the lifetime (as derived in the *Exposure Assessment* section and shown in Table 1) (f/cc)

URF = Unit risk factor for inhalation of asbestos [0.23 $(f/cc)^{-1}$].

Upper-bound lifetime excess cancer risk estimates ranging from 4×10^{-6} to 9×10^{-5} (Table 3) were calculated for the off-road riding, other activities scenarios, and combined scenarios described in the *Exposure Assessment* section and in Table 2. The risk estimates were also derived using the 95-percent upper confidence limit on the mean concentrations for off-road vehicles (motorcycles and ATVs) and for all other site uses from the BLM dataset (these concentrations are 0.066 and 0.04 f/cc, respectively).

Although the determination of an acceptable risk level is ultimately a decision to be made by risk managers, the findings presented here are compared with the range of acceptable risks cited in the EPA National Contingency Plan (which EPA describes as the "regulatory blueprint for implementing the Superfund law"). The National Contingency Plan states that risk levels in the range of 10^{-4} to 10^{-6} and lower are considered to be within the range of acceptable risks for Superfund sites. While this investigation was not conducted under Superfund, this range of risks has also been used by other EPA programs and by other federal agencies responsible for mitigating public health risks and is offered here to place the findings in perspective.

Although these risk estimates fall within the range of risks considered acceptable to many governmental agencies, there are numerous uncertainties that may result in over- or underestimates of risk. The following section, *Uncertainty Assessment*, presents a qualitative evaluation of key uncertainties.

Uncertainty Assessment

Because risk characterization serves as a bridge between risk assessment and risk management, it is important that major assumptions, scientific judgments, and estimates

TABLE 3. UPPER-BOUND LIFETIME EXCESS CANCER RISK ESTIMATES ASSOCIATED WITH ACTIVITIES AT THE CCMA[a]

	Excess Cancer Risk at Exposure Levels[a]		
Exposure Scenarios	1-Day	RME[b]	High Estimate[c]
Off-road riding	4×10^{-6}	2×10^{-5}	6×10^{-5}
Other activities	1×10^{-5}	3×10^{-5}	--[c]
Combined activities	1×10^{-5}	5×10^{-5}	9×10^{-5}

[a] Risk estimates are based on inhalation exposures only.

[b] RME - reasonable maximum exposure.

[c] The high estimate was derived from a site visitor's estimate of site use for off-road vehicle riding. The RME estimate for other activities was combined with this estimate.

of uncertainties be described in the assessment. EPA has identified several categories of uncertainties associated with risk assessments (U.S. EPA 1989c). These include uncertainties in identification of contaminants of concern, including measurement of contaminant concentrations, as well as uncertainties in toxicity values and exposure assessment.

The human health risk assessment for the CCMA includes the following key uncertainties:

- **Concentration Data Used in Risk Calculations**—PCM measurements of asbestos concentrations in air may over- or underestimate concentrations of asbestos fibers most closely associated with the induction of disease.
- **Toxicity Value for Asbestos**—The URF for asbestos inhalation is based on early studies using PCM or less precise methods and thus may over- or underestimate risks for a given exposure environment. It may also under estimate risks associated with ingestion of asbestos; and also overestimate risks associated with exposure to chrysotile asbestos found at the CCMA.
- **Relationship Between Asbestos Exposure and Smoking**—Risks of developing lung cancer following exposure to asbestos are substantially increased in persons who also smoke tobacco.
- **Exposure Assessment**—The extent to which one individual may use the site is difficult to estimate precisely; RME exposure estimates derived here may over- or underestimate site use and risk estimates.

This section presents an evaluation of the potential influence of each of these categories of uncertainties on the final risk estimates and is intended to facilitate interpretation of the risk assessment findings. A final section presents a summary of findings.

Concentration Data

As discussed above, PCM measurements are associated with considerable uncertainty and may tend to over- or underestimate concentrations of asbestos fibers in air most closely associated with adverse health effects. Although the finding of a statistically significant correlation between PCM and TEM measurements of 10 BLM samples supports the use of this particular PCM dataset for evaluating risks at the CCMA, discrepancies between asbestos concentrations measured by BLM and those reported by Popendorf and Wenk (1986) still raise concerns regarding the PCM data gathered by BLM. The 95-percent upper confidence limits on mean concentrations reported by Popendorf and Wenk for Run A are nearly 2 orders of magnitude higher than those from the BLM dataset. The reasons for this discrepancy cannot be fully determined without a reanalysis of archived samples from Popendorf and Wenk (1986). However, differences in counting and fiber fixation between the NIOSH (1977) methods used in the analyses conducted by Popendorf and Wenk (1986) and the current NIOSH method (NIOSH 1989) may partially account for the divergent results. Other factors that may account for differences observed between the datasets include variance in meteorologic conditions or experimental design (i.e., the size, speed, or spacing of offroad vehicles).

The BLM dataset includes QA/QC data and, thus, is thought to be more reliable than the data from Popendorf and Wenk (1986) where QA/QC data are lacking; however, the latter dataset was used to calculate risk estimates based on RME case assumptions for off-road vehicle riders (5.4 hours per day, 5 days per year, for 30 years). For Runs A and B, respectively, use of the 95-percent upper confidence intervals on mean concentrations (3.37 f/cc and 1.5 f/cc) results in upper-bound lifetime excess cancer risk estimates of 1×10^{-3} and 5×10^{-4}. These risk estimates are both above the 1×10^{-4} level often used by governmental agencies as an upper limit of acceptable risk. Thus, although this dataset is thought to be less reliable than the data collected by BLM and used in the formal risk assessment, this alternate dataset suggests that the excess cancer risk associated with the RME exposure estimate for off-road vehicle riders may be 38 to 84 times higher than the risk estimates presented in Table 3.

Toxicity Value for Asbestos

There are several uncertainties associated with the evaluation of the toxic effects of asbestos. Three aspects of the toxicity assessment may tend to underestimate risks. First, there is no reference dose for noncarcinogenic effects of asbestos. However, asbestosis and other noncarcinogenic adverse health effects associated with exposure to asbestos occur at much higher exposure levels than carcinogenic effects. Therefore, exposure levels set to mitigate potential cancer risks will also protect against other adverse effects. Similarly, whereas the current URF for asbestos is based on risks following inhalation only, there is limited evidence of carcinogenicity following oral exposure. However, available evidence indicates that potential excess cancer risks following oral exposures (if any) are much less than cancer risks associated with inhalation exposures. Therefore, the most significant risks have been quantified in this risk assessment.

A third aspect of the current URF, i.e., the lack of precision in analytical methods used in the occupational studies it was derived from, may result in over- or underestimation of risks. One aspect of this problem is that the active fraction of asbestos fibers could not be accurately identified in studies forming the basis of the URF. Although exact quantification of this uncertainty is not possible, preliminary results from EPA-sponsored research evaluating methods used to measure asbestos suggest that use of the current URF may result in a 50-fold or greater under- or overestimate of risks (Berman 1992, pers. comm.).

The most significant variable tending to overestimate risks at the CCMA is the fact that the URF is based on workplace exposures to a variety of different asbestos types, while asbestos at the CCMA is almost entirely chrysotile. Thus, exposures at the CCMA may be associated with risks closer to those observed in chrysotile workers in mining and milling than the risks observed in other data used to derive the URF. Several lines of evidence suggest that chrysotile has a lower carcinogenic potency than other types of asbestos (i.e., crocidolite and amosite) particularly when exposure occurs in mining and milling operations, as opposed to production of textiles. As discussed in the *Toxicity Assessment* section of this risk assessment, $_u$*URF*s derived from data on exposure to chrysotile asbestos in mining and milling operations are 7- to 200-fold lower than the current URF for all types of asbestos combined. Thus, use of the URF based on a variety of types of asbestos may overestimate risks associated with exposure to chrysotile at the CCMA.

The potential underestimation of risks related to the URF for asbestos is as least partially offset by factors that are likely to overestimate risks. The most significant variable tending to overestimate risks at the CCMA is the fact that the URF is based on workplace exposures to a variety of different asbestos types, while asbestos at the CCMA is almost entirely chrysotile. Several lines of evidence suggest that chrysotile has a lower carcinogenic potency than other types of asbestos (i.e., crocidolite and amosite) particularly when exposure occurs in mining and milling, as opposed to production of textiles. As discussed in the *Toxicity Assessment* section of this risk assessment, URFs for chrysotile asbestos are 7- to 200-fold lower than the current URF for all types of asbestos combined. Thus, use of the URF based on a variety of types of asbestos may result in a 7- to 200-fold overestimate of risks associated with exposure to chrysotile at the CCMA. In addition, because the URF for asbestos is based on PCM measurements, which may over- or underestimate concentrations of asbestos in air, risk estimates derived using the URF may also be over- or underestimated.

Relationship Between Asbestos Exposure and Smoking

As discussed in the *Toxicity Assessment* section, the risk of developing lung cancer following exposure to asbestos may be up to ten times higher in persons who also smoke tobacco. However, because the URF was derived without taking into account smoking habits of exposed or control populations, CCMA visitor's risks, as shown in Table 3, may be over- or underestimated in individuals whose smoking habits differ from those of the populations in studies used to derive the URF.

Exposure Assessment

The extent to which one individual may use the site is difficult to estimate precisely. The RME exposure estimates derived here are based on national surveys of time spent in a variety of activities and on comments made at a public meeting regarding the site. The RME estimates used in the risk assessment are intended to err on the side of overestimation of exposure and, thus, risks. However, certain individuals may visit the site more frequently or spend longer periods of time at the site than assumed in the RME estimates. To evaluate a range of risks at various exposure levels, risks were calculated for exposure frequencies from 1 day to 60 days for the off-road vehicle scenario, for the other site use scenario (i.e., camping, hiking, and other activities), and for the combined scenarios. These calculations were based on additional exposure variables presented in Table 2 including the ambient air concentrations derived from the BLM dataset. As demonstrated in Table 4 and Figure 9, risks do not reach the 1×10^{-4} level until exposures are greater than 9 days per year for 30 years. These calculations can be used to help risk managers develop management alternatives for the CCMA and help visitors to make decisions about site use.

Summary

Use of the variables described in the preceding paragraphs results in uncertainties surrounding the risk estimates that span several orders of magnitude. Table 5 presents a summary of the relative contributions of various factors to uncertainty in the risk assessment. Comparison of concentration data derived from the BLM dataset with those from Popendorf and Wenk (1983) suggest that the BLM concentration data used in the risk assessment for offroad vehicle riders may be underestimated by 38 to 84 times. However, the lack of quality assurance data for the Popendorf and Wenk (1983) dataset and the fact that the BLM dataset was collected over a broader range of exposure conditions (i.e., through all seasons and within many areas of the CCMA) suggest that the BLM data are the more representative values. In addition, comparison of the EPA URF for asbestos used in the risk assessment with URFs calculated using mesothelioma and lung cancer data from populations exposed to chrysotile asbestos in mining or milling indicates that use of the EPA URF may result in 7- to 200-fold overestimates. Thus, the uncertainties associated with these two variables result in a net overestimate of risks particularly when the relative strength of the Popendorf and Wenk (1983) dataset is taken into consideration. However, uncertainties associated with use of PCM data may tend to over- or underestimate risks and lung cancer risks may be underestimated for site visitors who smoke.

Potential over- or underestimates associated with other variables are more difficult to quantify. Exposure frequency and duration are expected to vary considerably with individuals. However, the RME variables are expected to overestimate exposures and risks for most people based on available national averages for similar activities. Underestimates of exposure for persons who use the site more frequently than the RME estimate are expected to be less than 18-fold. That is, site use over a thirty year period is unlikely to be higher than the highest estimate in Table 4 (i.e., 60 visits to ride off-road vehicles and 60 visits to engage in other activities), which would result in an estimated risk 18 times higher than the RME estimate. The degree to which the current URF for asbestos may under- or overestimate risks is unknown, but may be as high as 50-fold in either direction based on preliminary data.

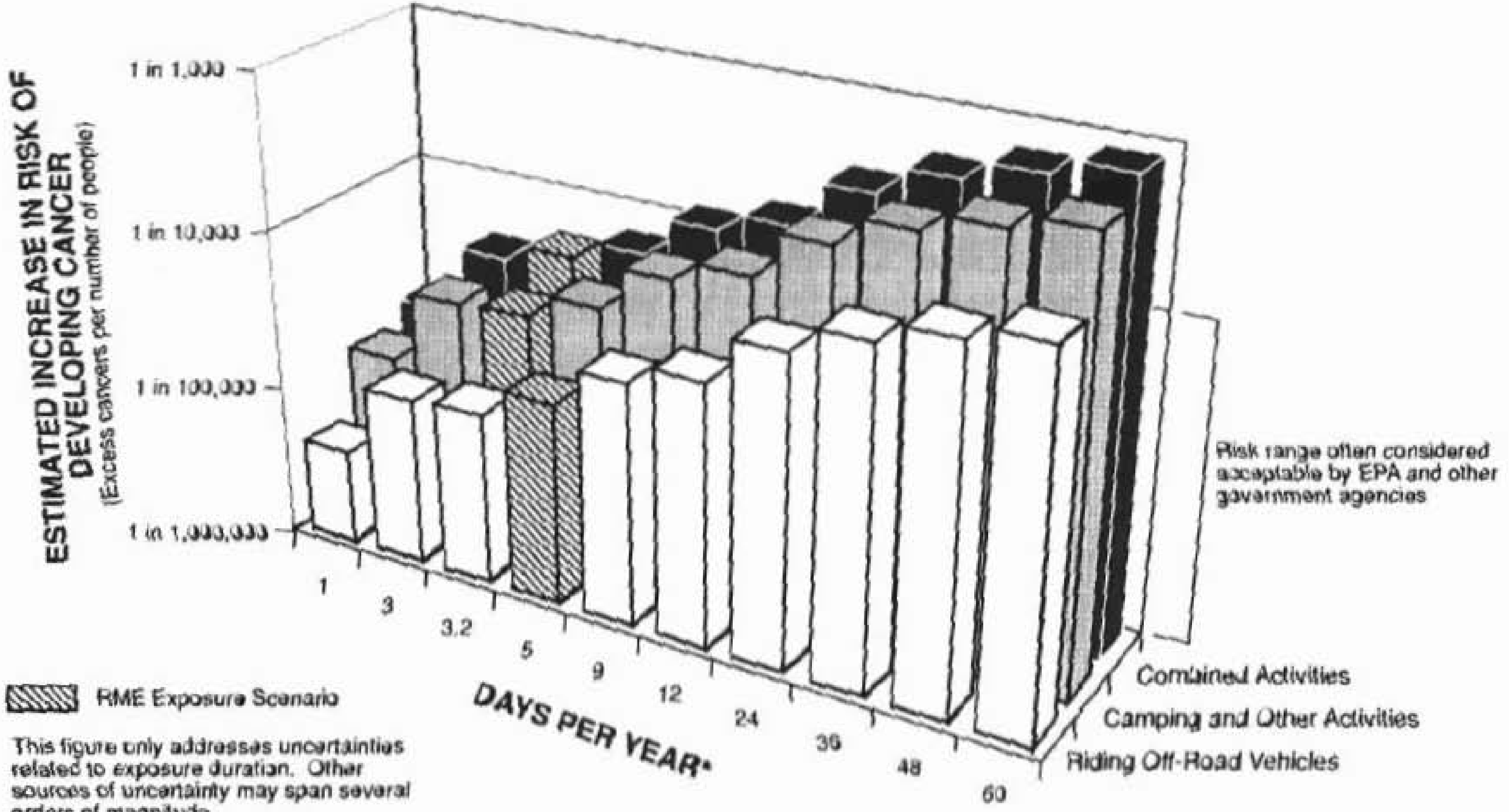
Although uncertainties span a total range of more than three orders of magnitude (Table 5), it is extremely unlikely that all sources of underestimation would exert their effects without concurrent opposing sources of overestimation. Moreover, although uncertainties cannot be precisely quantified, there appears to be greater total sources of overestimation rather than under estimation. Thus, consideration of key sources of

TABLE 4. UPPER-BOUND LIFETIME EXCESS CANCER RISK ESTIMATES AT INCREASING LEVELS OF EXPOSURE

Number of Days of Exposure/Year for 30 Years	Upper-Bound Lifetime Excess Cancer Risk Estimates By Activity		
	Off-Road Vehicle Riding	Other Activities	Combined Activities
1	4×10^{-6}	1×10^{-5}	1×10^{-5}
3	1×10^{-5}	3×10^{-5}	4×10^{-5}
RME estimate[a]	2×10^{-5}	3×10^{-5}	5×10^{-5}
5	2×10^{-5}	5×10^{-5}	7×10^{-5}
9	4×10^{-5}	1×10^{-4}	1×10^{-4}
12	5×10^{-5}	1×10^{-4}	2×10^{-4}
24	1×10^{-4}	3×10^{-4}	4×10^{-4}
36	1×10^{-4}	4×10^{-4}	5×10^{-4}
48	2×10^{-4}	5×10^{-4}	7×10^{-4}
60	2×10^{-4}	6×10^{-4}	9×10^{-4}

Note: Based on exposure variables presented in Table 2 with the exception of the days of exposure as noted. Also based on exposure concentrations derived from the BLM dataset (Table 2).

[a] RME exposure scenarios are based on 5 days of off-road vehicle riding and 3.2 days of other activities.



This figure only addresses uncertainties related to exposure duration. Other sources of uncertainty may span several orders of magnitude.

* Exposure is evaluated in days per year over a 30 year exposure duration.

Figure 9. Estimated increase in risk of developing cancer following exposure to asbestos at the CCMA.

TABLE 5. CONTRIBUTION OF SELECTED VARIABLES TO UNCERTAINTY

Variable	Over- or Underestimate; Magnitude	Basis
PCM data	Over- or underestimate	Imprecision of PCM method may result in over- or underestimate of exposures and risks
BLM dataset (PCM)	May underestimate; up to 38- to 84-fold	Popendorf and Wenk asbestos concentration data are considerably higher than BLM data
Asbestos unit risk factor	Overestimate; 7 to 200-fold	URFs derived based on exposure to chrysotile asbestos in mining and milling are much lower than the EPA URF based on exposure to a variety of types of asbestos in various exposure settings
Asbestos unit risk factor	Under- or overestimate; unknown, may be 50-fold or greater	URF for asbestos may not account for all biologically active fibers
Tobacco smoking	Over- or underestimate	Risks of developing lung cancer following asbestos exposure may be substantially increased in persons who smoke tobacco
Exposure assessment	Overestimate for most individuals, underestimate for some; unknown	Site use is expected to be highly variable with individuals

uncertainty in the risk assessment variables indicates that the RME estimate is a conservative estimate of risks.

Because of the inability to precisely estimate toxicity and exposure in environmental settings, uncertainties of this magnitude are not uncommon in risk assessment. Where uncertainties exist, assumptions made in risk assessment are designed to ensure that risks are not underestimated. As a result, use of these assumptions is likely to overestimate risks. Therefore, risk assessment results should be regarded as a risk management tool rather than an exact quantification of human health risks. This risk assessment provides information on the relative magnitude of risks associated with various CCMA uses that can be used in identification and selection of CCMA management options.

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TABLE A-1. COMPARISON OF EXPOSURE ASSUMPTIONS FOR OFF-ROAD VEHICLE RIDERS USING THE CLEAR CREEK MANAGEMENT AREA

	U.S. EPA Atlas RI Risk Assessment[a]		Respondents at Public Meeting[b]			U.S. EPA Exposure Factors Handbook[c]	
Parameter	Average	Maximum	Rider 1	Rider 2	Rider 3	Average	Reasonable Maximum
Hours/day	3	5	3-4	6	7	0.52/2 per week	0.52 per week
Days/week	1	1	1	2	2	NA	NA
Weeks/year	16	32	4	4 (also p. 146)	6	52	52
Total hours/year	48	160	16	48	84	14	27
Years	5	5	No data: 9 assumed	25 (also pp. 135, 149)	No data: 30 assumed	9 years	30 years
Total hours/lifetime	240	800	144	1,200	2,520	126	811

[a] U.S. EPA (1990a) estimate for campers, hikers, and hunters in areas around Atlas Mine and Johns-Manville Coalinga Mill.

[b] U.S. EPA (1990b): Comment from rider 1 recorded on page 131; comment from rider 2 on pages 144-145; comment from rider 3 on pages 146-147.

[c] Exposure estimate based on U.S. EPA *Exposure Factors Handbook* (U.S. EPA 1989a) estimate that men spend 0.52 hours per week in the following activities: motorcycling, biking, walking, hiking, jogging, running, and horseback riding.

person stated that he visited the site 12 days/year and rode for about 7 hours/day for a total of 84 hours/year (U.S. EPA 1990b, pp. 146–147). These exposure frequencies are considerably lower than the U.S. EPA (1990a) maximum estimate of 160 hours/year (5 hours for 32 days/year). However, several people indicated that they had been visiting the site for 25 or more years (U.S. EPA 1990b, pp. 135, 144-145, and 149), in contrast with the U.S. EPA (1990a) estimate of 5 years. Thus, while the exposure frequency used by U.S. EPA (1989a) is higher than that indicated in public comments, application of the exposure duration results in similar total hours of exposure over the lifetime (Table A-1).

Although no nation- or region-specific data are available on the amount of time people spend riding off-road vehicles, U.S. EPA (1989a) indicates that men spend 0.52 hours/week in the following activities: motorcycling, biking, walking, hiking, jogging, running, and horseback riding. Because motorcycling is just one of these activities, it seems reasonable that only one-half of that time might be spent riding off-road vehicles for the average case, with 0.52 hours/week as a reasonable maximum estimate. U.S. EPA (1989a) recommends using an exposure duration of 9 years for the average length of time people might visit one recreational area. This estimate is based on the fact that 9 years is the median length of time people in the United States live at one residence. Similarly, a 30-year duration, the 90th-percentile residential duration, is recommended by U.S. EPA (1989a, 1991) for estimates of the RME duration for recreational use. The 30-year exposure duration and the exposure frequencies derived using U.S. EPA (1989a) guidelines are generally consistent with estimates made by site visitors who spoke at the public meeting (Table A-1). In addition, the maximum estimate of total hours of exposure over the lifetime, derived through use of values in U.S. EPA (1989a), is essentially the same as that derived in U.S. EPA (1990a). However, the average exposure estimate derived by U.S. EPA (1990a) is about twice that derived through application of values from U.S. EPA (1989a).

Other CCMA Uses

U.S. EPA (1990a) derived exposure estimates for hikers, campers, and hunters based on the assumption that in the average case, an adult would visit the Atlas Mine or Johns-Manville Coalinga Mill sites for 8 hours/day, 52 days/year, for 10 years. As a maximum case, U.S. EPA (1990a) assumed that someone would visit the CCMA for 8 hours/day, 104 days/year, for 20 years (Table A-2). Public comments suggested that this level of site use was too high. An estimate for hiking of 4 hours/day, for 4 days/year was suggested by one meeting participant (U.S. EPA 1990b, p. 131) (Table A-2). In addition, a member of an association of 24 rock hound clubs "throughout this part of the state" indicated that ". . . the rock hound people only go down there maybe once or twice a year, maybe for one or two days" (U.S. EPA 1990b, p. 123). Participants at the public meeting did not comment on the number of years that people might visit the CCMA for these activities. U.S. EPA (1989a) presents results from a national survey indicating that men spend 1.49 hours/week outdoors in the following activities: hunting, fishing, boating, sailing, canoeing, camping at the beach, and other activities. This

TABLE A-2. COMPARISON OF EXPOSURE ASSUMPTIONS FOR CAMPERS, HIKERS, HUNTERS, AND ROCK COLLECTORS USING THE CLEAR CREEK MANAGEMENT AREA

	EPA Atlas RI Risk Assessment[a]		Respondents at Public Meeting[b]		U.S. EPA Exposure Factors Handbook[c]	
Parameter	Average	Maximum	Rock collecting	Hiking/Camping	Average	Reasonable Maximum
Hours/day	8	8	8	4	1.49/2 per week	1.49 per week
Days/week	1	2	1-2	1-2	NA	NA
Weeks/year	52	52	1-2	2	52	52
Total hours/year	416	832	16	16	39	77
Years	10	20	No data: 9 assumed	No data: 30 assumed	9	30
Total hours/lifetime	4,160	16,640	144	480	351	2,310

[a] U.S. EPA (1990a).

[b] U.S. EPA (1990b): Comments from rock collectors recorded on page 123; comment on hiking and camping recorded on page 131.

[c] Exposure estimate derived from U.S. EPA *Exposure Factors Handbook* (U.S. EPA 1989a) estimate that men spend 1.49 hours per week outdoors in the following activities: hunting, fishing, boating, sailing, canoeing, camping at the beach, and other activities.

estimate was used to derive average and reasonable maximum estimates of 39 and 77 hours/year, respectively (Table A-2). Application of the U.S. EPA (1989a) recommendations on duration of exposure, as described in the discussion for off-road vehicle riders, results in estimates of 351 and 2,310 hours over the lifetime, for the average and reasonable maximum cases, respectively (Table A-2). These estimates are considerably lower than the U.S. EPA (1990a) average and maximum estimates of 4,160 and 16,640 hours over the lifetime.

Conclusions

Comparison of the exposure assessment conducted by U.S. EPA (1990a) with comments from the public meeting and with the EPA exposure assessment guidance document suggests that the exposure variables derived from EPA's *Exposure Factors Handbook* (U.S. EPA 1989a) are the most appropriate for use in a risk assessment of alternatives for the CCMA (Tables A-1 and A-2). Exposure estimates for off-road vehicle riders derived from U.S. EPA (1989a) are close to the U.S. EPA (1990a) maximum estimate and to both estimates derived from public comments, but they are somewhat lower than the U.S. EPA (1990a) average estimate. Similarly, estimates derived from U.S. EPA (1989a) for other site uses are somewhat higher than the limited information gathered at the public meeting and are about an order of magnitude lower than estimates derived by U.S. EPA (1990a) for the average and maximum cases.