NORTH SANTA BARBARA COUNTY

CRYSTALLINE SILICA STUDY

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Region IX

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EXECUTIVE SUMMARY

INTRODUCTION

Crystalline silica particulates are mainly comprised of quartz, cristobalite, tridymite and a host of minor components such as coesite or tripoli. The major components are known to be toxic substances with variable toxicity (dependent on the form and size). For example, breathing very small particles of crystalline silica over years causes silicosis, a serious lung ailment. In 1986, the International Agency for Research on Cancer listed crystalline silica as a suspected carcinogen. In 1988, the state of California established a cancer risk factor for crystalline silica, based on laboratory animal cancer findings. A Santa Barbara County Air Pollution Control District ("District") review in 1990 showed that the County contains **major** facilities (with 100 tons/year or more of permitted PM emissions), which also emit crystalline silica. These facilities include rock and gravel production facilities, and diatomaceous earth processing plants that **calcine** this mineral to obtain products often containing more than 65 per cent quartz and cristobalite. Therefore, the District examined the impact of crystalline silica emissions from these facilities and assessed potential cancer risks and possible chronic health effects in this study. Since the emissions occur mainly in the north County, the study targeted this area only.

ANALYSIS DESCRIPTION

The District analysis consists of quantifying crystalline silica emissions, assessing the ambient concentration, i.e., population exposure due to these emissions, and estimating the health risks. The study also examines limited available data on measured ambient concentrations of the pollutant and compares these with model-projected exposure.

Emissions Inventory: For initial screening, **actual annual** PM_{10} emissions from plant facilities with greater than 25 tons/year **permitted** PM emissions were computed. Based on the screening results, a number of **major** PM_{10} sources were reviewed for crystalline silica fraction in their PM_{10} emissions. In a final listing, actual annual crystalline silica emissions were projected for eight (8) major sources. The preliminary inventory of **inhalable** (less

than 10 μm MMAD) crystalline silica emissions for each facility was sent to the facility operators for their review and input. Based on their response, the final emissions inventory was assembled for PM_{10} and inhalable crystalline silica. As a follow-up, the study conservatively estimated the ambient impact of **respirable** (less than 3.5 μm MMAD) particulate emissions. Since available EPA equations and emission factors compute emissions of "fine" particulates (2.5 μm MMAD or less) only, this study uses $PM_{2.5}$ emissions as surrogates for "respirable" particulate emissions.

Exposure Assessment: Adverse exposure of a population to crystalline silica occurs only through "inhalation" or "respiration" of particulates. Hence, this study examined crystalline silica concentrations in ambient air only. Since data on measured ambient concentrations of crystalline silica are extremely limited, area-wide crystalline silica concentrations were computer-projected, based on the EPA-recommended Industrial Source Complex (ISCST) dispersion model. Using crystalline silica emissions from all sources and local, hourly meteorological data as input, the computer model predicted crystalline silica levels in ambient air over industrial, commercial and residential areas.

Major emission sources in north County are located near Santa Maria, Lompoc and Buellton/Santa Ynez. Hence, modeling was confined to rectangular blocks of 400-500 sq.km in each of these areas. In addition to the maximum concentrations (often next to plant boundary), concentrations at the nearest residential area and at "sensitive" receptors such as schools, hospitals and nursing homes are presented in this study.

In an additional analysis, qualitative estimates of "inhalable" dust emissions due to paved road traffic were provided as input to the model. Vehicular traffic re-entrainment is considered by many experts as a factor that can be significant in PM_{10}, and consequently, crystalline silica impact. Therefore, the predicted PM_{10} levels at two PM_{10} monitors, namely, Santa Maria downtown (urban, population-oriented) and Santa Ynez airport (rural, background) were examined to evaluate re-entrainment effects due to vehicular traffic.

Finally, this study examined actual crystalline silica concentrations at three north County PM_{10} monitoring sites, namely, Watt Road (rural background), Santa Ynez airport and Santa Maria downtown. A limited number of filters (about 50) from these samplers, obtained for pre-selected days with high PM_{10} readings, were analyzed using x-ray crystallography and inhalable crystalline silica levels in the ambient air were determined.

Risk Assessment: Health risks associated with crystalline silica exposure were estimated using the Assessment of Chemical Exposure (ACE-2588) model. This model integrates toxicological algorithms and ambient exposure data (from the ISCST model) to predict health impacts. Cancer risks are calculated using two different cancer potency unit risk factors specified by the California Office of Environmental Health Hazard Assessment. A three-tiered approach is used to describe the risk to receptors, namely, risks to the theoretical maximally exposed individual (MEI), risks at the nearest actual receptor (residence), and risks at the closest sensitive receptor (schools, hospitals). Non-carcinogenic, chronic health effects are expressed in terms of a hazard index (HI), with an HI value greater than one signifying an unacceptable exposure.

ANALYSIS RESULTS

The results of the analysis indicated crystalline silica emissions in excess of 100 tons/year from the north County sources, cancer risks in excess of 10 in a million at sensitive receptors and hazard indices < 1 at residences or sensitive receptors.

Emission Inventory: The emissions inventory for **crystalline silica** was obtained for calendar year 1989, which is the highest for the north County facilities during the CY 1988-92 period.

The results are summarized as follows:

- Approximately 104 tons of **inhalable** emissions were generated;
- 73% of the total **inhalable** emissions were generated by process operations; and,
- 28 tons of "fine" or surrogate **respirable** particulates were emitted (27% of the inhalable emissions)

Exposure Assessment: Inhalable emissions around rock and gravel processing facilities projected ambient concentrations between 0.5 and 17 $\mu g/m^3$ of crystalline silica at or just beyond the plant boundaries. In the worst case situation, two adjacent Santa Maria area plants contributed to an impact of 17 $\mu g/m^3$ at the MEI receptor located less than 500 m from their common plant boundary. In Lompoc area, the larger of the two diatomaceous earth processing facilities contributed 1.5 $\mu g/m^3$ levels of crystalline silica at about 1.5 km from its mine site. To estimate the hazard indices at Santa Maria and Lompoc area sensitive receptors the impact of cristobalite emissions was computed, since adverse **chronic** health effects are known only for this substance. The computed maximum ambient level for all sensitive locations is about 0.1 $\mu g/m^3$ of cristobalite.

Respirable (fine) emissions at the two adjacent sand and gravel facilities in Santa Maria area projected an ambient concentration of 5.9 $\mu g/m^3$ of crystalline silica at 500 m beyond their common boundary. In Lompoc area, respirable emissions from the larger of the two diatomaceous facilities projected about 0.7 $\mu g/m^3$ of crystalline silica exposure at about 0.5 km from the plant boundary. For all residential sectors, the estimated maximum impact of cristobalite emissions at key/sensitive locations (e.g., schools/hospitals) is about 0.01 $\mu g/m^3$.

Concentrations due to PM_{10} emissions from the industrial plants were calculated at the nearest actual monitor stations which were located 5 km or more away. This showed insignificant impacts of 0 - 0.2 $\mu g/m^3$. In contrast, PM_{10} road re-entrainment impact from vehicular traffic at these monitors shows that the projected PM_{10} levels approximate the actual PM_{10} levels observed at the two monitors. Thus, PM_{10} (or crystalline silica) re-entrainment effect can be considered as a significant factor at these two monitors.

Finally, the examination of monitored and modeled crystalline silica levels at three monitors show that:

(a) **Measured** 24-hour concentrations range from a minimum of 0 $\mu g/m^3$ (Buellton) to a maximum of 3.45 $\mu g/m^3$ (Santa Maria);

(b) **Modeled** 24-hour impact of the industrial emissions at the monitors ranges between 0

and 0.2 $\mu g/m^3$: and,

(c) **Limited measured** data for Buellton/Santa Ynez area monitors do not reveal any high ambient levels of crystalline silica **that can be associated with industrial sources.**

Risk Assessment: The study results indicate a health impact in excess of 100 in a million cancer risk at and very near the theoretical MEI receptor, with the more remote residential areas and sensitive receptors (schools, etc.) affected to a much lesser extent. These results are tabulated below.

"Inhalable" Emissions

Receptor Type	Santa Maria Area		Lompoc Area		Buellton Area	
	Cancer Risk*10^{-6}	**Hazard Index**	**Cancer Risk*10^{-6}**	**Hazard Index**	**Cancer Risk*10^{-6}**	**Hazard Index**
MEI	5000/776	0.72	438/68	0.66	129/20	0.02
Residence	100/15	<0.1	50/7	<0.25	20/3	<0.001
Sensitive	15/2	<0.1	50/7	<0.25	15/2	<0.001

* -- High/low values, based on risk potency values

Respirable ("Fine") Emissions

Receptor Type	Santa Maria Area		Lompoc Area		Buellton Area	
	Cancer Risk*10^{-6}	**Hazard Index**	**Cancer Risk*10^{-6}**	**Hazard Index**	**Cancer Risk*10^{-6}**	**Hazard Index**
MEI	1724/267	0.25	191/30	0.25	37/6	0.01
Residence	40/6	<0.1	20/3	<0.1	20/3	<0.001
Sensitive	20/3	<0.1	20/3	<0.1	15/2	<0.001

* -- High/low values, based on risk potency values

CRITICAL REVIEW OF RESULTS

A critical review of the results pinpoints four potential limitations and the directions for a regulatory policy on crystalline silica. These limitations resulted from the constraint of relatively limited data available (in particular, air quality data), that precluded more in-depth analysis. The effects of this constraint and the emerging regulatory policy are discussed below.

(a) Emission Inventory -- Compilation of the emission inventory uncovered four potential limitations. First, compilation of an accurate emission inventory for <u>all</u> sources, including minor ones, requires vast resources and, thus, forced a review of only the **major** industrial sources. Next, the $PM_{2.5}/PM_{10}$ emission factors are based on EPA's AP-42 data, based on limited EPA field studies. Also, **most** of the EPA emission factor studies focussed on limestone or phosphate rock processing whereas the Santa Barbara county plants processed mainly granite rocks and diatomaceous earth. Thus, some PM emission computations are tentative, particularly for respirable dust emissions. Finally, fugitive crystalline silica emission computation is based on the assumption that the fraction of the crystalline silica present in the process line grab sample truly represents the fraction of crystalline silica present in the process/fugitive emissions. This is very plausible, but could not be conclusively proved during the limited time frame of this study. A good possibility exists that this asumption may have caused an overstatement of non-process fugitive emissions. Therefore, the predicted exposure assessments, particularly for respirable particulate emissions, should not be accepted as conclusive until more definitive non-process, fugitive emission factors for respirable crystalline silica are obtained.

(b) Health Risk -- Results of this study projected cancer risk well in excess of 100 in a million for the MEI. However, there is uncertainty associated with the emissions inventory (as described above) and with California OEHHA's listed "screening-purpose cancer risk factor range" for crystalline silica. In accordance with OEHHA's suggestions, these values should be used for screening purposes only and no final cancer risk conclusions for crystalline silica should be drawn from results of this study until a nationally acceptable,

single cancer risk factor for this pollutant is established by the ongoing EPA and other studies. Also, it would be helpful to obtain monitored and quality-assured PM_{10} and crystalline silica data near the industrial sources.

(c) Regulatory Strategy -- The study indicates that the north county facilities, which annually emitted about 104 tons of inhalable crystalline silica in 1989, contributed to about 3 per cent of 1989 total PM_{10} emissions in the entire county, **at a maximum**. PM_{10} sampler data analysis performed by the District in 1989 showed that the rest of the sources including the south county sources do not contribute measurably to north county crystalline silica impact. In other words, only a small fraction of PM_{10} sources in north county contributes to the north county crystalline silica burden. Therefore, source-specific PM_{10} or crystalline silica reduction strategies need to be considered instead of a county-wide control approach.

RECOMMENDATIONS

The following recommendations are based on this study:

A. In future, if the EPA health scientists project a crystalline silica "cancer risk factor," then the data compiled for this study must be revisited for a final analysis.

B. Estimates of crystalline silica fraction in the fugitive PM emissions should be improved through a multiple, actual on-site sampling process, particularly for secondary emissions such as traffic-generated emissions.

C. Ambient monitoring data for crystalline silica would be helpful along with any source-specific data obtained for non-process fugitive emissions. We suggest that future studies should consider setting up suitable PM_{10} and dichotomous samplers within 1 km or less from **major** industrial sources to better assess

their emissions impact and verify the PM_{10}/$PM_{2.5}$/crystalline silica emission factors.

D. Any future PM_{10}/crystalline silica regulatory strategy should pursue source-specific emission reduction conditions rather than county-wide emission reduction measures.

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CHAP. I INTRODUCTION

1. Purpose of Study

Harmful health effects have been associated with crystalline silica inhalation by people at their work place since early 1900s. Crystalline silica has been known to cause silicosis, particularly among stone quarry, mine and stone crushing workers. However, it has been listed only recently as a suspected carcinogen by the International Agency for Research on Cancer (IARC)[1]. California Air Resources Board (ARB) and Office of Environmental Health Hazards Assessment (OEHHA) have also identified crystalline silica as a substance for which potential cancer risks to the population needs to be roughly (i.e., screening type analysis) estimated[2].

Large sources of anthropogenic crystalline silica emissions exist in Santa Barbara County. Therefore, Santa Barbara County Air Pollution Control District (SBCAPCD or "District") felt considerable interest in examining crystalline silica emissions health impact. The District staff drafted a study proposal in July, 1990 to investigate crystalline silica emissions, exposure and risk and submitted it to the U.S. Environmental Protection Agency (EPA). The study aimed to determine the likelihood and extent of significant health risks posed by anthropogenic emissions of crystalline silica. As a corollary, if the estimated crystalline silica health risks exceeded significant levels of harmful health effects, e.g., cancer affliction risk, the study would provide guidance to the District for implementing strategies to reduce identified health risks to **acceptable** levels. The study was also of interest to the EPA. Since there are large sources of anthropogenic crystalline silica emissions in

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1 International Agency for Cancer research, IARC Monograph #42: IARC Working Group on the Evaluation of the Carcinogenic Risk of Chemicals to Humans: Silica and some Silicates(1986), Lyon, France.

2 California Air Pollution Control Officers Association: AB 2588 Risk Assessment Committee, Risk Assessment Guidelines (January, 1992), Sacramento, CA.

Nevada, Idaho and Maryland, SBCAPCD's study conclusions and recommendations may, conceivably,provide useful information for interested public and regulatory agencies in these states. Actual commencement of the study at the District was postponed until August, 1992 due to sudden staff losses. The study has been completed in June, 1993.

2. Study Goals

Goals of this study are modest. The study is confined to two source categories: (i) mining, production and use of diatomaceous earth, and (ii) production, storage and on-site haul of sand, rock and gravel materials. This restriction originates from the fact that a vast majority (more than 90 per cent) of crystalline silica emissions occur at these two source categories only. Also, based on data obtained during the study (see Chapter III on emissions), the crystalline silica impact analysis was ultimately confined to **north County sources only**.

The four phases of the study are listed below, as follows:

(a) *Emission Inventory Development* -- As a first task, the emissions of "**inhalable** (i.e., $< 10\ \mu m$ diameter)" crystalline silica for base year 1989 was quantified. A 1990 preliminary District analysis, fulfilling the District's AB 2588 commitments, showed very high crystalline silica exposures around some industrial sources. However, the emissions data serving as the modeling analysis input was found to be based on inaccurate equipment and operations estimate. This pointed out the need to obtain detailed, quality-assured data. Therefore, information was obtained for this study through additional information requests under CA Health & Safety Code, Section 42303, and used to compile a detailed inventory. For additional quality assurance, the initial inventory compiled by the District was allowed to be reviewed

for accuracy by the inventory-listed sources.

For major particulate (PM_{10}) emissions sources which contribute significantly to the crystalline silica inventory, available emissions testing data were scrutinized first. Generally, results from such tests, including size-distribution and speciation of PM_{10} emissions, can provide a more accurate picture of crystalline silica emissions. However, the detailed review found that collection methods in the test had violated EPA/ARB protocols. This resulted in rejection of the PM_{10} test data. Since no other data were available, standard PM_{10} emission factors listed in EPA guidelines were used to compute emissions. Fugitive emissions caused by the materials handling activities at sources were also inventoried, based on EPA/ARB guidance documents.

A qualitative emission inventory survey was performed for area sources in the north County area. ARB estimated emissions from anthropogenic sources such as unpaved road vehicular traffic and agricultural tilling for base year 1989 were examined. This data was used to qualitatively estimate area source impact, if any.

Finally, based on EPA's AP-42 listed emission factors, an inventory was prepared for "fine (i.e., < 2.5 μm diameter)" crystalline silica emissions from industrial sources for base year 1989. This was necessary due to the fact that adverse health effects of crystalline silica are predominantly caused by "respirable" particulates, i.e., particulates less than 3.5 μm diameter (mostly in the 0.1 - 2 μm diameter range).

(b) ***Sampling and Analysis*** -- As the second task, ambient air sampling filters and product "grab" samples at the plants were analyzed to quantify crystalline silica fractions in the samples.

Ambient air analysis in north County area was performed in a previous District

study[3] to determine the PM_{10} species profile for ambient air. The "source-receptor-analysis" determined the impact of emissions from generic source categories such as sea-borne aerosols, combustion sources and geological matter. Filters used in that study were reviewed in this analysis to estimate ambient crystalline silica levels. To ensure detection and fractionation, only high PM_{10}-reading filters from three monitors in the region were sent to a laboratory to estimate the crystalline silica fraction in the filters. All sampling and analysis procedures followed established protocols. As a corollary analysis, measured crystalline silica levels were compared to modeling-estimated crystalline silica exposures at the monitors, mainly to determine the culpability of emission sources.

Product "grab" samples were taken at various locations throughout the two diatomaceous earth processing plants and at the final process points of the rock and gravel facilities. These samples were analyzed to obtain the crystalline silica fraction. Data on this fraction were incorporated in the emission inventory calculations.

(c) ***Exposure Assessment*** -- After the crystalline silica emissions were quantified, air quality modeling was performed to estimate the ambient air impacts of the emissions. Since both point and area sources contributed to the emissions, and particle deposition rates were factors, EPA's ISC-ST model was employed for exposure assessment. Meteorological data representative of Lompoc and Santa Ynez Valley area and of Santa Maria area were used to calculate long-term ambient air impacts (acute short-term effects of crystalline silica have not been established to date).

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3 ABB Environmental Services Inc., 1989 PM-10 Monitoring Report for Santa Barbara County, June 1990, Camarillo, CA

The effects of particle reentrainment on ambient air quality impacts was also examined by using the vehicular traffic emissions data in the modeling study.

(d) ***Risk Characterization*** -- Finally, the exposure (modeling) analysis-projected ambient air impacts were translated into expected carcinogenic risks and non-carcinogenic chronic health effects. Results for both "inhalable" and "respirable" crystalline silica emissions were extended to characterize the risks and the chronic effects.

Of the three major constituents of crystalline silica, cristobalite and tridymite, are often considered significantly higher threats to public health as compared to the third and the dominant component, quartz. The current study solicited information from the industries addressed by this study on the fraction of cristobalite and tridymite present in the product samples. Only the two diatomaceous plants detected the cristobalite and tridymite component in their product samples. No detectable amounts of tridymite were reported from the rock and gravel sources, and the cristobalite fractions were relatively low (about 5 per cent of total crystalline silica) at these facilities. All cristobalite emissions were included in the inventory, where applicable, to estimate the **chronic** health effects (no potential cancer risks for cristobalite or tridymite are individually listed).

Due to the proximity of two large diatomaceous earth processors, considerable public concern exist in the Lompoc area regarding crystalline silica health risk. Therefore, this report has sought public review and will address public input, where appropriate, prior to its final release.

CHAPTER II. SURVEY OF CRYSTALLINE SILICA PROBLEM

1. Geology of Crystalline Silica

Silica is the popular name for silicon dioxide (SiO_2), which occurs naturally in both amorphous and crystalline forms. The most common form of natural **amorphous** silica are diatomite, opal and flint; and, the common synthetic **amorphous** forms are silica gel, precipitated silica and fumed silica. All of these substances possess the same chemical composition, i.e., SiO_2. The most common naturally occurring **crystalline** silica is quartz. Two other relatively common forms of crystalline silica are cristobalite and tridymite (other naturally occurring crystalline silica minerals are coesite, tripoli, keatite, stishovite). Although the first three are chemically identical SiO_2, they differ from each other physically and in their crystalline structures.

Crystalline silica change their forms under different conditions of temperature and pressure[1]. Alpha-quartz, the principal form of crystalline silica changes to alpha-tridymite at about 1593°F and alpha-tridymite changes to alpha-cristobalite at about 2678°F. Note that alpha cristobalite changes to amorphous fused silica above 3110°F. Table 2-1 (next page) lists the diverse properties of the three common crystalline silica substances.

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[1] International Agency for Research on Cancer (IARC), IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans: Vol. 42 (Silica and Some Silicates), 1987, World Health Organization, Lyon, France.

Table 2-1. Physical Differences between Crystalline Silica Forms[2].

Criteria	Quartz	Cristobalite	Tridymite
Phys.Appear.	Solid, no color or white,black purple or green	Solid, no color or white or yellowish	Solid, no color or white
Crystalline Form	Hexagonal; also in anhedral massive form	Octahedral; rarely cubical, also in massive form	Pseudohexagonal, tabular; also in massive form
Density	2.65	2.33	2.26
Hardness (Mohr Scale)	7	6.5	7
CAS Number	14808-60-7	14464-46-1	15468-32-3

Physical properties such as crystalline structure, particle size (i.e., 2.5 μm or less), surface-area-to-volume ratio, surface charge (+ve or -ve) or pH values for various silica (SiO_2) are major factors in assessing their health effects. This study will focus on the crystalline varieties of silica, since to date amorphous silica has not been shown to present as severe a health hazard as crystalline silica.

2. Sources and Occurrences of Crystalline Silica

Silica or silicate minerals constitute about 25 per cent of all known minerals. The fundamental form of silicate minerals is the silicon tetrahedron SiO_4. This tetrahedron consists of a central silicon ion with oxygen ions attached at the corners of the tetrahedron so that each oxygen is also common to two tetrahedra[3]. Differences in orientation of these tetrahedral units with respect to each other result in new symmetry; and, various cations and anions are found as substitutes in the tetrahedral matrix to yield different silicate minerals, such as kaolin, talc, mica,

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2 Ibid.

3 Coyle, T.D., Silica: in Encyclopedia of Chemical Technology; Edited by Kirk,Othmer et.al, Vol. 20, 3rd. Ed. (1982), John Wiley, New York, NY.

vermiculite, bentonite and feldspar. With a few minor exceptions all of the igneous rock-forming minerals, which constitute over 90 per cent of the earth's crust, are silicates.

The largest source of quartz bearing minerals in the U.S. are crushed stone and rocks (about 1.2 billion tons per year in 1990[4]), particularly those produced from granite, and sand and gravel (about 900 million tons per year[5]). These materials are used in the production of concrete and asphaltic concrete and utilized for related building and construction purposes. In Santa Barbara County, crushed sand, rock and gravel production by major industrial sources (100 tons per year or more of particulate emissions) alone exceeded 3 million tons in 1989.

Another major source of silica in Santa Barbara County is the naturally occurring and extensively mined diatomaceous earth, a loosely coherent chalk-like sediment from unicellular algae containing up to 94 per cent SiO_2 [6]. Major industries in Santa Barbara County produce industrial and commercial filter materials in processes that use diatomaceous earth. The mineral is **calcined** either alone or in the presence of other chemicals and subsequently processed. The finished products often contain more than 65 per cent quartz and cristobalite by weight.

3. Industrial and Other Exposures

Silica is widely used in industries and is one of the most common substances to which

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4 Hillman, Barry A., The Need for Responsible Risk Assessment in Formulating Public Policy, A Case study: Crystalline Silica, 1991, Condor Earth Technologies, Inc., Sonora, CA.

5 Ibid.

6 IARC, 1987

workers are routinely exposed. A 1983 NIOSH survey estimated that about 3.2 million workers in 23,800 plants are potentially exposed to silica[7]. Industrial processes that result in significant silica exposure include specific mineral mining, rock and gravel quarrying and tunneling, stone cutting, abrasive blasting and grinding, glass manufacturing, foundry/metallurgical sand operations, boiler scaling and vitreous enameling (ceramics)[8]. Even in farming operations, silica exposure occurs during processing of crops contaminated with crystalline silica mixed soil or during incineration of agricultural residues[9]. General population exposure can also occur as the result of windblown dust from industrial or other sources of crystalline silica.

4. Measurement Methods

Crystalline silica fraction in an industrial grab sample is quantified through three distinct methods, all recommended by the U.S. National Institute of Occupational Safety and Health (NIOSH). NIOSH Method 7501 is a "wet chemical" method with a detection range of 0.02 - 2.5 mg/kg of SiO_2. Unfortunately, this method does not distinguish between the various polymorphs of crystalline silica. The infra-red spectrometry Method 7602, recommended by NIOSH, is used to quantify the quartz fraction in a bulk sample with a detection range of 10 - 160 μg/kg of SiO_2, and a lowest detectable level of 5 μg/kg. Once again, crystobalite, tridymite, coesite and

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7 U.S. Dept. of Health and Human Services, Public Health Service Division, Review of the Literature on Crystalline Silica, (1983), National Technical Information Service, Springfield, VA

8 Ziskind, M., Jones, R.M. and Weill, H.,"Silicosis, " Am. Rev. Resp. Disease, 1976, Vol. 113, pp 643-665.

9 ENSR Consulting and Engineering, Air Monitoring Operation, Wadham Energy Company Williams Facility, (February 1991), Alameda, CA.

even common kaolinite create interference in obtaining an accurate measurement using this method. Therefore, the third NIOSH-recommended Method 7500 is commonly used to quantify crystalline silica. This method utilizing the X-ray diffraction phenomenon analyzes the crystal structure of SiO_2 and differentiates and measures quartz, cristobalite and tridymite fractions in a sample.

In Method 7500, the atomic arrays within the crystals are used as three-dimensional gratings to diffract a monochromatic beam of X-ray. The angles at which the beam is diffracted are controlled by the following relationship:

$$n\lambda = 2\ d\ \sin\Theta, \text{ where}$$

n = an integer; λ = wavelength of the monochromatic X-ray beam;
d = interplanar spacing of the atomic array; and Θ = angle of diffraction.

Thus, the angle of diffraction provides data on the interplanar atomic spacings (d-spacings), and thus information on how the atoms are arranged within the crystalline structure. The crystallographic structure feedback clearly differentiates the three polymorphs of crystalline silica even when they are chemically identical. For example, three peaks are observed for quartz at 3.34, 4.26 and 1.82 Angstrom units while for cristobalite the three strong peaks are seen at 4.04, 2.49 and 2.89 Angstorm units. To quantify the fractions of the polymorphs in a given sample, the step counting method[10] is followed using a goniometer (angle measurement device) and a computer-controlled stepping motor. Basically, the method is statistical and highly accurate, but time consuming and costly. The detection range is usually 0.02 - 2 mg/kg, with a lowest detection limit of 0.005 mg/kg. Depending on their relative configuration, mica, feldspar and aluminum phosphate sometime tend to interfere with the diffraction process. Also, if the bulk field sample has a significantly deviant

[10] NIOSH Manual of Analytical Methods: Method 7500 (1989 Rev.)

distribution of the polymorphs as compared to the National Bureau of Standards (standard) sample, sizeable errors may occur in the analysis. Fractionating cristobalite and tridymite can be trouble-prone in this respect.

No standard methods exist to **directly** measure the crystalline silica fraction present in either **ambient** air or **stack** effluent. California Air Resource Board (ARB) staff efforts to establish approved methods and minimum detectable levels for crystalline silica are ongoing. Candidate analytical methods are the NIOSH Methods 7500 (X-ray diffraction), 7602 (Infra-red Spectrometry) and 7601 (Color photometry). All three equipment for **ambient** sample collection, namely, the hi-vol (40 cfm), medium-vol dichotomous (16.7 l/min) and low-vol (1.7 l/min), are being tested. ARB method 501 is the prime candidate for **stack** sampling method. Target minimum detectable limits at this time seem to be 0.03 $\mu g/m^3$ for ambient air sampling and 30 $\mu g/m^3$ for stack sampling.

Based on the above listed information and availability of samples, the District proposes to estimate ambient levels of crystalline silica in the north County region by re-examining available 24-hour PM_{10} hi-vol filters using Method 7500.

5. Toxicity and Health Effects

Since 1929, silica has been recognized as a major occupational hazard causing disability and deaths among stone workers and miners[11]. The causal relationship between inhaling crystalline silica-laden dust and silicosis (a chronic fibrotic lung

[11] Russell, A. E., et al, "The Health of Workers in Dusty Trades. II. Exposure to Siliceous Dust" in Public Health Bulletin, # 187; U.S. Treasury Dept., U.S. Public Health Service,(1929), Government Printing Office, Washington D.C.

disease with lung inflammation and necrosis) is well established[12],[13],[14]. To date however, synthetic amorphous silica has not been identified as severe a health hazard as quartz.

Toxicity of crystalline silica particulates varies depending on their crystalline form and size. For example, cristobalite is suspected of being more hazardous than quartz because the crystalline lattice structure of cristobalite induces more cellular interaction and cytotoxicity[15]. Also, **respirable silica particles** ($< 3.5\ \mu$m diameter) are regarded as more pathogenic than **inhalable silica particles** ($< 10\ \mu$m diameter). This stems from the fact that the smaller size respirable particles more readily migrate and deposit in the airways and alveoli within the lower respiratory tract where they are retained. In contrast, the larger inhalable particles are usually deposit in the bronchi and bronchiole within the upper respiratory tract, and are usually translocated to the gastro-intestinal tract and ultimately removed from the body. Interestingly, health experts are now focussing their attention on crystalline silica particles with mass median aerodynamic diameter of $< 2\ \mu$m ($0.1 - 2\ \mu$m)[16],[17], since mainly

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12 Theriault, G.P., Peters, J.M. and Johnson, W.M., "Pulmonary Function and Roentgenographic Changes in Granite Dust Exposure," (1974), Arch. Environ. Health, Vol. 28, pp. 23-27.

13 National Institute for Occupational Safety and Health (NIOSH), "Silica Flour: Silicosis (Crystalline Silica)," (1981), Current Intelligence Bulletin # 36, Dept. of Health & Human Services Publication, pp 81-137.

14 Goldsmith, J.R., "Comparative Epidemiology of Men Exposed to Silica, Asbestos, and Man-Made Mineral Fibers," in Goldsmith et al, Silica, Silicosis and Cancer, (1986), Praeger Publishers, New York, NY.

15 Rabovsky, J., "Laboratory Studies on Silica Induced Toxicity and Carcinogenicity" in The Emerging Risk Assessments for Crystalline Silica Conference Proceedings; (September, 1992), Monterrey, CA.

16 Davis, G.S., "Pathogenesis of Silicosis: Current Concepts and Hypotheses" (1986), Lung, Vol. 164, pp. 139-154.

17 National Institute for Occupational Health and Safety (NIOSH), "Diseases Associated with Exposure to Silica and Nonfibrous Silicate Minerals" (1988), Arch. Pathol. Lab. Med., Vol. 112, pp 673-720.

particles of this size range have been found in the lower respiratory tracts.

A brief review of the observed adverse health effects of crystalline silica is presented in Appendix A.

6. Existing Health Regulations and Standards

Inhalation R_fC for Crystalline Silica -- In 1987, IARC designated crystalline silica (Quartz) as a Class 2A carcinogen, based on carcinogenicity in animals and limited evidence in humans. Subsequently, in 1989 California's health agencies [Air Resources Board (ARB), Office of Environmental Health Hazards Assessment (OEHHA) and Dept. of Toxic Substances Control (DTSC)] established a "screening" cancer potency values for crystalline silica for their "Toxic Hot Spots Program (AB-2588)." **The screening potency values for crystalline silica ranges from 4.5×10^{-5} to 2.9×10^{-4} per microgram per cubic meter (for 70 years of continuous exposure)**, and apply to all forms of crystalline silica with MMAD less than 10 μm. These values were obtained by extrapolating animal studies results to humans, via the established linearized multistage "Global 86" analytical method. However, "Global 86" extrapolation requires that the chemical substance being analyzed be soluble and absorbable across a surface such as the lung alveoli, and crystalline silica particles are not soluble. Therefore, the health agencies recommended the cancer potency value obtained as a "screening" value, not to be used for regulation development. In August 1992, the agencies relaxed the AB-2588 requirement of computing the population health risk assessment due to crystalline silica inhalation, by making it an optional procedure.

Both OEHHA and USEPA are now working to establish an inhalation "**reference**

concentration (R_fC) for crystalline silica. EPA scientists[18] have noted that preliminary conservative estimates of silica inhalation R_fC seems to range from 0.03 to 2 $\mu g/m^3$, based on human epidemiological studies of silicosis. The data appears to be in the same approximate range of an R_fC of 0.02 $\mu g/m^3$ used in establishing the AB-2588 "screening" cancer potency value of 4.5×10^{-5} cited earlier. Some more definitive results are likely to be available at the annual crystalline silica workshop scheduled to be held in San Francisco in October, 1993.

LOAEL/NOAEL Values for Crystalline and Amorphous Silica -- Based on the adverse health effects observed in both humans and animals, various agencies have established permissible industrial exposure guidelines for silica, both crystalline (LOAEL) and amorphous (NOAEL) variety. These agencies include the American Conference of Governmental Industrial Hygienists (ACGIH), National Institute for Occupational Safety and Health (NIOSH), Mine Safety and Health Administration (MSHA), Occupational Safety and Health Agency (OSHA) and IARC. A summary of permissible exposure guidelines stipulated by these agencies is presented on the next page in Table 2.2 (on page 20). Note that these exposure levels are meant to apply to **industrial workers only**. The AB-2588 mandates from ARB and OEHHA lists a value of **1.2 $\mu g/m^3$ as suggested LOAEL for crystalline silica "chronic" exposure as applicable to the general population and for cristobalite exposure only**.

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18 DRAFT Inhalation Toxicology of Silica (Contract # 7631-86-9), In Support of the Derivation of a Reference Concentration, (1992), USEPA, Office of Health and Environmental Assessment, Research Triangle Park, NC.

Table 2.2. Permissible Industrial Exposure Levels for Silica

SILICA TYPE	AGENCY	PERMITTED LEVEL DESCRIPTION	SAFE EXPOSURE LEVEL
CRYSTALLINE SILICA (only as "respirable" silica)			
QUARTZ	OSHA	PEL* (as 8-hour TWA*)	100 $\mu g/m^3$
	ACGIH	TLV* (as 8-hour TWA)	100 $\mu g/m^3$
	NIOSH	recommended occupational exposure workshift limit as 10-hour TWA	50 $\mu g/m^3$
	MSHA	recommended coal mine exposure limit	100 $\mu g/m^3$
CRISTOBALITE/TRIDYMITE	OSHA	PEL (as 8-hour TWA)	500 $\mu g/m^3$
	ACGIH	TLV (as 8-hour TWA)	50 $\mu g/m^3$
	NIOSH	recommended occupational exposure workshift limit as 10-hour TWA	50 $\mu g/m^3$
FUSED SILICA	OSHA	PEL (as 8-hour TWA)	100 $\mu g/m^3$
	ACGIH	TLV (as 8-hour TWA)	100 $\mu g/m^3$
AMORPHOUS SILICA			
PRECIPITATED/GEL	OSHA	PEL (as 8-hour TWA)	6,000 $\mu g/m^3$
	ACGIH	TLV (as 8-hour TWA)	10,000 $\mu g/m^3$
DIATOMACEOUS EARTH	OSHA	PEL (as 8-hour TWA)	6,000 $\mu g/m^3$
	ACGIH	TLV (as 8-hour TWA)	10,000 $\mu g/m^3$

* -- **PEL** = Permissible Exposure Level; **TLV** = Threshold Limit Value; **TWA** = Time-weighted Average

CHAPTER III. CRYSTALLINE SILICA EMISSION INVENTORY

1. Industrial Emissions

Preliminary Assessment -- Preliminary assessments for crystalline silica emissions from industrial sources followed the same methodology as suggested for AB-2588 inventorying process. The computations constituted of initially reviewing sources with greater than 25 tons/year **permit-allowed** PM emissions (Reference: AB-2588 mandate, note also EPA significance level of 25 tons/year for PM); and, estimating their **actual**, annual PM_{10} emissions. Next, based on the fractional crystalline silica content in the PM emissions from these sources [as determined from a grab sample analysis (NIOSH 7500 Method) of the process products], the actual annual crystalline silica emissions were projected for each source. The 25 TPY cutoff proved to be a good *de minimis* level, since sources with permitted PM emissions at this level often had (i) very low actual PM_{10} emissions (see Table 3.1) or (ii) contained non-detectable **crystalline silica** fractions (particularly in the south zone of the County) in their emissions[19]. A listing of the rock, sand and gravel processing facilities with their permitted PM_{10} emissions and actual CY 1989 total PM emissions is provided in Table 3.1 (on page 17). Observed **crystalline silica fractions at PM grab samples** from these facilities are also listed in the table.

Besides Table 3.1, data from District files for CY 1989 actual PM emission survey indicate that about 90 per cent of industrial source **crystalline silica** emissions occur in the north zone of the County, around Lompoc, Buellton and Santa Maria area. These emissions came from the rock, sand and gravel processing (involving granitic rock crushing) facilities in these areas and from two diatomaceous-earth-calcining/processing facilities located near Lompoc. The south zone of the County,

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19 Santa Barbara Air Pollution Control District AB-2588 Emission Inventory Data for Crystalline Silica - CY 1989.

Table 3.1 PM/PM_{10} Emission Inventory for

Santa Barbara County Sand Rock/Gravel Sources

ID #	SOURCE NAME	PERMITTED PM_{10} "PROCESS" EMISSION (TPY)	1989 PM EMISSN (TPY)	ESTIMATED INHL CRYS.SI.FRAC.IN GRAB SAMPLE	SOURCE LOCATION
North County Sources					
1735	Celite	1,560	267.3	Variable -- upto 70%	Lompoc
4411	Coast Rock(G)	380	24.1	29.7%	StaMaria
1661	So.Pac.Millg.	210	27.6	17.5%	Sisquoc
1542	Grefco	166	13.3	variable -- upto 70%	Lompoc
1226	Buellflat	163	13.5	20.8%	Buellton
1366	Coast Rock (D)	87	4.6	20.8%	StaMaria
1551	Gordon Sand*	81	5.0	12.5%	Guadalupe
1883	Lynch Ready Mx*	81	1.2	N.D. - 10%	Solvang
1516	Gen.Prod.*	70	9.2	variable -- upto 13%	Ventucopa
1536	Granite (B)	65	6.8	11.1%	Buellton
2372	Solvang Transit*	54	4.2	N.D. - 10%	Solvang
3885	So.Pac.Mlg.(SM)*	52	2.0	N.D.	StaMaria
1702	Troesch Rdy Mx*	38	2.0	N.D. - 10%	Lompoc
4421	Union Asphalt	12(?)	9.4	29.7%	StaMaria
South County Sources					
1249	CalMat (SB)*	62.2	3.0	N.D. - 5%	StaBrbra
1527	Goleta Rdy Mx*	27	2.0	N.D. - 5%	Goleta
1162	Bee Rock	26	12.4	0.5%	Goleta
3695	Sta Barbra Snd*	26	5.0	4%	StaBarbra

N.D. = No crystalline silica fraction data available for the source

NOTE: * -- No crystalline silica fraction data was available for sources with estimated "actual" PM emissions of less than 10 TPY. Based on the reasonable assumption (see discussions later) that this fraction is probably the same for all sources in the same source category, computed crystalline silica emissions from the < 10 tpy sources amount to less than 10 per cent of the > 10 TPY sources.

with its numerous small sand and gravel sources (crushing mainly limestone rocks), emitted PM/**amorphous silica** but was indicated to be a minor (less than 10 per cent) contributor to the overall industrial emissions of PM/**crystalline silica.** Hence, the study focussed on the crystalline silica emissions from the north zone industries.

2. Detailed Source Emissions Review

Accurate emissions can be obtained based on analyzing the process rate and the hours operated data for **each individual PM emissions unit.** However, none of the industrial PM sources in the north County record such details of operation for each equipment. The records available were mostly the monthly and annual fuel use or throughput rates. Therefore, it was necessary to review **each entire process line** and estimate the emissions at each operation in the line involved. This , of course, involves the assumption that the feed rate for each entire line remains the same for each equipment (no line feed losses or no recycling). Such an assumption may overestimate some of the emissions and underestimate others, but not to any significant (more than 5 per cent) extent for sand and gravel processing lines -- based on engineering analyses of their individual process operations.

A review of the PM/crystalline silica emission inventory suggested that the original PM emissions data submitted by the facilities often contained underestimation (processes not considered) and overestimation (due to use of outdated e.g., AP-42, 1983 Ed. PM emission factors) errors. Consequently, both PM/PM_{10} and crystalline silica emission inventories for these sources were extensively updated. The methodology followed to establish facility emissions is described below.

I. Process Point Source Emissions

Inhalable crystalline silica emission computations are based on (a) "less-than-10-micron size" particulate matter (PM_{10}) emissions from various emissions unit operating at a facility, and (b) the fraction of crystalline silica found in a "particulate" grab sample from the unit. These two data items are quantified as follows:

(a) The PM_{10} emissions are obtained following a detailed review of the particulate matter (PM) and PM_{10} emissions processes in the facility. If source test data are not available, then current AP-42 emission factors, as they relate to emissions from the process lines, are used. For sand, rock and gravel sources, factors listed for PM/PM_{10} emissions in AP-42, Chapters 8 and 11 were used as applied to each process operation in the facility.

(b) "Inhalable" crystalline silica fraction (Cr. Si_{10}) data is obtained from Laboratory analysis (NIOSH 7500 Method) of grab samples collected at process product lines. Available source test results did not provide any data for crystalline silica fraction in a flow stream after it has passed through control devices. In absence of such data, the fraction of inhalable crystalline silica in controlled plume PM_{10} is assumed to be the same as the fraction of total crystalline $silica_{10}$ in the flow stream (process line) grab sample. This assumption appears to be valid based on the observation that particulate size speciations follow the same pattern before or after flow stream processing in control devices[20]

Details of the two-step crystalline silica emission calculations are described below for different process/emission control equipment.

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20 Personal communication from James McCormack, Monitoring and Laboratory Division, CA Air Resources Board, March 1993.

(a) PM_{10} EMISSIONS

Baghouses: Based on the U.S. Environmental Protection Agency (EPA) and industry guidelines[21],[22] , PM_{10} emissions from baghouses are computed from the exhaust flow (scfm or dscfm) out of the baghouse and the particulate grain loading (gr/scf or dscf) occurring in the flow.

Exhaust flow -- Exhaust flow data are based on baghouse blower ratings and are obtained from the emissions unit operator. This flow rate must not exceed the product of the baghouse cloth area (sq.ft) and the manufacturer-specified maximum air-to-cloth ratio (acfm/sq.ft) for the operation. The ratio, often known as the filtering velocity, is listed for various process operations in pollution control engineering manuals[23],[24]. The District has used the calendar year 1989 flow rate data supplied by the emissions unit operators to compute the PM_{10} emissions. **All operators were requested to comment on the validity of their flow data, or the District-used flow data, if the District data are different from theirs.**

Exhaust grain loading -- The District has used validated source test data from the operators to establish the average exhaust grain loading (gr/scf) expected for PM

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21 Control Technologies for Hazardous Air Pollutants, (June, 1991), U.S. Environmental Protection Agency, Office of Research & Development, Pub. No. EPA/625/6-91-014, Washington, D.C.

22 Workbook on Estimation of Emissions ... Particulate Sources, (September, 1981), Prepared for Utility Air Regulatory Group, Washington D.C., by Environmental Research Technology, Inc., (ERT, now ENSR), Document No. P-A857, Washington, D.C.

23 Air Pollution Engineering Manual, (May 1973), U.S. Environmental Protection Agency, Office of Air Quality Planning & Standards (OAQPS), Pub. No. AP-40, 2nd.Ed., Research Triangle Park, NC.

24 Air Pollution Engineering Manual, (June, 1992), Buonicore, A.J. & Davis, W.T., Editors, published for Air & Waste Management Association by Van Nostrand Rheinhold Publishers, New York, NY.

emissions. In a number of cases, the operators provided process PM emission rates based on mass emissions observed during recent (i.e., within five years), District-validated source tests. These data have been examined to see if the operations during the source test were within 10 per cent of the maximum level of operations usually reached during the year. Next, the data have been checked for exhaust grain loadings during the tests. If these values were within the acceptable range of average exhaust grain loading (i.e., 0.003 - 0.005 gr/dscf) and matched previous performances by the unit (or similar units), these exhaust grain loading data have been given preference for computing. Otherwise, an average exhaust grain loading figure of 0.004 gr/dscf has been used for the baghouse. Finally, the exhaust grain loading data for PM has been reduced to grain loading data for PM_{10} by multiplying the emission factor with the PM_{10}/PM ratio for the operation, as listed in EPA's AP-42 guideline document. **Comments were sought from all operators on the accuracy of the baghouse exhaust grain loading data used to compute emissions from their baghouse operations.**

Scrubbers: PM_{10} emissions from wet scrubbers are generally computed from the input to the scrubber and the scrubber PM_{10} removal efficiency data[25]. However, the wet scrubber removal efficiency varies logarithmically as the pressure drop, and should be based on the individual equipment performance curve. This data is usually not available to the District. An acceptable alternative, therefore, is to accept validated source test results for emission rates during representative load operations, and use these data. The District have used the average exhaust PM grain loading data for the scrubbers and the operator supplied outlet flow rates to compute scrubber PM emissions.

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25 Op. Cit. (see footnotes 3,4 earlier)

words, computation methodology identical to the baghouse emissions has
ı followed to obtain PM_{10} emissions from wet scrubbers used in various
. **All operators were requested to evaluate the data used by the District**
ıte their PM_{10} emissions from the wet scrubbers.

$^{2}M_{10}$ Emission Computations

e: A baghouse unit operator reports 36,000 acfm outlet flow at 70°F
during CY 1989. The operator also lists 0.21 lbs/hour as the representative
ssions rate from the unit. This emissions data represents an extrapolation,
the PM removal efficiency observed during a non-validated source test on
erformed during February, 1982.

ons -- The permit file for the unit lists 9000 sq.ft. as the cloth area for the
and a manufacturer-specified air-to-cloth ratio of 4.0 : 1. Thus, the
flow rate for the baghouse is 9000 * 4.0 = 36,000 acfm. This is further
by permit data showing that air to the unit is moved by a blower with a
m rating. Thus, **the flow rate data is accepted for use.** However, mass
rate for the unit translates to the following grain loading:

ır)*7000(gr/lb)/[60(min/hr) * 36,000(cfm) * (460° + 70°) / (460° + 60°)]
)5 gr/scf.
e does not match the PM removal performance by similar units at the
nd is much lower than the normal average figure of 0.003 - 0.005 gr/dscf
r operations (note, dscf/scf ratio for this flow was estimated to be about
Calc. Data Sheet A, attached). Further, the source test data was neither
r validated. Therefore, **an average exhaust grain loading rate of**
0.005)/2 = 0.004 gr/dscf, that translates to 0.004/1.02 (dscf/scf ratio) =
·/scf was selected for that unit; and, the operator was apprized of the

tached) for
85,
e is

$_{0}$ lb/PM lb)

nissions
: is based on
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No
s submitted.
; CY 1990

vs.
rate for the
ıst grain
e test)
erature for
: 233,000

39.94 lbs/hr,
1990

CALC. DATA SHEET A

Ratio of Wet-to-Dry Cubic Feet of Air *

Flow Stream Temperature (°F)	lbs of Water (W_S) per lb of Air (W_a) for "Saturated" Stream at Flow Temperature	Volume Ratio = (1.0 + 1.608 * W_S)
60	0.0108	1.0174
70	0.0155	1.0249
80	0.0224	1.0360
90	0.031	1.0495
100	0.036	1.0579
120	0.0815	1.1311
150	0.10	1.1608

* Ref: Thermal Environmental Engineering, Threlkeld, J.V., Prentice-Hall Inc. May 1965 (Englewood Cliffs, NJ).

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CALC. DATA SHEET B

PM_{10}/PM RATIOS IN "CONTROLLED" EMISSIONS
AP - 42 (4th.Ed.); Appendix C.1

A. **Data from phosphate rock processing:**

1. CALCINER (fired with #2 oil: production rate = 70t/hr; feed = processed rock)
   After cyclone + wet scrubber = **0.98** (Rating = C)

2. DRYER (process rate ≈ 150 - 300 t/hr; feed = rock)
   With #5 oil:
   After wet scrubber + ESP = **0.938** (Rating = C)
   Using #6 oil:
   After cyclone + wet scrubber = **0.966** (Rating = D)

3. CRUSHER (Rate = 80t/hr)
   Ball Mill - After cyclone = **0.31** (Rating = C)
   Roller + Bowl Mills - After cyclone + baghouse = **0.90** (Rating = D)

B. **Data from feldspar rock processing:**

1. CRUSHER (Rate = Unknown)
   Ball Mill - No control = **0.323** (Rating = D)

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average flow rate and the source test-verified exhaust grain loading data to compute the mass emissions. EPA guidelines list the **PM_{10}/PM fraction in emissions from a wet scrubber (used for similar operations) to be = 0.98** (Calc. Data Sheet B).

Hourly PM_{10} emission rate = 0.02(gr/scf)*245000(scfm)*60(min/hr)*0.98(PM_{10}/PM ratio)/7000(gr/lb) = 41.2 lbs/hr (cf: operator PM_{10} data is 42 * 0.98 = 41.2 lbs/hr).

Baghouse-controlled Asphaltic Concrete Batch Plant: In the absence of data on flow rates (cfm) and outlet PM_{10} grain loading (gr/dscf), annual PM_{10} emission "E1" from a baghouse controlling an asphaltic concrete batch plant process emissions is estimated by: E1 = Q * EF, where,
Q = materials processed each year (tons/yr), and EF= PM_{10} emission factor = 0.008 lbs/ton (of material processed) [Ref:AP-42, Table 8.1-2].
Hourly PM_{10} emissions from the baghouse "E2" is obtained by the equation:
E2 = E1 / Annual hours of operation (provided by operator).

Calculation -- Consider an asphaltic concrete batch plant operation, controlled by a baghouse, where the only available data on the baghouse system is the **annual** material processing rate, namely, 100,000 tons/yr. Annual emissions "E1" from the baghouse is given by:

E1 = 100,000 (tons/yr) * 0.008 (lbs/ton processed) = 800 lbs/yr.

If the baghouse operates for 1000 hours in a year, then hourly emission E2 is:
800 (lbs/yr) / 1,000 (hrs/yr) = 0.8 lbs/hr.

(b) INHALABLE CRYSTALLINE SILICA EMISSIONS

Emissions of crystalline silica from an emissions unit is based on PM_{10} emissions and the crystalline silica fraction data reported for that unit by the operator under the provisions of AB-2588. This data was acquired by obtaining a grab sample of

particulate from the unit, using x-ray diffraction technique (NIOSH 7500 Method) and directly measuring the fraction of crystalline silica present in the grab sample.

Crystalline silica emissions from baghouse stacks are predominantly (75%+) "inhalable" particulates (less than 10 microns). In absence of data to the contrary, the District has assumed that the fraction of crystalline silica present in the total "particulate" grab sample also corresponds to the same fraction as inhalable (less than 10μ diameter) crystalline silica fraction in PM_{10} stack emissions from the unit.

Sample Inhalable Emission Calculation:

Baghouse/Wet scrubber/Uncontrolled Emissions -- An operator reports the crystalline silica fractions at a grab sample obtained from an emissions unit in CY 1989 are -- quartz 3 per cent, cristobalite 55 per cent and tridymite as not detectable. Earlier, the PM emission rate from the same unit was calculated to be 0.0039 gr/scf, the PM_{10}/PM ratio is = 0.96, and the average exhaust flow from the unit was estimated to be 36,000 scfm. The crystalline silica emissions from the unit is computed as follows:
Crystalline silica emissions = [0.0039 * 0.96 * 36,000 * 60 / 7000] * (0.55 + 0.03) = 0.67 lbs/hr; Cristobalite emissions = 0.67 * 0.55/0.58 = 0.635 lbs/hr.

A template to compute process "point source" emissions is shown in Appendix B, Table 1. The data shown in the table is for illustration purposes only .

II. Process Fugitive Emissions

As in the case of "point source" emissins, **inhalable** "fugitive' crystalline silica computations are based on (a) "less-than-10-micron size" particulate matter (PM_{10}) fugitive emissions from various field process units operating at a facility, and (b) the

fraction of crystalline silica found in a "particulate" grab sample from the units. These two data items are quantified as follows:

(a) The PM_{10} emissions are obtained following a detailed review of the particulate matter (PM) and PM_{10} fugitive emissions processes in the facility. Since no source test data are available, AP-42 emission factors are used. For sand, rock and gravel sources, factors listed for PM/PM_{10} emissions in AP-42, Chapters 8 and 11 were used as applied to each **process** operation in the facility. A copy of the Chapter 8 emission factors is listed in Table 3.2 (page 30) as a quick reference. Chapter 11 emission factors, based on AP-42 equations and driven by facility-specific parameters, were used to compute fugitive emissions arising from **material storage and handling** processes. The process fugitive "emissions template" used to compile emissions from each facility is shown in Appendix B, Table 2.

(b) "Inhalable" crystalline silica fraction (Cr. Si_{10}) data is obtained from Laboratory analysis (NIOSH 7500 Method) of grab samples collected at process product lines. In absence of other data, the fraction of inhalable crystalline silica in the fugitive PM_{10} is assumed to be the same as the fraction of total crystalline $silica_{10}$ in the grab sample. As in the case of "point source" emission computations, these grab samples were obtained from the process product line or storage piles, as appropriate. The template used to compute fugitive crystalline silica emissions is shown in Table 3.3.

III. Inhalable Emissions Data

Prior to this study, the only existent emission inventory for crystalline silica was the AB-2588 reports based on unverified data and outdated emission factors; it also computed only total particulate matter (30 μm MMAD). Therefore, a preliminary inventory of **Inhalable** (less than 10 μm MMAD) crystalline silica emissions was compiled for all the facilities included in this study. A copy of this inventory was

sent to the facility operators for their review and input. Based on their responses and corrections, a final base year (CY 1989) PM/PM_{10} emission inventory was prepared. Table 3.4 summarizes the north County sources and compares the preliminary (AB-2588) inventory and the final **estimated "annual" crystalline silica emissions** for CY 1989. Considering the fact that inhalable particulates are a fraction of total PM, particularly for non-process fugitives, the AB-2588 total PM inventory is seen to have significantly underestimated the inhalable crystalline silica emissions.

A complete listing of **inhalable** (10 μm MMAD or less) crystalline silica emissions is provided in Appendix C: Part I **[confidential data under CA "hot spots act"; thus not included in this report]** of this study. The final, revised inventory that provides an estimate of the emissions during CY 1989 is summarized below, as follows:

(a) Estimated **inhalable** crystalline silica emissions in the north county zone exceed 104 tons annually;

(b) Approximately, 73 per cent of the emissions are generated by process operations;

(c) About 23 per cent of the process operation emissions do not exhaust through a PM control device; and,

(d) Most of the non-process operations emit fugitive emissions (27 per cent of total) including dust from unpaved road traffic or from storage pile erosion.

Table 3.2. Emission Factors for Process "Fugitive" PM Emissions

OPERATION	NEDS/SCC CODE#	SUGGESTED E.F.(PM)*	AP-42(Section)	SUGGESTED E.F.(PM)*
A. STONE QUARRYING (Primary Ref.: AP-42; Section 8.19.2)				
1. Crushing				
a. Primary	3-05-020-01	0.50/(tons raw material)	Table 8.19.2-1	0.28/(tons raw material)-dry 0.018/(tons raw matl.) - wet
b. Secondary	3-05-020-02	1.50/(tons raw material)	Table 8.19.2-1	0.28/(tons raw material)-dry 0.018/(tons raw matl.) - wet
c. Tertiary	3-05-020-03	6.00/(tons raw material)	Table 8.19.2-1	1.85/(tons raw material)-dry
2. Reerush/screening	3-05-020-04			
3. Fines/Mill	3-05-020-05			
4. Screen/Conveying	3-05-020-06	**/(tons processed)	Table 8.19.2-2	0.0034/tons conveyed-tnl.belt
5. Open Storage	3-05-020-07	0.33/(tons prod. stored)	See Section 11.2.2	**
6. Cut Stone	3-05-020-08			
7. Blasting	3-05-020-09	0.16/(tons raw material)	Table 8.19.2-2 MRI Developed EF	No data 961*A^0.8/(D^1.8*M^1.9)lb/blst
8. Drilling	3-05-020-10	**/(tons raw material)	Table 8.19.2-2	0.0008/(tons raw material)-wet
9. Hauling	3-05-020-11	52.00/(VMT)	See Section 11.2-2	**
10. Drying	3-05-020-12	35.00/(tons dryed)	**	**
11. Bar -- Grizzlies	3-05-020-13			
12. SCREENS see SCC	3-05-025-11	0.16/(tons raw material)	Table 8.19.1-1	0.16/(tons raw material)-dry
a. Shaker	3-05-020-14			
b. Vibrating	3-05-020-15			
c. Revolving	3-05-020-16			
13. Drilling	3-05-020-20	**/(feet drilled)		
14. Unclassified	3-05-020-99			
Truck ldg./unldg.(batch drop or cont.conveyor)			Table 8.19.2-2	0.0003/(tons raw material)
B. SAND/GRAVEL (Primary Ref.: AP-42; Section 8.19.1)				
A**. TOTAL plant -- General	3-05-025-01	0.10/(tons produced)		
1. Aggregate Storage (inactive)	3-05-025-02	0.33/(tons produced)	Table 8.19.1-1	1,277.5/(acre)
2. Transfer Station	3-05-025-03	0.03/(tons produced)	Table 8.19.1-1	0.029/(tons processed)
3. Hauling	3-05-025-04	52.00/(VMT)	See Section 11.2	**
4. Pile Forming (stack in use)	3-05-025-05	0.13/(tons produced)	Table 8.19.1-1	0.13/(tons processed)
5. Bulk Loading	3-05-025-06	0.02/(tons produced)	Table 8.19.1-1	0.056/(tons produced)
6. Storage Pile (active)	3-05-025-07	3796.00/(acre of area)	Table 8.19.1-1	4818.00/(acre)
7. Dryer	3-05-025-08			
8. Cooler	3-05-025-09			
9. Crushing	3-05-025-10	0.02/(tons produced)	Table 8.19.1-1	0.28/(tons raw matl.)-dry 0.018/(tons raw matl.)-wet
10. Screening	3-05-025-11	0.16/(tons produced)	Table 8.19.1-1	0.16/(tons raw matl.)
11. Not Classified	3-05-025-99			

Table 3.3. Fugitive Crystalline Silica Emission Calculations

INHALABLE CRYSTALLINE SILICA FUGITIVE EMISSIONS:

A. TOTAL ANNUAL FUGITIVE PM_{10} EMISSIONS DUE TO ALL THE SAND, ROCK AND GRAVEL "PROCESSING OPERATIONS" LISTED ABOVE ARE = Table 3.4: [1] + [2] + [3] + [4] + [5] = **** LBS/YEAR

Based on X-Ray diffraction analysis done by **, crystalline silica fraction is found to be = **** per cent (by wt)

Also, based on the same analysis, the cristobalite fraction on-site is found to be equal to = **** per cent (by wt)

Assuming that inhalable crystalline silica (and cristobalite) are emitted as PM/10 components at the same fractional rates as the bulk sample fractions listed above, --

INHALABLE CRYSTALLINE SILICA EMISSIONS = *** LBS/YR

INHALABLE CRISTOBALITE PM EMISSIONS = **** LBS/YR

****

B. TOTAL ANNUAL FUGITIVE PM_{10} EMISSIONS DUE TO ALL "STORAGE AND RETRIEVAL" OPERATIONS IN THE SAND/ROCK/GRAVEL FACILITY = Table 3.4:[1] + [2] + [3] + [4] = **** LBS/YR

Based on X-Ray diffraction analysis done by ****, crystalline silica fraction is found to be: _____

Also, based on the same analysis, the cristobalite fraction on-site is found to be = _____

Assuming that inhalable crystalline silica (and cristobalite) are emitted as PM/10 components at the same fractional rates as the bulk sample fractions listed above, --

INHALABLE CRYSTALLINE SILICA EMISSIONS = **** LBS/YR

INHALABLE CRISTOBALITE EMISSIONS= **** LBS/YR

C. EXAMPLE INVENTORY OF FUGITIVE "CRYSTALLINE SILICA" EMISSIONS AT: ***** FACILITY

	PROCESS OR OPERATION	"INHALABLE PM_{10}" EMISSIONS (lbs/yr)	COMMENTS	"CRYSTALLINE SI_{10}" EMISSIONS (lbs/yr)
1.	Rock Crushing	****	AP-42:Sec. 8.19.2	
2.a.	Conveyor (Transfer Stations)	****	AP-42:Sec.8.19.1	
2.b.	Conveyor (Belt)	****	AP-42:Sec.8.19.2	
3.	Crushed Rock Screening	****	AP-42:Sec.8.19.1	
4.	Feeder/Hopper Operations	****	AP-42:Sec.8.19.1	
5.a.	Mining (Drilling) Operations	****	AP-42:Sec.8.19.2	
5.b.	Mining (Rock Blasting)	****	Ref. Eqn.	
6.a.	Vehicular Travel (Unpaved Road)	****	AP-42:Sec.11.2.1	
6.b.	Vehicular Travel (Paved Road)	****	AP-42:Sec.11.2.6	
7.	Stockpiling (Active or Inactive Piles)	****	AP-42:Sec.11.2.3	
8.	Loadout (Active Piles)	****	AP-42:Sec.11.2.3	
9.	Inactive Storage Pile Wind Emissions	****	AP-42:Sec.8.19.1	
	TOTAL EMISSIONS	***		

CHECK:

TOTAL ANNUAL "INHALABLE" PM/10 EMISSIONS = **** LBS/YR
CRYSTALLINE SILICA FRACTION (BASED ON X-RAY DIFFRACTION):
INHALABLE CRYSTALLINE SILICA EMISSIONS (lbs/yr) = **** LBS/YR

Table 3.4 SANTA BARBARA CRYSTALLINE SILICA STUDY
CY 1989 EMISSION INVENTORY REVISION

SSID	SOURCE NAME and LOCATION	REPORTED* PROCESS EMISSIONS (lbs/yr)	REPORTED* FUGITIVE EMISSIONS (lbs/yr)	"REVISED" PROCESS EMISSIONS** (lbs/yr)	"REVISED" FUGITIVE EMISSIONS** (lbs/yr)	REASONS FOR ERROR
1162	Bee Rock Quarry near Lake Cachuma	31.51	7.36	23.64	63.00	OUTDATED EM.FCTR.
1226	Buell Flat Rock --Buellton	4898.96	6677.35	3619.41	4,662.41	"
4411	Coast Rock -- Santa Maria	26,886.87	23,135.49	17,097.69	32,572.93	"
1536	Granite (Gard.) -- Buellton	2,318.60	1,733.58	2600.85	1,713.27	"
1542	Grefco -- Lompoc	16,499.00	29.59	15,337.24	547.36	"
1661	So.Pac.Milling -- Sisquoc Plnt	3,654.80	701.23	3,957.72	6,502.45	"
1735	Celite Corp. -- Lompoc	61,707.00	0.00	102,857.81	2,749.15	"
****	Union Asphalt -- Santa Maria	3,654.80	701.23	6575.63	8,014.02	"
	TOTAL:	**119,651.54**	**32,985.83**	**152,069.99**	**56,824.59**	

Note: * -- Reported Silica Emissions are as total "PM" (TSP); ** -- Revised Silica Emissions are as inhalablePM_{10}

3. Area Source Emissions Estimate

One of the critical elements of this study is to examine the effects of particulate matter reentrainment on ambient air quality impacts. Northern Santa Barbara County comprises of large mountainous tracts, canyons and relatively open farm and agricultural operations. The semi-arid climate of the county zone along with relatively high canyon winds prevalent in the region contribute to significant levels of wind-blown dust that are deposited everywhere, including highways and freeways. Also, thousands of people commute daily from the County northern zone to Santa Barbara and San Luis Obispo cities, contributing to significant dust loading. Not unsurprisingly, vehicular reentrainment was seen as a major factor in ambient PM_{10} lading at a number of Santa Barbara particulate matter monitoring sites (see also discussions in Chapter V).

The PM_{10} emission inventory for area sources in the District was compiled by California Air Resources Board staff as part of their State Implementation Plan analysis for PM_{10}. This inventory represents county-wide emissions; and, emissions from smaller sub-county grids are not available. For purposes of this study, a **qualitative** estimate was obtained for area source PM_{10} emissions around Santa Ynez-Buellton airport area (100 sq.km area) and around Santa Maria area (64 sq.km area). Based on road maps and an estimated knowledge of road traffic on highways around these areas (Vehicular Miles Travelled), traffic-generated PM_{10} emissions were computed as a fraction of total county-wide roads plus traffic (VMT). PM_{10} generation by different activities are listed in Table 3.5 (Santa Ynez area) and Table 3.6 (Santa Maria area). Note that these emissions represent a **qualitative estimate only** and are expected to occur mainly during daylight hours (6 AM to 8 PM). PM_{10} emissions due to traffic over paved roads

Table 3.5 Santa Ynez Area Source Emissions

PM_{10} EMISSION BY SOURCE CATEGORIES
(1989 Base Year)

AREA SOURCE TYPE	COUNTY'S PROCESS RATE	EMISSION FACTOR	COUNTY'S EMISSION (T/yr)	STUDY AREA	FRACTION OF TOTAL EMISSION	ESTIMATED PM EMISS. (T/yr)	ESTIMATED* PM_{10} EM. (T/yr)
1. Paved Road	2975*10E6 VMT	17,526.97 lbs/MM VMT	26,075.30	STA.YNEZ	10%	2607.53	1199.47
2. Unpaved Cnty Rd.	191*10E3 VMT	5253.42 lbs/MM VMT	503.30	BUELLTON	2%	10.06	6.14
3. Unpaved Farm Rd.	469*10E3 VMT	4728.07 lbs/MM VMT	1,110.70	AREA	2%	2.22	1.35
4. Agricult.Tilling	624,956 acre/passes	8.95 lbs/acre ps	2,796.70	(100 km^2	1%	27.97	12.59
5. Agricult.Windblwn	52193 acres	59.96 lbs/acre	1564.70	around the	1%	15.65	7.83
6. Unpaved Rd (Wind)	235 acres	136.19 lbs/acre	16.00	airport)	1%	0.2	0.1

* -- Computed PM_{10} emissions are based on the various PM_{10}/PM ratios listed in ARB's Area Source Methodology manual.

Table 3.6 Santa Maria Area Source Emissions

PM_{10} EMISSION BY SOURCE CATEGORIES
(1989 Base Year)

AREA SOURCE TYPE	COUNTY'S PROCESS RATE	EMISSION FACTOR	COUNTY'S EMISSION (T/yr)	STUDY AREA	FRACTION OF TOTAL EMISSION	ESTIMATED PM EMISS. (T/yr)	ESTIMATED* PM_{10} EM. (T/yr)
1. Paved Road	2975*10E6 VMT	17,526.97 lbs/MM VMT	26,075.30	SANTA	20%	5215.00	2398.90
2. Unpaved Cnty Rd.	191*10E3 VMT	5253.42 lbs/MM VMT	503.30	MARIA	0.1%	0.50	0.31
3. Unpaved Farm Rd.	469*10E3 VMT	4728.07 lbs/MM VMT	1,110.70	AREA	0.2%	2.22	1.35
4. Agricult.Tilling	624,956 acre/passes	8.95 lbs/acre ps	2,796.70	(64 km^2	0.3%	8.39	3.77
5. Agricult.Windblwn	52193 acres	59.96 lbs/acre	1564.70	around the	0.1%	1.56	0.78
6. Unpaved Rd (Wind)	235 acres	136.17 lbs/acre	16.00	MONITOR)	0.1%	0.02	0.01

* -- Computed PM_{10} emissions are based on the various PM_{10}/PM ratios listed in ARB's Area Source Methodology manual.

represent about 99 per cent of total emissions, in these estimates. As expected, agricultural tillings or wind-blown dusts are small, minor sources of PM_{10} emissions at these two non-rural blocks. It is of interest to note that annual PM_{10} emissions from non-industrial emissions can potentially exceed 3000 tons for these two significant blocks.

4. "Fine" Particulate Emissions Estimate

We noted in Chapter II that frankly apparent and unmistakable adverse health effects such as silicosis and malignant tumors occur due to crystalline silica impact on breathing airways. In all cases, these adverse effects are observed to occur in the lower respiratory tracts (bronchi, bronchioles and alveoli) only. Therefore, health scientists believe that silica particulates larger than "inhalable" size (10 μm MMAD or less) do not pose any health risks, because their larger sizes prevent them from reaching the lower respiratory tracts. This is also acknowledged by the current regulatory guidelines[26].

Current health effects studies seem to suggest that even "inhalable" particulates may be too large to adversely impact the lower respiratory tracts. In all probability, only "respirable" (i.e., 3.5 μm MMAD) size particulates can enter and deposit in the minuscule airways of these tracts. We noted in Chapter III that all animal studies were performed using α-quartz with MMAD in the < 2.5 μm range. Also, NIOSH/ACGIH adverse health effect levels are set for "respirable" particulates only. Hence, it would be reasonable to estimate the ambient impact of "respirable" particulate emissions in this study. Unfortunately, available EPA

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26 Risk Assessment Guidelines, (1993), prepared by the AB-2588 Risk Assessment Committee of the California Air Pollution Control Officers Association, Sacramento, CA.

equations and emission factors for computing particulate emissions do not address "respirable" particulates. Instead, they compute emissions of "fine" particulates of 2.5 μm MMAD or less. Therefore, this study uses "fine" or $PM_{2.5}$ particulates as surrogates for "respirable" particulates and estimates a population exposure for the "fine" emissions.

A "fine" ($PM_{2.5}$) particulate emission inventory was prepared for each industrial source included in this study. For controlled point source process emissions, EPA guidelines listed in AP-42, Appendix C were followed. A $PM_{2.5}$ emissions factor chart based on these EPA guidelines is presented in Table 3.9. For process fugitive or other fugitive emissions, EPA emission factors listed in AP-42, Chapter 11 and Appendix C were used, as appropriate. Following these $PM_{2.5}$ emission calculations, a "fine" size crystalline silica emissions inventory was computed based on the same assumptions made earlier. That is, the fraction of **fine** size crystalline silica present in the uncontrolled $PM_{2.5}$ emissions is the same as the **inhalable** crystalline silica fraction in the PM_{10} emissions. The estimated **fine** particulate emissions inventory for the industrial sources is listed in Appendix C: Part II of this study **[confidential data under CA "hot spots act"; not included in this report]**. These emissions can be summarized as follows:

(a) **Total fine/respirable** crystalline silica emissions are estimated to be about 28 tons annually. These are about 27 per cent of total **inhalable** emissions;

(b) Total annual point source emissions (15 TPY) comprise nearly 54 per cent of total emissions. These emissions are controlled (using baghouse) to 98 per cent or more;

(c) Annual process and non-process fugitive emissions amount to about 13 tons. Most of these (about 70 per cent) occur just outside of Santa Maria. A significant fraction of these emission can be attributed to road dust;

5. Historical Maximum Emissions Inventory

Historical maximum emissions from a source are defined, in the regulatory context, as the highest actual emissions from the source -- observed during the past five years beginning from the date of study. This practical criteria is used to ensure that the "historically worst" emissions case is included in the study. Also, as indicated earlier, actual annual emissions are significantly different (higher) for the purpose of exposure analysis only if they differ from one another by more than five percent.

No crystalline silica emissions data are available for years prior to 1989 nor for years later than 1992. Also, the **actual** emissions data prior to 1988 do not cover comprehensively all emission units. Hence, the study reviewed emissions data related to each of the major industrial sources for the period CY 1988-1992. In estimating the historical maximum year emissions, the study focussed on the production rates (or other appropriate parameters) to estimate the historical maximum emissions by combining them with the emission factors used in the base year study (interestingly, each source agreed to this scheme for computing their historical maximum emissions). This data, provided as confidential information, is stored in the District files.

The actual annual process/feed rates for each source is listed in Table 3.10 (next page). Since process rates are confidential, the source names are not listed; and, the data is presented "normalized" in terms of the study year (CY 1989) process rate. Table 3.7 shows that annual throughput rates varied among sources by up to 70 per cent during the last five years. It also showed that except for two sources, the process rates during the study year (CY 1989) represents the highest

TABLE 3.7 HISTORICAL DATA BASE FOR "PROCESS" PM EMISSIONS

NON-METALLIC MINERAL PROCESSING PLANTS

SANTA BARBARA NORTH COUNTY ZONE

FACILITY	ACTUAL ANNUAL THROUGHPUT (Normalized w.r.t. CY 1989 Throughput)					COMMENTS
	1992	1991	1990	1989	1988	
SOURCE -- A	0.77	0.81	1.03	1.00	0.68	Max.Rate=CY 1989+3%
SOURCE -- B	0.73	0.58	0.85	1.00	0.77	Max.Rate=CY 1989
SOURCE -- C	0.48	0.51	0.57	1.00	0.85	Max.Rate=CY 1989
SOURCE -- D	0.51	0.64	0.91	1.00	0.68	Max.Rate=CY 1989
SOURCE -- E	0.83	0.86	0.71	1.00	0.82	Max.Rate=CY 1989
SOURCE -- F	0.34	0.51	0.72	1.00	Not Avail.	Max.Rate=CY 1989
SOURCE -- G	0.85	1.30	1.41	1.00	1.02	CY 1990 Data Used
SOURCE -- H	0.83	0.80	0.83	1.00	0.85	Max.Rate=CY 1989

rate. For source "A", CY 1989 process rate (and consequently, PM emission) is about 3 per cent less than the preceding year's PM emission, i.e., the difference is negligible. For source "G", process rate data for CY 1989 was not available at the time the study started; so, CY 1990 process rate data was used, which, fortuitously, represents the maximum process rate. **In other words, the CY 1989 data also represents the historical maximum emissions data. No analysis for emissions during the other four years is, therefore, necessary for the "worst-case scenario" investigation.**

CHAP.IV EXPOSURE ASSESSMENT FOR CRYSTALLINE SILICA

1. Exposure Estimate Methods

The first step to assess the adverse health risk effects of crystalline silica would be to establish the extent of population exposure to the toxic pollutant. Population exposure to crystalline silica particulates occurs through various pathways. These pathways comprise of the following: (a) direct inhalation/respiration of silica particulates present in ambient air, (b) ingestion of silica particulates deposited on plants/animals and consumed through natural food chains, and (c) direct absorption of silica particulates through skin/external body surfaces. Up to this time, serious and irreversibly adverse health effects (silicosis, cancer etc.) of crystalline silica have been observed only in the lower respiratory tracts. Since these effects are caused by "inhaled" or "respired" particulates, this study computed ambient air crystalline silica concentrations (caused by emissions from anthropogenic sources). The concentration values provide data necessary to estimate the adverse health effects (chronic effects) and health risks (excess cancer probability) due to crystalline silica respiration.

Ambient air concentrations of any particulate pollutant can be obtained via two distinct methods. First, the pollutant concentration may be directly measured using a suitable particulate sampler. The procedure and results obtained based on this principle will be discussed in the next chapter. Unfortunately, the sampler data represents the ambient air concentration in the immediate vicinity of the sampler itself. The result cannot be extrapolated to obtain the particulate concentration at any other place, even as near as a city block away. In the second method, an area-wide air quality is projected based on known pollutant emissions in the area and the local meteorological data, both of which are incorporated in a complex, computerized mathematical model. Since the main interest of this study

is to obtain the population exposure to crystalline silica over wide areas, detailed air quality modeling was performed to estimate area-wide ambient air concentrations of **inhalable** and **respirable** crystalline silica. A brief description of the study is presented next.

2. Air Quality Modeling

In the north zone of the Santa Barbara county, industrial point sources (kiln and dryer stacks and vents) as well as fugitive area sources (construction material processing, sand, rock and gravel plant open air operations or paved road traffic dust) contribute significantly to crystalline silica emissions. Therefore, EPA-recommended Industrial Source Complex - Short Term (ISCST) model is used in this study to project ambient air concentrations of crystalline silica. A brief description of the model and information on its uses can be found in EPA modeling guidelines[27]. The pollutant concentration estimating algorithm uses Gaussian dispersion equation which assumes Gaussian dispersion characteristics for the pollutant plume in an Eulerian (space-time) frame. Hourly concentrations of the pollutant at user-selected plume-receptor points are computed for a whole year and then averaged to obtain the annual average pollutant concentration at the point. Some of the detailed inputs to the model are listed in the next paragraph.

Emission Parameter Input -- Besides the hourly pollutant emission rate, point source information data such as stack heights and diameters, stack exit flow volumes and exit flow temperatures must be input for each point source. For area sources (fugitive emissions), area-wide pollutant emission rates need to be input

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27 Guideline on Air Quality Models (revised), (July, 1986), EPA-450/2-78-027R, US Environmental Protection Agency, Office of Air Quality Planning & Standards, Research Triangle Park, NC.

along with pollutant release height and area dimensions. Area source emissions that did not occur during night hours, namely industrial road traffic from rock and gravel plants or rock and gravel storage piling, were modulated to be effective only during the hours they actually occurred.

Meteorological Data Input -- Detailed local hourly meteorological data must be input. These include information on ambient temperature, wind speed and direction along with the height at which wind data is measured, wind variation with height, atmospheric mixing height and atmospheric stability.

Micro-meteorological Factors -- Data on local topographical factors that may influence pollutant plume dispersion are included in the input. These data consist of heights of nearby high buildings that approach the stack height along with the dimensions of such buildings.

Receptor Information -- The modeling output consists of pollutant concentrations predicted at user-selected points (called receptors) away from the emission sources. While selecting the points, the user must indicate the location of these points relative to the emission sources using cartesian or polar coordinates.

3. Regional Air Quality Estimates

In Chapter III, the emission inventory process showed that all major industrial sources for crystalline silica emissions are located in the northern zone of the County. A brief review indicated that these major emission sources are clustered around three distinct areas, namely, Santa Maria, Lompoc and Buellton/Santa Ynez. Therefore, the exposure assessment study could be confined to rectangular blocks of 400-500 sq.km around each of these towns, and still estimate pollutant

concentrations at "sensitive" receptors such as schools, hospitals and nursing homes in the county north zone.

Emission Estimates:

Santa Maria -- The emission inventory showed that three major crystalline silica sources are located near Santa Maria. These are Southern Pacific Milling at Sisquoc, Coast Rock at Garey and Union Asphalt located next to Coast Rock. All three industrial facilities are at least 5 km from Santa Maria central business district. Both point and fugitive (area source) emission data for each of these sources were formatted for input to the model to include emission heights, flow volumes and temperatures, and area source dimensions. A listing of this formatted data is included in Appendix D for reference.

Lompoc -- Two large diatomaceous earth processing facilities, Celite and Grefco, are located on either side of Lompoc township, about 10 km from the central business district. Numerous points of emissions at both facilities emit relatively large amounts of crystalline silica (including cristobalite) that are subsequently entrained in building downwashes. Strong local ambient air impact on either side of the town is, therefore, expected. A listing of formatted emission parameters is included in Appendix D.

Buellton/Santa Ynez -- This area includes two large rock and gravel facilities, Granite (Gardner facility) and Buellflat Rock. Both facilities also process asphaltic concrete; and, both are located at least 1 km away from Solvang central business district. Emission parameters for these two sources, formatted for modeling input, are listed in Appendix D.

South County Sources -- In compiling the preliminary emission inventory for the County, the Bee Rock facility was identified as one with relatively large (for South County) emissions. Rock blasting also occurs at this facility located near Lake Cachuma about 50 km from downtown Santa Barbara. This facility was

included in the modeling study to assess if it caused any severe ambient air impact. The formatted emission parameters are listed in Appendix D.

Meteorological Data:

Hourly surface meteorological data from airport weather stations and a number of local "industrial site weather monitoring stations (termed PSD sites)" were available. Air flow data for each site was studied for site- representativeness. Based on this analysis, 1963 surface air data from Santa Maria airport were used for Buellton-Santa Ynez area modeling, 1989 surface air data from Santa Maria Battles Plant site were used for Santa Maria area modeling and 1989 surface air data from Lompoc HS&P Plant site were used for Lompoc area modeling. Upper air data measured at regional Vandenberg Air Force Base (VAFB) site were used to obtain hourly mixing heights for each modeling scenario.

Receptor Location:

Each region modeled consisted of a rectangular block, ranging from 400 - 600 square kilometers. Each rectangle was subdivided into 1 square kilometer grids, so that each receptor was no further than 1 km away from the next one. Sensitive receptors (school or hospital or nursing home) were addressed in designing the grids. Also, all particulate (PM) monitoring stations, one each at Santa Maria downtown, Santa Ynez airport and VAFB Watt Road site that operated during 1989, were included as receptors. All receptors were assumed to be at 1.5 meter height, corresponding to normal human breath intake height. For conservative air impact estimates, any rolling terrain effect was assumed to be insignificant and all local topological data for the receptors were ignored in the modeling.

4. **Exposure Assessments**

ISCST Model-predicted hourly and average annual ambient concentration of

crystalline silica were directly input to a health risk assessment model used by the Agency, namely Assessment of Chemical Exposure (ACE-2588), to obtain the resultant health risk effects. Detailed health risk effects, both carcinogenic and chronic, are discussed in Chapter VI of this study. Hence, details of ambient exposure estimates, e.g., concentration isopleths that merely constitute the intermediate step of a health risk assessment, are omitted from this chapter. A brief description of the results is, however, presented below. Figures 4.1, 4.2 and 4.3 are attached (following pages) for reference, identifying the worst impact receptor for each area.

I. Inhalable Emissions Exposure Assessment -- Fugitive process emissions and industrial vehicular traffic at plant sites were significant for all the rock and gravel processing facilities; and, each of these facilities projected high ambient concentrations (0.5 -17 $\mu g/m^3$) of crystalline silica at or just beyond the plant boundaries. Two adjacent Santa Maria area plants contributed to the worst impact of 17 $\mu g/m^3$, but the MEI location was less than 500 m from their common plant boundary and 1.5 kilometers away from any residential area. In Lompoc area, the larger of the two diatomaceous facilities also projected 1.5 $\mu g/m^3$ levels of the toxic substance at about 1.5 km from the plant mine site (away from residential area), mainly caused by the fugitive dust from mining traffic over unpaved roads. These exposure levels declined steeply from the point of estimated maximum impact. Since all the industrial facilities were located at considerable distances away from the central business districts and sensitive receptors (schools, hospitals etc.), the estimated impact of the industrial emissions at these key locations (see Figures next page) were about 1/1000th of the ACGIH/NIOSH listed "permitted exposure levels" of 100 $\mu g/m^3$ for α-quartz.

II. Respirable/Fine Emissions Exposure Assessment -- As in the case of

inhalable emissions, fugitive process emissions and industrial vehicular traffic at plant sites were significant for the rock and gravel processing facilities. As before, the two adjacent Santa Maria facilities projected high ambient concentrations (5.9 $\mu g/m^3$) of crystalline silica at the MEI location 500 m beyond the common plant boundary. In Lompoc, respirable emissions from the larger of the two diatomaceous facilities projected about 0.7 $\mu g/m^3$ of crystalline silica exposure at about 0.5 km from the plant boundary, with the impact mainly attributed to stack downwash. These exposure levels declined steeply from the point of estimated maximum impact. For all residential sectors, the estimated impact of the industrial emissions at key/sensitive locations (e.g., schools and hospitals) were about 1/10,000th of the ACGIH/NIOSH listed "permitted exposure levels" of 100 $\mu g/m^3$ for α-quartz (see figures attached in the preceding pages).

III. Reentrainment Effcts -- An auxilliary study was performed to estimate the impact of vehicular traffic inthe northern county. Qualitative projections of "inhalable" paved road dust emissions, estimated for CY 1989, were input to the model and the impact of these emissions at two PM_{10} monitors (Santa Maria downtown and Santa Ynez airport) computed using CY 1989 meteorological data. The industrial sources "24-hour projected average impact" at these two monitors

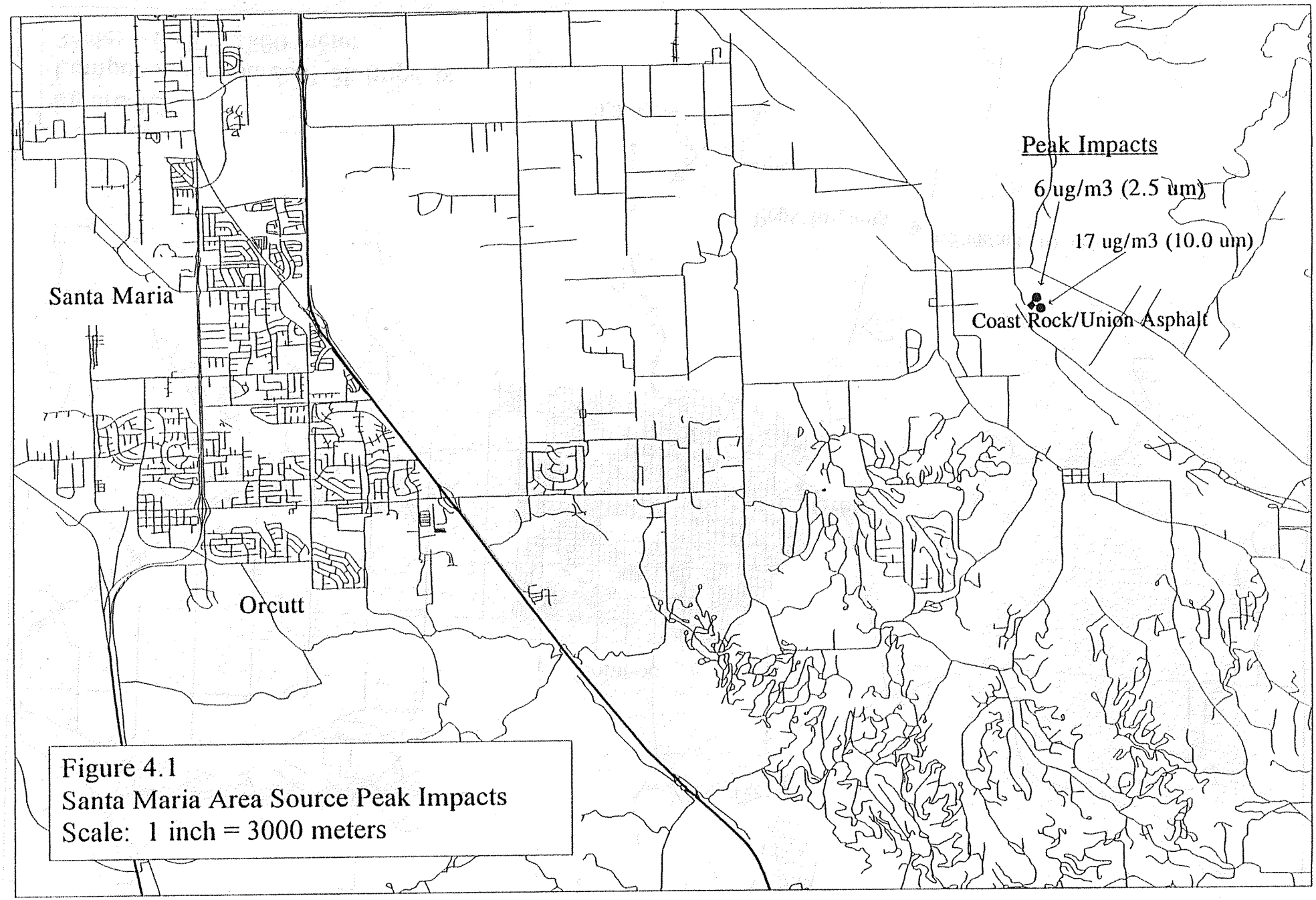

Figure 4.1
Santa Maria Area Source Peak Impacts
Scale: 1 inch = 3000 meters

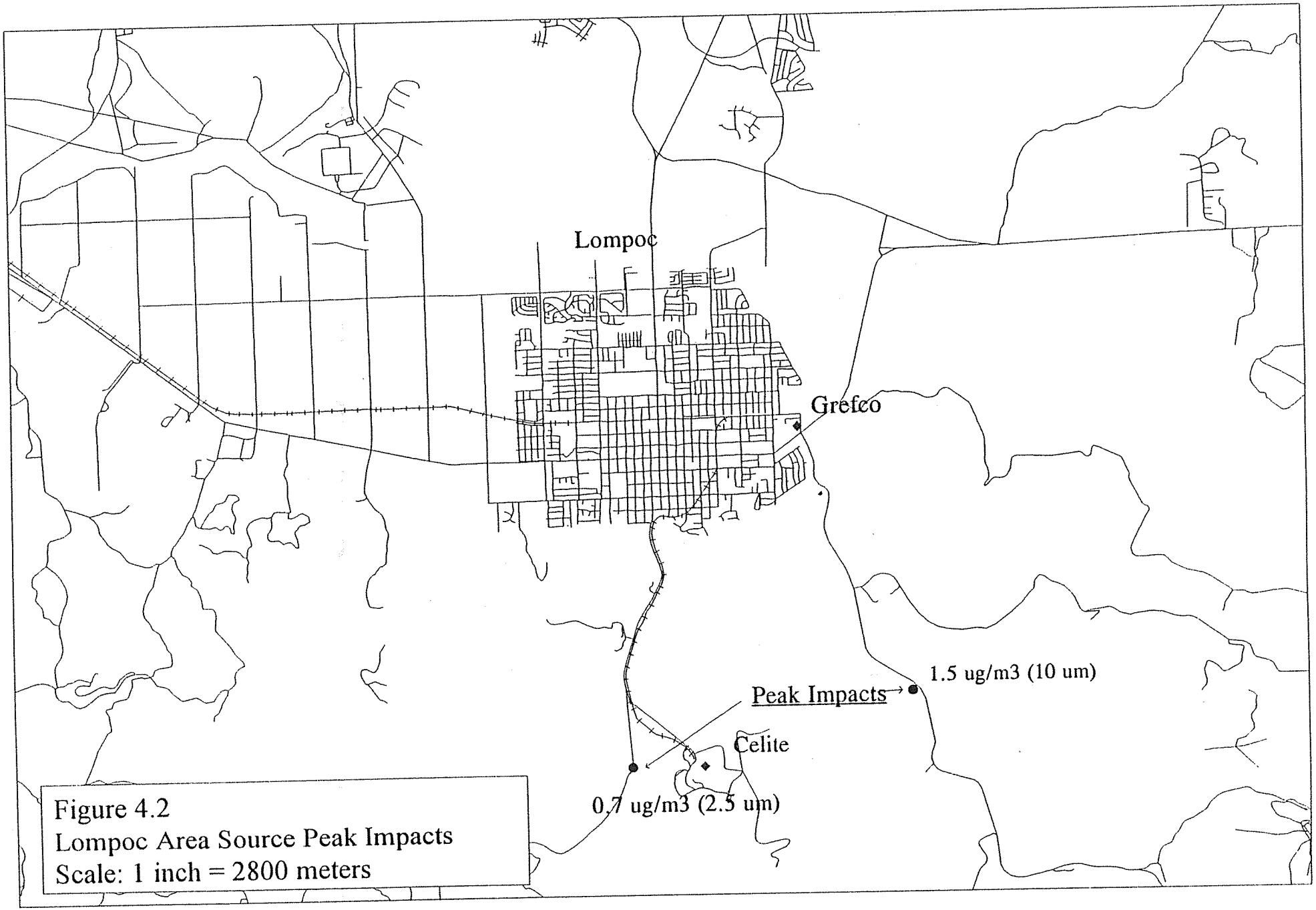

Figure 4.2
Lompoc Area Source Peak Impacts
Scale: 1 inch = 2800 meters

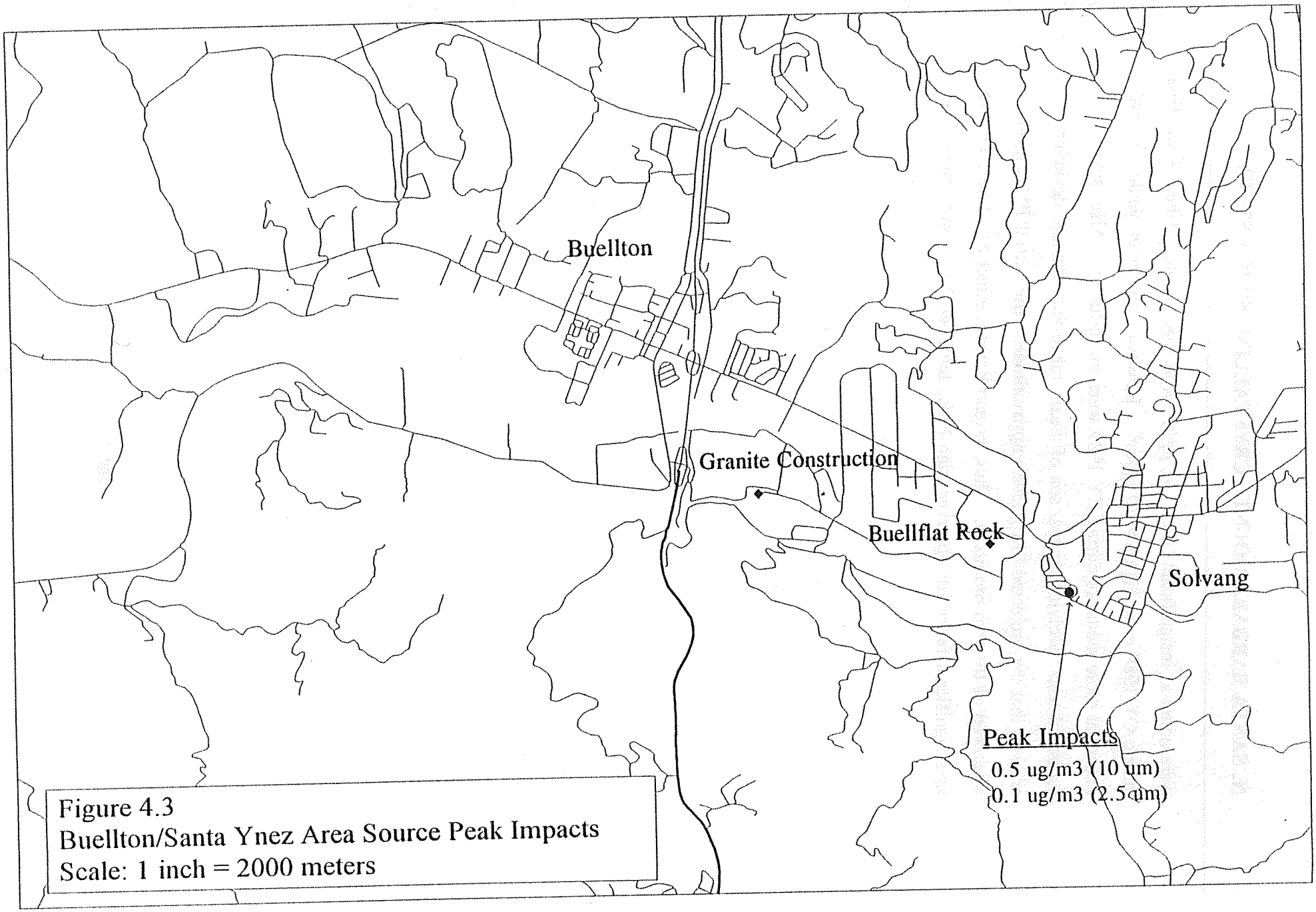

Figure 4.3
Buellton/Santa Ynez Area Source Peak Impacts
Scale: 1 inch = 2000 meters

were noted as insignificant, i.e., 1 -2 $\mu g/m^3$ when actual total 24-hour PM_{10} levels during CY 1989 were high (> 20 $\mu g/m^3$). However, computed vehicular traffic impact at these monitors during CY 1989 were much higher. Also, simple statistical tests involving comparison of mean, range and standard deviation showed that the projected PM_{10} levels **approximated the actual PM_{10} levels observed at the two monitors.** Thus, re-entrainment effect could be considered as a significant factor for observed high PM_{10} levels at these north county sites.

CHAP.V MONITOR DATA FOR CRYSTALLINE SILICA

1. Available Ambient Monitoring Data

The most reliable information on existing ambient air concentrations of a pollutant is obtained by actually sampling the polluted air and quantifying the pollutant fraction present in the sample. For crystalline silica, an appropriate sampler can be used to collect known volumes of polluted ambient air that contain crystalline silica particulates, and trap the particulates in a pre-weighed filter. The filter can then be re-weighed to obtain the weight of silica collected. In conjunction with the air volume data, the mass data would yield the mass concentration of crystalline silica in ambient air. Unfortunately, the adverse health effects of crystalline silica was acknowledged only as late as 1987. Hence, no ambient monitoring stations collected data for crystalline silica (using the generic procedure outlined above or any other procedures), and no crystalline silica ambient air concentration results were available.

To solve the problem, this study aimed to extract crystalline silica ambient concentration information from available PM_{10} monitoring sites. PM_{10} monitoring sites preserve the particulate-trapping fiters for a number of years after these filters are weighed and analyzed. Also, in most cases, the filter material itself does not interfere with the x-ray diffraction analysis used to quantify any crystalline silica fraction present in the filter-collected particulate mass. Therefore, a review of county-wide PM monitoring sites was performed to assess the availability of PM_{10} filters and to find if the filter material was suitable for x-ray analysis to yield crystalline silica fraction data.

2. Monitoring Network

N. SANTA BARBARA COUNTY CRYSTALLINE SILICA STUDY

The Santa Barbara County Air Pollution Control District conducted specialized PM_{10} monitoring in the County during 1989 as part of a proposed year-long PM_{10} emission reduction study. The major aim of this study was to ascertain the impact of both natural and anthropogenic PM_{10} emission sources, on PM_{10} levels in the County. Using the results, the District was to formulate necessary regulations to reduce emissions from existing PM_{10} sources that contribute to observed high, ambient PM_{10} levels. The study was conducted for one year only from January 10, 1989 through December 30, 1989. Monitors at each of the six sites constituting the network collected PM_{10} samples with identical samplers on a cycle of **one sample every six days.** The PM_{10} data collection and analysis followed a peer-reviewed and approved monitoring/analysis workplan[28]. Figure 5.1 (next page) shows the PM_{10} monitoring network, with three of the sites located in the northern Zone of the County, namely at Santa Maria Public Library (urban), Santa Ynez Airport (rural) and Vandenberg Air Force Base Watt Road station (remote background).

All PM_{10} monitoring sites listed above used fiber glass filters instead of the cheaper quartz filters. Fiberglass, though not an ideal material for the purpose, did not cause any significant problems in the process of x-ray diffraction anlysis to detect and quantify crystalline silica fraction in the filter-trapped mass. Therefore, filters from the samplers were transmitted to Desert Research Institute (DRI), Las Vegas, Nevada. Note that DRI staff conducted the initial chemical analysis on each filter sample in 1990 for constituents such as organic and elemental carbon,

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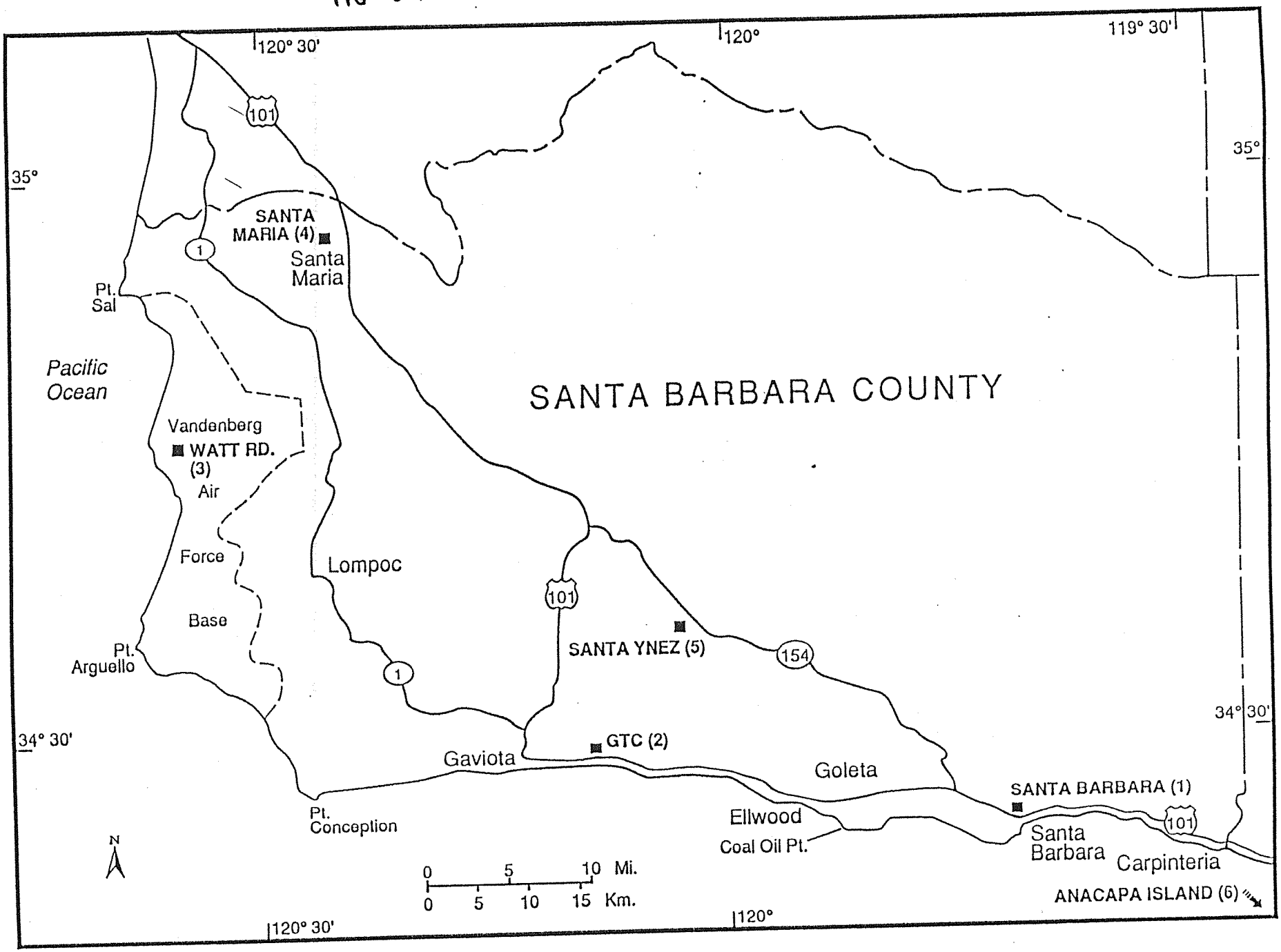
[28] Monitoring Workplan for Santa Barbara County PM-10 Emission Reduction Study; prepared by ABB Environmental Services, Inc. for the Santa Barbara County APCD, January 3, 1989.

FIG 5.1 LOCATIONS OF PM10 STUDY MONITORS



sulfate, nitrate, **silica including amorphous silica and silicates**, ammonium and 35 other elements. These results have been compiled in a comprehensive report[29]. Unsurprisingly, the analysis did not address the question of crystalline silica ambient impact. However, enough of the filter material were saved and were still available for analyzing and quantifying the crystalline silica fraction in the filters for each of the 1989 sampling days[30]. Thus, an estimate of the ambient crystalline silica levels at the three north County monitors was possible. The District contracted with the Desert Research Institute to analyze the filters for Crystalline Silica ambient levels for a number of pre-selected days.

3. Selection of 1989 Sampling Days for Crystalline Silica Analysis

As noted in Chapter IV (Exposure Assessment), the large industrial sources of crystalline silica in northern County are all located at significant distances (i.e., greater than 16 km) away from dense population areas and PM_{10} monitors. Thus, they are expected to cause minimal pollution impact on population areas. This was confirmed by detailed dispersion modeling studies of the crystalline silica emissions from these sources. On the other hand, preliminary qualitative dispersion studies cited in Chapter IV of emissions from Northern County area sources such as paved, unpaved and farm road dusts from vehicular traffic and dust from agricultural tilling showed that these could contribute significant amounts of PM_{10}, at least at the rural monitors, on certain days. Therefore, the filter analysis portion of this study only intended to find out:

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29 1989 PM-10 Monitoring Report for Santa Barbara County; report prepared by ABB-ES for Santa Barbara APCD, June 27, 1990.

30 Personal Communication from Dr. Judith Chow, DRI, August 1992.

(i) Non-industrial source crystalline silica impact -- estimated from the level of crystalline silica at the remote background monitor when the filter data indicated high PM_{10} or high silica (including amorphous silica and silicates) levels, and

(ii) Non-modeled source contribution to ambient loading -- evaluated from the Crystalline silica levels at rural or urban monitors when the PM_{10} or silica levels at these monitors were high and the wind blew both to or from the direction of large industrial sources.

These data from the PM_{10} monitors could lend support or conclusively deny our modeling study conclusions about the contribution of the industrial sources versus the anthropogenic area sources in the Northern County region.

Table 5.1 lists the days in 1989 when high $\mathbf{PM_{10}}$ levels (top 10 per cent of the observed $\mathbf{PM_{10}}$ levels) were monitored at the samplers at Watt Road (remote background), Santa Ynez airport (rural) and Santa Maria public library (urban) sites. High **silica** level days (top 10 per cent of the observed **silica** levels) at these three monitors are listed separately in Table 5.2. Both tables list the predominant vector-averaged wind speed and wind direction data (10 m height data) obtained from the instrument site. A number of interesting ambient PM loading patterns are revealed by the two tables. For example:

(a) At Watt Road remote background site, the top 10 per cent of the high PM_{10} days did not coincide with any of the high (top 10 per cent) silica level days. On the high PM_{10} days, the wind blew predominantly from the west and northwest directions whereas, there was no set pattern to wind direction on high silica level days. Both PM_{10} and silica mean annual levels were low at this site compared to mean annual levels at the Santa Maria urban site. These

observation are in conformity of the general PM_{10} loading (annual mean = 20.3 ug/m^3) at this site, which showed a dominance of marine and sulfate PM fractions[31] (combined total of 33 per cent).

(b) At Santa Ynez rural site, only one high PM_{10} day showed a relatively high silica level as well. Once again the wind directions on high PM_{10} level days were the west and northwest, while the high silica level days did not show any consistent wind direction pattern. We note that the PM_{10} mean annual level (19.0 ug/m^3) was about the same as at the Watt Road site, but the silica levels were more than three (3) times higher[32].

(c) At Santa Maria urban site, three of the observed high PM_{10} days coincided with observed high silica level days; and, the other high PM_{10} days showed significant levels of silica. Interestingly, wind directions on either high PM_{10} days or high silica days were from west/northwest or east/southeast. The mean annual PM_{10} level was 27.3 ug/m^3 at this monitor, while the silica level was more than four (4) times higher than at the Watt Road site[33]. In all probability, the high silica levels at the Santa Maria site can be traced to higher than average "re-suspended paved road dust" impact[34], as was indicated by the earlier area source modeling analysis.

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31 Source Apportionment Report for Santa Barbara County; Report prepared by ABB-Es for the SBAPCD, February 25, 1991.

32 Ibid.

33 Ibid.

34 Ibid.

Clearly, Tables 5.1 and 5.2 support the following concepts:

(a) the "remote background" site high PM_{10} levels are significantly influenced by the ocean (i.e., sea salt) contribution;

(b) the "rural" monitoring site does not show a significant correlation between high PM_{10} and high silica levels indicating that the same sources are not responsible for high PM_{10} and high silica levels; and,

(c) the "urban" monitor shows a significant correlation between the high PM_{10} level and the high silica level days, signifying that the same (anthropogenic) sources contributed to both problems.

Since crystalline silica is essentially an industrial product, no apparent inferences could be drawn about its contribution to the ambient PM loading at the three monitors. However, analyzing the monitor-collected filters for crystalline silica for carefully selected days **with distinct wind direction patterns** could provide two significant pieces of secondary data , namely :

i. Expected background (i.e., non-variable, ambient) levels of crystalline silica -- quantifying the magnitude of crystalline silica problem in the entire County. Analysis of "remote background" filter data for carefully screened wind direction days, e.g., days when industrial or even anthropogenic sources are least likely to contribute to a monitor, may provide this information.

ii. Impact of non-modeled sources of crystalline silica -- to be added to modeled industrial source crystalline silica impact to obtain an estimated total ambient loading of the pollutant at locations near the industries. Conceivably, "rural" or "remote background" monitor filter data can provide distant "industrial" source or even regional "non-industrial" source impact.

Based on all of the above considerations, it was decided to analyze approximately fifty (50) filters. These selected days consisted of:

(i) both "high and low" PM_{10}/silica level days at the "remote background" Watt Road and rural Santa Ynez sites.

(ii) high PM_{10} and high silica level days at the urban Santa Maria monitor and,

In conjunction with the wind speed and direction patterns observed on these days, data from the rural and remote background monitors were expected to provide non-industrial and possibly non-anthropogenic source contributions. In addition, data from the Santa Maria monitor was supposed to provide both "unknwn plus unquantified" and "quantified non-industrial" source impact (including possible "paved road dust re-entrainment" contributions).

Table 5.3 lists the days selected for analyzing the filters at each of the three sites and the anticipated PM data collection function of each of the monitors on those days. In the comment column in the table lists these functions as follows:

"S" -- indicates that the PM data collected on these days possibly represent modeled industrial SOURCE(S) impact on the monitor; and,

"B" -- indicates that the monitor data may serve as BACKGROUND (including non-modeled sources impact) for modeled sources;

Acronyms "SY" and "SM" used with "S" and "B" stand for Santa Ynez and Santa Maria sources.

4. Results of Filter Analysis for Crystalline Silica Levels

Overall, the filter analysis data show that **24-hour** crystalline silica levels at a relatively

pristine monitoring site within the north county zone, such as the VAFB Watt Road station, are usually close to zero but can reach a relatively high level of 1 $\mu g/m^3$ on high PM_{10} days. A rural north county monitoring site, such as the Santa Ynez airport station, show similar trends, except that **24-hour** crystalline silica levels are frequently non-zero on high PM_{10} days. Note that the NIOSH/ACGIH guidelines stipulate permissible "**chronic**" exposure levels of 50 $\mu g/m^3$ for healthy adults, that is usually translated to 1.2 $\mu g/m^3$ for sensitive population.

At Santa Maria downtown monitor, observed levels of crystalline silica ranged between 1-3 $\mu g/m^3$ on a **24-hour** basis for the high PM_{10} days selected. This level of crystalline silica deserves further analysis regarding the possible sources of silica. A review was performed to see if the industrial sources contributeed to the crystalline silica levels at all the monitoring stations.

5. Comparison of Model-predicted and Observed Pollution Levels

For comparison purposes, two sets of air quality modeling were performed for north County sources. The first one projected the impact of industrial facilities emissions at tth three selected monitors (Watt Road, Santa Ynez Airport and Santa Maria Downtown). The second one qualitatively estimated the impact of anthropogenic area sources, e.g., traffic-generated dust, at these monitors. Details of these modeling results were presented in Chapter IV (Population Exposure).

Actual observed and model-predicted crystalline silica levels at each monitor on the selected days are shown in Table 5.4. Note that the model-predictions address both point and area source impacts at the Santa Maria and Santa Ynez monitors only. As noted earlier, area source impact at the "remote background" Watt Road monitor was not attempted due to inherent uncertainties in the area source data inventory for the region

surrounding this monitor.

Santa Ynez Airport Monitor -- Predicted industrial source contributions to this monitor were close to zero, indicating that the industrial point source emissions of crystalline silica were not expected to reach this distant location. Om the other hand, modeled-predictions of the area source contributions, consisting chiefly of vehicular traffic-generated particulates, approximated actual observed crystalline silica levels at the monitor. In other words, **re-entrainment** possibly plays a major role in PM impact at this site.

Santa Maria Downtown Monitor -- Predicted industrial source contributions to this monitor were also very, very low (though higher than that for Santa Ynez), indicating that the sources were too distant from the monitor to affect its readings. Also, as at the Santa Ynez monitor, the modeled-predictions for the area source contributions --translated as the vehicular traffic-generated particulates -- qualitatively matched actual observed crystalline silica levels at this monitor. Thus, **re-entrainment** was also a major factor at this monitor too.

Overall, the comparison indicates that the industrial source crystalline silica contributions at the actual PM_{10} monitoring sites are nearly insignificant. However, re-entrainment of dust by vehicular traffic may be a potentially significant factor in increasing the PM levels in the north zone of the County.

6. Summary Review of Monitor Data

Analysis of the observed PM_{10} and "inhalable" crystalline silica levels at the three north County monitors lead to the following conclusions:

(a) Impact of the industrial facilities emissions at the population-oriented monitors are insignificant, since the monitors are relatively distant from emission units;

(b) PM_{10} reentrainment caused by large volumes of traffic can cause significant impact at some of the existing monitors, and is probably the main cause of the high PM_{10} readings at these sites;

(c) Existing PM_{10} data covers only a one-year period; and, "inhalable" crystalline silica data available from the PM_{10} data base provides a limited view. A wider data base would provide a better understanding of ambient crystalline silica levels at sensitive locations in the County;

(d) Available limited data do not reveal any deleterious ambient levels of crystalline silica at two of the three monitors reviewed, namely, Watt Road and Santa Ynez airport sites. The Santa Maria downtown monitor showed 24-hour levels of up to 3.45 $\mu g/m^3$ on very high PM_{10} days. However, those readings could be, conceivably, ascribed to high winds and dust reentrainment by vehicular traffic. Industrial sources contributed insignificantly to the monitor on those days.

Table 5.1 Identification of Days
for Filter Analysis

HIGH PM_{10} DAYS

Date	Measured PM_{10} ($\mu g/m^3$)	Measured Si ($\mu g/m^3$)	Predominant Wind Direction/Speed	Filter ID
Site: Watt Road				
1/28	36.97	0.38	306/0.7	WT 3004
2/27	30.31	0.20	342/1.9	WT 3009
5/28	36.03	0.26	294/2.4	WT 3025
6/9	30.69	0.27	285/2.9	WT 3027
6/21	54.94	0.83	273/1.2	WT 3029
7/9	34.17	0.12	262/1.9	WT 3032
7/21	41.26	0.05	243/1.3	WT 3034
Site: Santa Ynez				
1/28	26.38	0.69	306/0.7	YT 5004
6/21	41.23	4.92	273/1.2	YT 5039
7/9	32.47	2.09	262/1.9	YT 5044
7/15	29.22	2.44	258/2.0	YT 5045
7/21	41.63	3.00	243/1.3	YT 5046
9/7	27.01	2.47	300/1.7	YT 5059
11/6	32.87	1.37	273/0.7	YT 5074
Site: Santa Maria				
6/21	66.17	5.92	284/1.7	MT 4039
7/21	51.56	3.16	243/1.3	MT 4046
5/28	46.98	7.37	275/4.1	MT 4033
1/28	44.02	3.15	306/0.7	MT 4004
2/27	40.36	6.50	317/2.3	MT 4011
7/3	39.23	3.80	282/2.1	MT 4043
6/9	39.14	3.87	282/3.6	MT 4037
12/30	21.17	3.16	339/1.1	YT 5087
9/13	23.11	2.97	246/1.0	YT 5060
10/7	20.07	2.57	244/0.9	YT 5066
6/15	16.63	2.36	270/1.5	YT 5038

Table 5.2 Identification of Days for Filter Analysis

HIGH SILICA DAYS

WATTS ROAD			SANTA YNEZ			SANTA MARIA (Battles - W.D.)		
Date	Si (PM)	WD/WS	Date	Si (PM)	WD/WS	Date	Si (PM)	WD/WS
10/19	3.53 (28.5)	174/0.6	10/19	5.64 (24.0)	174/0.6	5/28	7.37 (47.0)	275/4.1
4/4	3.23 (24.8)	18/3.6	12/12	5.05 (22.9)	286/0.8	10/19	6.63 (37.9)	123/0.9
12/12	2.98 (19.7)	286/0.8	11/18	3.79 (16.7)	34/0.3	2/27	6.50 (40.4)	317/2.3
10/31	1.89 (17.8)	326/0.8	10/31	3.41 (18.6)	326/0.8	6/21	5.92 (66.2)	284/1.7
12/24	1.28 (19.7)	10/0.5	12/24	3.28 (13.8)	10/0.5	4/22	5.82 (25.8)	297/4.0
12/18	1.20 (21.1)	10/1.0	12/30	3.16 (21.2)	337/1.1	6/15	5.74 (31.3)	273/2.8
1/16	1.20 (17.8)	5/3.3	5/4	3.08 (21.7)	385/1.4	11/18	5.06 (26.1)	112/2.1
4/16	1.17 (22.0)	270/0.7	9/13	2.97 (23.1)	246/1.0	10/31	4.61 (28.8)	116/1.2
12/30	0.94 (24.3)	339/1.1	10/7	2.57 (20.1)	244/0.9	12/12	4.07 (25.1)	113/2.3
2/21	0.80 (19.6)	271/0.6	6/15	2.36 (16.6)	270/1.5	6/9	3.87 (39.1)	282/3.6
11/30	1.11 (14.49)	344/0.6	6/21	4.92 (41.2)	273/1.2	7/3	3.80 (39.2)	282/2.1
6/21	0.83 (54.9)	273/1.2	7/21	3.00 (41.6)	243/1.3	5/22	3.80 (23.3)	288/2.6
11/12	0.69 (23.7)	273/1.1	4/4	2.72 (15.3)	18/3.6	12/18	3.74 (36.7)	109/1.9
4/28	0.66 (19.4)	316/1.8	9/7	2.47 (27.0)	300/1.7	11/30	3.73 (22.5)	112/2.2
10/25	0.68 (17.7)	315/2.2	12/18	2.31 (25.1)	10/1.0	5/4	3.72 (32.8)	274/3.0

Table 5.3 LIST OF DAYS SELECTED FOR FILTER ANALYSIS

STATION NAME	DATE	FILTER ID	Meas. PM/10	Meas. Tot. Si	Obs. Wndspd	Obs.Wndir	Monitor Clas.*	COMMENTS
			(ug/m3)	(ug/m3)	(m/s)	(DEG)	For the Day	
WATT ROAD	1/16/89	WT 3002**	17.75	1.2	3.3	5	"S -- SM"	
	1/28/89	WT 3004	36.97	0.38	0.7	306	"B -- SY"	
	2/21/89	WT 3008	19.59	0.8	0.6	271	"B -- SY"	
	4/4/89	WT 3015**	24.79	3.23	3.6	18	"S -- SM"	
	4/16/89	WT 3018**	22.05	1.17	0.7	270	"B -- SY"	
	5/28/89	WT 3025	36.03	0.26	2.4	294	"B -- SY"	
	6/9/89	WT 3027	30.69	0.27	2.9	285	"B -- SY"	
	6/21/89	WT 3029	54.94	0.83	1.2	273	"B -- SY"	
	7/9/89	WT 3032	34.17	0.12	1.9	262	"B -- SY"	
	7/21/89	WT 3034	41.26	0.05	1.3	243	"B -- SY"	
	8/8/89	WT 3038	7.75	0.06	1.8	261	"B --SY"	
	9/13/89	WY 3044	8.8	0.35	1	246	"B -- SY"	
	10/19/89	WT 3050**	28.54	3.53	0.6	174	"S -- ??"	
	12/18/89	WT 3061**	21.07	1.2	1	10	"S -- SM"	
	12/24/89	WT 3062**	19.72	1.28	1	10	"S -- SM"	
	2/27/89	WT 3009	30.31	0.2	1.9	341	"?? -- ??"	
	3/11/89	WT 3011	4.71	0.2	0.7	334	"?? -- ??"	
	12/30/89	WT 3063	24.34	0.94	1.1	339	"?? -- ??"	
SANTA YNEZ	1/28/89	YT 5004	26.38	0.69	0.7	306	"S -- ??"	
	2/3/89	YT 5007	2.94	0.13	0.9	166	"B -- SM"	
	2/9/89	YT 5008	6.22	0.16	2.1	159	"B -- SM"	
	5/4/89	YT 5029**	21.71	3.08	1.4	285	"S -- SY"	
	6/15/89	YT 5038**	16.63	2.36	1.5	270	"S -- SY"	
	6/21/89	YT 5039**	41.23	4.92	1.2	273	"S -- SY"	
	7/9/89	YT 5044	32.47	2.09	1.9	262	"S -- SY"	

STATION NAME	DATE	FILTER ID	Meas. PM/10	Meas. Tot. Si	Obs. Wndspd	Obs.Wndir	Monitor Clas.*	COMMENTS
			(ug/m3)	(ug/m3)	(m/s)	(DEG)	For the Day	
	7/15/89	YT 5045	29.22	2.44	2	258	"S -- SY"	
	7/21/89	YT 5046	41.63	3	1.3	243	"S -- SY"	
	9/7/89	YT 5059	27.01	2.47	1.7	300	"S -- SY"	
	9/13/89	YT 5060**	23.11	2.97	1	246	"S -- SY"	
	10/7/89	YT 5066**	20.07	2.57	0.9	244	"S -- SY"	
	11/6/89	YT 5074	32.87	1.37	0.7	273	"S -- SY"	
	12/12/89	YT 5082**	22.94	5.05	0.8	286	"S -- SY"	
	1/10/89	YT 5001	6.77	0.63	2.2	347	" ?? -- ??"	
	10/31/89	YT 5072	18.56	3.41	0.8	326	" ?? -- ??"	
	12/30/89	YT 5087**	21.17	3.16	1.1	339	" ?? -- ??"	
SANTA MARIA	2/27/89	MT 4011**	40.36	6.5	2.3	317	"B -- SM"	
	4/22/89	MT 4025**	25.8	5.82	4	297	"B -- SM"	
	5/4/89	MT 4029	32.76	3.72	3	274	"B -- SM"	
	5/22/89	MT 4032	23.31	3.8	2.6	288	"B -- SM"	
	5/28/89	MT 4033**	46.98	7.37	4.1	275	"B -- SM"	
	6/9/89	MT 4037**	39.14	3.87	3.6	282	"B -- SM"	
	6/15/89	MT 4038**	31.3	5.74	2.8	273	"B -- SM"	
	6/21/89	MT 4039**	66.17	5.92	1.7	284	"B -- SM"	
	7/3/89	MT 4043	39.23	3.8	2.1	282	"B -- SM"	
	10/19/89	MT 4068**	37.86	6.63	0.9	123	"S -- SM"	
	10/31/89	MT 4072**	28.82	4.61	1.2	116	"S -- SM"	
	11/18/89	MT 4076**	26.15	5.06	2.1	112	"S -- SM"	
	12/12/89	MT 4082**	25.06	4.07	2.3	113	"S -- SM"	
	12/18/89	MT 4083	36.73	3.74	1.9	109	"S -- SM"	

* -- Monitor data classification is based on aver. wind speeed and direction for the day. 'S' indicates that the site monitor is going is to be impacted by SOURCE(S) nearby, and 'B' indicates that the monitor data is intended to serve as BACKGROUND for estimated impact of nearby source(s). Acronyms 'SY' and 'SM' used with "S" and "B" stand for Sta.Ynez & Sta.Maria source(s).

** -- These filters contained significantly high levels of SILICA (from all sources, anthropogenic or otherwise)

Table 5.4 Comparison of Model-predicted and Observed Crystalline Silica Levels

STATION NAME	DATE	Obs. Wndspd	Obs.Wndir	Meas. PM/10	Pt.srce.Cry.Si	Ar.srce.PM/10	Ar.srce.Cr.Si*	Pred. Cry. Si	Meas. Cry.Si	COMMENTS
		(m/s)	(DEG)	(ug/m3)	pred.-(ug/m3)	pred.-(ug/m3)	pred.-(ug/m3)	(ug/m3)	(ug/m3)	
WATT ROAD	1/16/89	3.3	5	17.75	0				0.53	
	1/28/89	0.7	306	36.97	0				0	
	2/21/89	0.6	271	19.59	0				0.23	
	4/4/89	3.6	18	24.79	0				1.15	
	4/16/89	0.7	270	22.05	0.01				0	
	5/28/89	2.4	294	36.03	0				0	
	6/9/89	2.9	285	30.69	0				0	
	6/21/89	1.2	273	54.94	0				0	
	7/9/89	1.9	262	34.17	0				0	
	7/21/89	1.3	243	41.26	0.03				0	
	8/8/89	1.8	261	7.75	0				0.2	
	9/13/89	1	246	8.8	0.09				0	
	10/19/89	0.6	174	28.54	0.01				0.33	
	12/18/89	1	10	21.07	0.02				0.25	
	12/24/89	1	10	19.72	0				0.49	
	2/27/89	1.9	341	30.31	0				0.2	
	3/11/89	0.7	334	4.71	0.01				Dat. not available	
	12/30/89	1.1	339	24.34	0				0.2	
SANTA YNEZ	1/28/89	0.7	306	26.38	0.02	10.41	0.26	0.28	0	
	2/3/89	0.9	166	2.94	0	11.97	0.30	0.30	0	
	2/9/89	2.1	159	6.22	0	12.28	0.31	0.31	0	
	5/4/89	1.4	285	21.71	0.01	18.97	0.47	0.48	0.85	
	6/15/89	1.5	270	16.63	0.01	20.07	0.50	0.51	0.75	
	6/21/89	1.2	273	41.23	0.001	28.27	0.71	0.71	1.03	
	7/9/89	1.9	262	32.47	0	24.3	2.00	2.00	0.24	

	7/15/89	2	258	29.22	0	24.66	0.62	0.62	0.48	
	7/21/89	1.3	243	41.63	0	23.87	0.60	0.60	0.37	
	9/7/89	1.7	300	27.01	0	17.66	0.44	0.44	0.6	
	9/13/89	1	246	23.11	0	30.59	0.76	0.76	0.5	
	10/7/89	0.9	244	20.07	0	25.98	0.65	0.65	0.52	
	11/6/89	0.7	273	32.87	0.01	17.76	0.44	0.45	0.2	
	12/12/89	0.8	286	22.94	0	8.83	0.22	0.22	1.44	
	1/10/89	2.2	347	6.77	0	4.58	0.11	0.11	Dat.Not Available	
	10/31/89	0.8	326	18.56	0	8.65	0.22	0.22	1.17	
	12/30/89	1.1	339	21.17	0	13.18	0.33	0.33	1.1	
SANTA MARIA	2/27/89	2.3	317	40.36	0	35.41	2.24	2.24	2.46	
	4/22/89	4	297	25.8	0	38.88	2.46	2.46	3.46	
	5/4/89	3	274	32.76	0	37.02	2.34	2.34	2.01	
	5/22/89	2.6	288	23.31	0.01	33.46	2.11	2.12	Dat. not available	
	5/28/89	4.1	275	46.98	0	31.14	1.97	1.97	2.84	
	6/9/89	3.6	282	39.14	0	26.68	1.69	1.69	Dat. not available	
	6/15/89	2.8	273	31.3	0.001	39.29	2.48	2.48	2.34	
	6/21/89	1.7	284	66.17	0	55.06	3.48	3.48	2.27	
	7/3/89	2.1	282	39.23	0.19	50.05	3.16	3.35	1.52	
	10/19/89	0.9	123	37.86	0	26.33	1.66	1.66	2.88	
	10/31/89	1.2	116	28.82	0.04	16.92	1.07	1.11	2.01	
	11/18/89	2.1	112	26.15	0	15.14	0.96	0.96	2.37	
	12/12/89	2.3	113	25.06	0.02	17.23	1.09	1.11	1.75	
	12/18/89	1.9	109	36.73	0.02	24.01	1.52	1.54	1.17	

* -- Assumed : (1) the area source PM/10 emissions contain a fixed fraction of crystalline silica, and (2) this fraction equals the ratio of measured Cr.Si to measured PM/10 at the monitor (small sample)

-- For Santa Ynez monitor, measured (avergd) PM/10 = 23.0 and measured (avergd) Cry. Si. = 0.58, thus yielding a ratio = 0.025 for the days studied. For Santa Maria, it is = 0.063.

CHAP. VI ADVERSE HEALTH EFFECTS ESTIMATE

1. Health Risk Estimation

Health risks, i.e., the potential excess cancer risk and the potential non-cancer chronic and acute adverse health effects, are determined by the population exposure data, measured in terms of ambient air concentrations of crystalline silica at area-wide receptors. Procedures used in this study to determine the cancer and health risks strictly follow the guidelines[35] listed by the California regulatory agencies. For example, the potential maximum excess cancer risk is estimated by multiplying the projected annual concentration at the maximum impact point outside the plant boundary by the unit risk factor, developed by the regulatory agencies[36]. The populationwide excess cancer burden is estimated, if required, by reviewing a population sector (township, census tract or subarea) and multiplying the number of people in that sector with the estimated individual excess cancer risk for that sector. Finally, the chronic adverse health effects of crystalline silica is expressed in terms of a "Hazard Index (HI)." This index is obtained by comparing the estimated annual concentation level of cristobalite at the maximum impact point outside the plant boundary to a reference concentation (the acceptable annual exposure level for cristobalite).

Following the guidelines referenced above, ISCST model-predicted hourly and average annual ambient concentration of crystalline silica were directly input to a health risk assessment model. The model, Assessment of Chemical Exposure (ACE-2588), is recommended by the California agencies to assess health risks

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35 Risk Assessment Guidelines, (January, 1992), Prepared by the AB-2588 Risk Assessment Committee, California Air Pollution Control Officers Association (CAPCOA), Sacramento, CA.

36 These California Environmental Protection Agency (Cal-EPA) offices are -- Office of Environmental Health Hazard Assessment (OEHHA) and Air Resources Board (ARB).

from a particular toxic pollutant exposure. It computes health risks both due to inhalation and non-inhalation assimilations. However, this report did not estimate the non-inhalation assimilation route for crystalline silica, since the impact of the pollutant acknowledgedly[37] occurs via inhalation/respiration only.

2. Cancer Risk Analysis Parameters

Four different parameters are usually considered in presenting the excess cancer risk estimates. These are:

(a) Risks due to **inhalable** crystalline silica impact;

(b) Risks due to **respirable** crystalline silica impact;

(c) Estimates of individual maximum excess cancer risk; and,

(d) Estimates of population-wide excess cancer burden.

Each of these parameters is briefly described below.

(a) **Inhalable crystalline silica impact** -- Appendix I of the Risk Assessment Manual prepared by the California health agencies mandates that cancer risks be estimated for inhalable (10 μm MMAD or less) crystalline silica particles. The agencies feel that these particles will reach the bronchi and can penetrate the lower respiratory tracts (e.g., lung alveoli) to produce silicosis and cancer tumors. Hence, this study provides an estimate of the **inhalable** crystalline silica impact.

(b) **Respirable (Fine) crystalline silica impact** -- Researchers have pointed out that all carcinogenic impact of crystalline silica particulates have been demonstrated only for smaller-than respirable (3.5 μm MMAD or less) particles of the compound. They also point out that only smaller-than-respirable particles can

[37] Op.Cit., see Footnote 1 earlier.

physically penetrate the constricted lower respiratory tracts; and, larger inhalable particles are generally transported out of the larger bronchial tracts by physiological muco-ciliary reactions before they can settle there.

For a proper perspective, crystalline silica impact assessment needs to be performed for respirable particulates too. Unfortunately, information available (cf: Chapter V) allows us to estimate PM emissions only for "inhalable" (10 μm MMAD or less) or "fine" (2.5 μm MMAD or less) particulates. Therefore, for this study fine particulate emission inventory has been accepted as a surrogate for the "respirable" particulate emission inventory. Throughout this report, the term **respirable (fine)** crystalline silica emissions means fine particulate emissions.

(c) **Individual maximum excess cancer risk** -- The cancer risk analysis in this report considers the maximum ambient air concentration at a point outside the plant boundary and assesses the cancer risk to the hypothetical "maximally exposed individual (MEI)" at this site, based on listed risk factors. For each of the three sectors of the north county analyzed here, the MEI was found to be residing 1-5 km away from the existing receptors (residences, businesses, schools and hospitals). This translates to much lower ambient concentrations of crystalline silica at these receptors.

(d) **Population-wide excess cancer burden** -- Since the ambient air concentrations decreased steeply as the distance from the maximum impact location and the MEI increased, it was apparent that the product of the maximum individual excess cancer risk in an existing populated sector (conservatively assumed 100 in a million) and the number of people living in that sector (conservatively assumed 100) would be low (see also results discussions later). Hence, **population-wide excess cancer burden results are not computed in this**

report.

3. Excess Cancer Risks due to "Inhalable" Crystalline Silica

Maximum individual excess cancer risks were computed for CY 1989 (historical maximum year), using actual crystalline silica emissions data and for the inhalable (10 μm MMAD or less) particulates. Results for the three north county sectors and one south county sector are listed below arranged in the order of decreasing health risks.

Santa Maria sector -- The highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) is found to be 5,000 in a million, based on the higher risk factor of 2.9E-04/$(\mu g/m^3)^{-1}$. This level drops to 776 in a million if the alternate risk factor of 0.45E-04/$(\mu g/m^3)^{-1}$ is used. The projected location of the MEI is about 0.1 km from the Coast Rock/Union Asphalt plants' boundary. This close proximity impact results from the data that approximately 98 per cent of the emissions are fugitive in nature and 45 per cent of the ambient level contribution is generated by vehicular traffic. The excess cancer risk decreases to less than 100 (or 15, using lower risk factor) in a million at a distance of 1.5 to 5 km from the maximum impact spot (or the projected MEI location). The nearest residence from the MEI is located at Garey about 1.5 km away (excess cancer risk here about 100 or 15/million) and the nearest sensitive receptor (Blockman school) is about 3.5 km away (excess cancer risk here is about 15 or 2/million). Excess cancer risk isopleths are shown in Figure 6.1.

Lompoc Industrial Sector -- Highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) amounts to 438 in a million based on the higher risk factor, and to 68 in a million based on the alternate factor. The projected location of the MEI is about 1.5 km from the

Celite plant. The projected location is east-northeast of the strip mining area and the low-rising emissions are generated by mines traffic over unpaved roads: and,

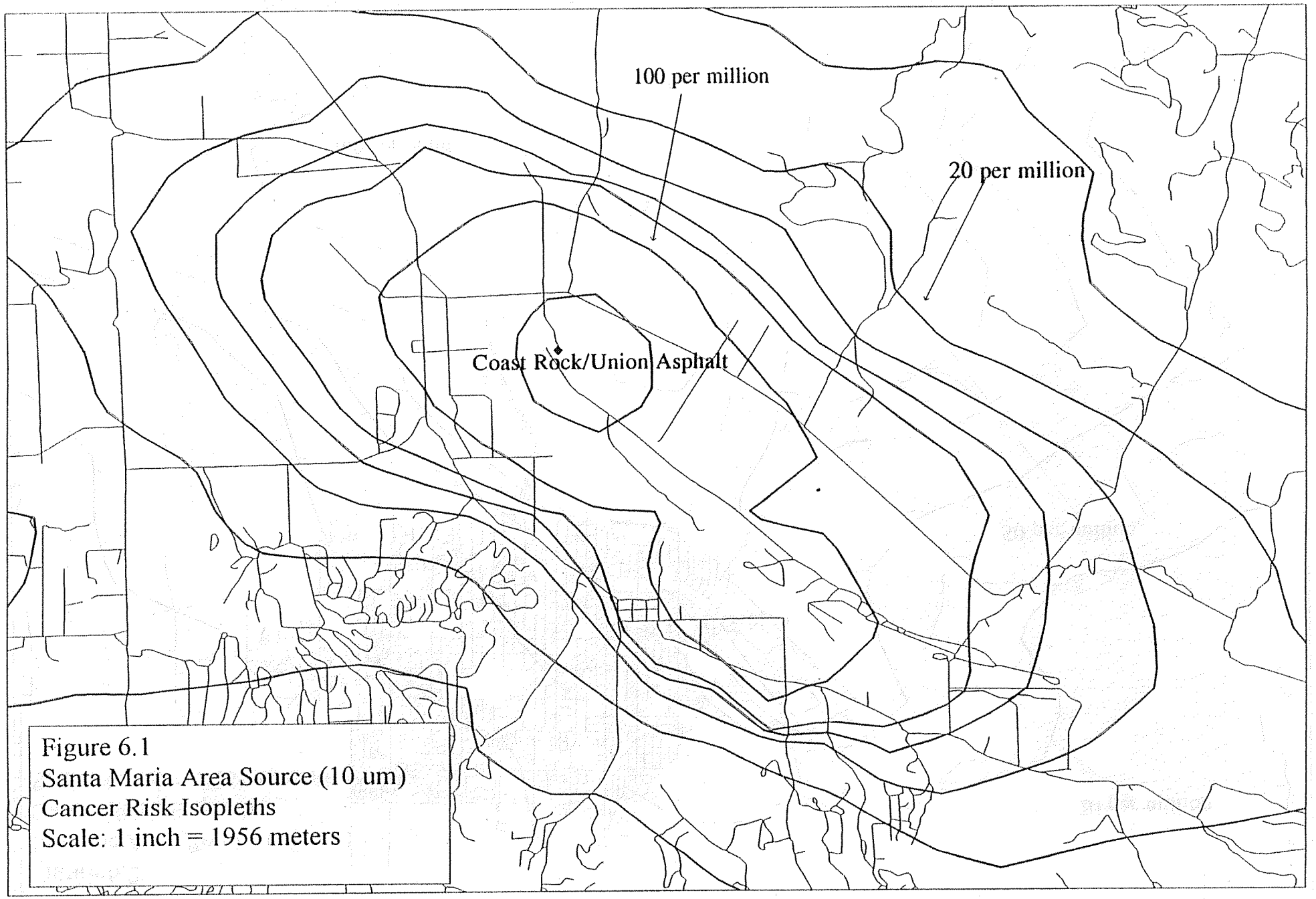

Figure 6.1
Santa Maria Area Source (10 um)
Cancer Risk Isopleths
Scale: 1 inch = 1956 meters

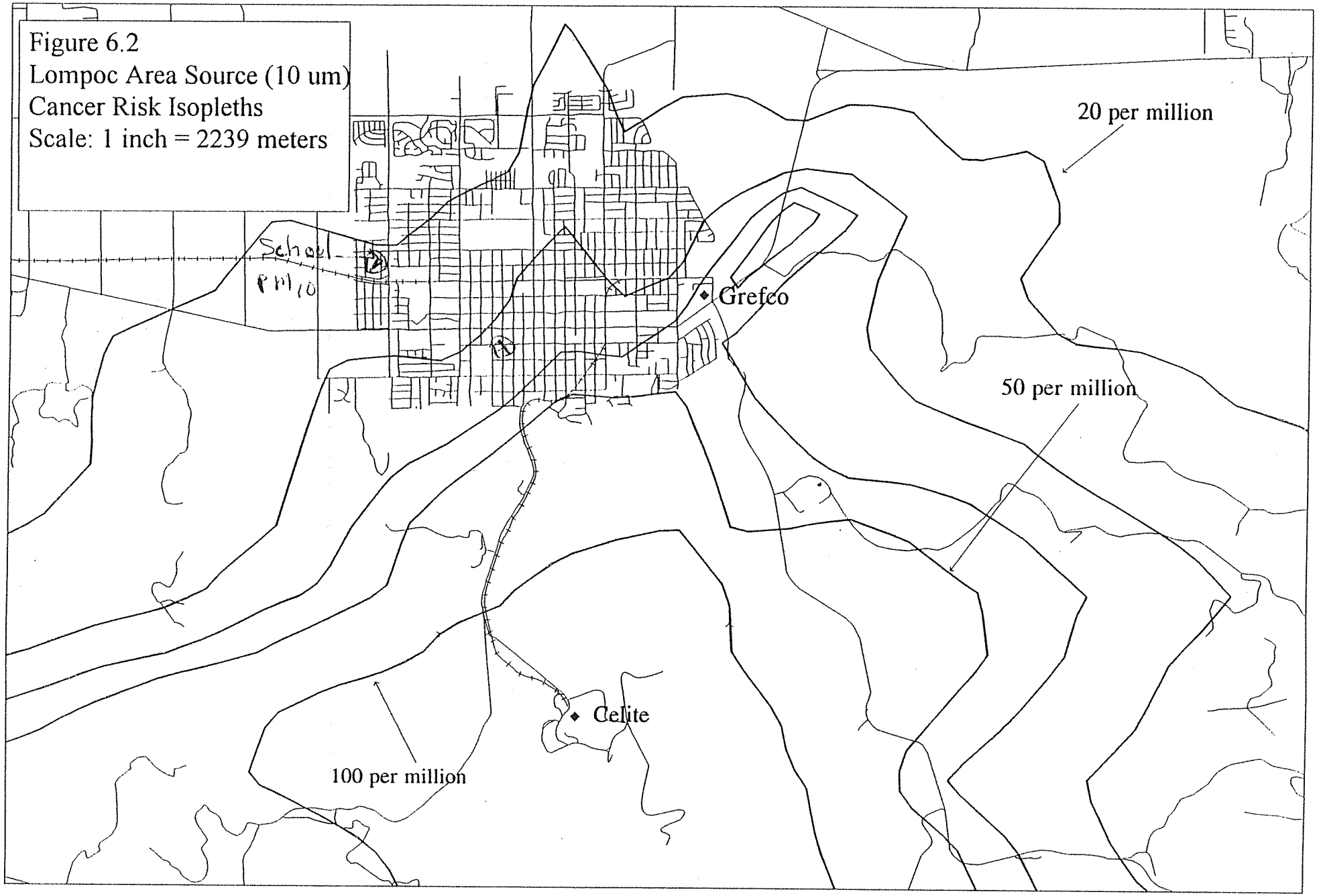
Figure 6.2
Lompoc Area Source (10 um)
Cancer Risk Isopleths
Scale: 1 inch = 2239 meters
20 per million
School
PM10
Grefco
50 per million
Celite
100 per million

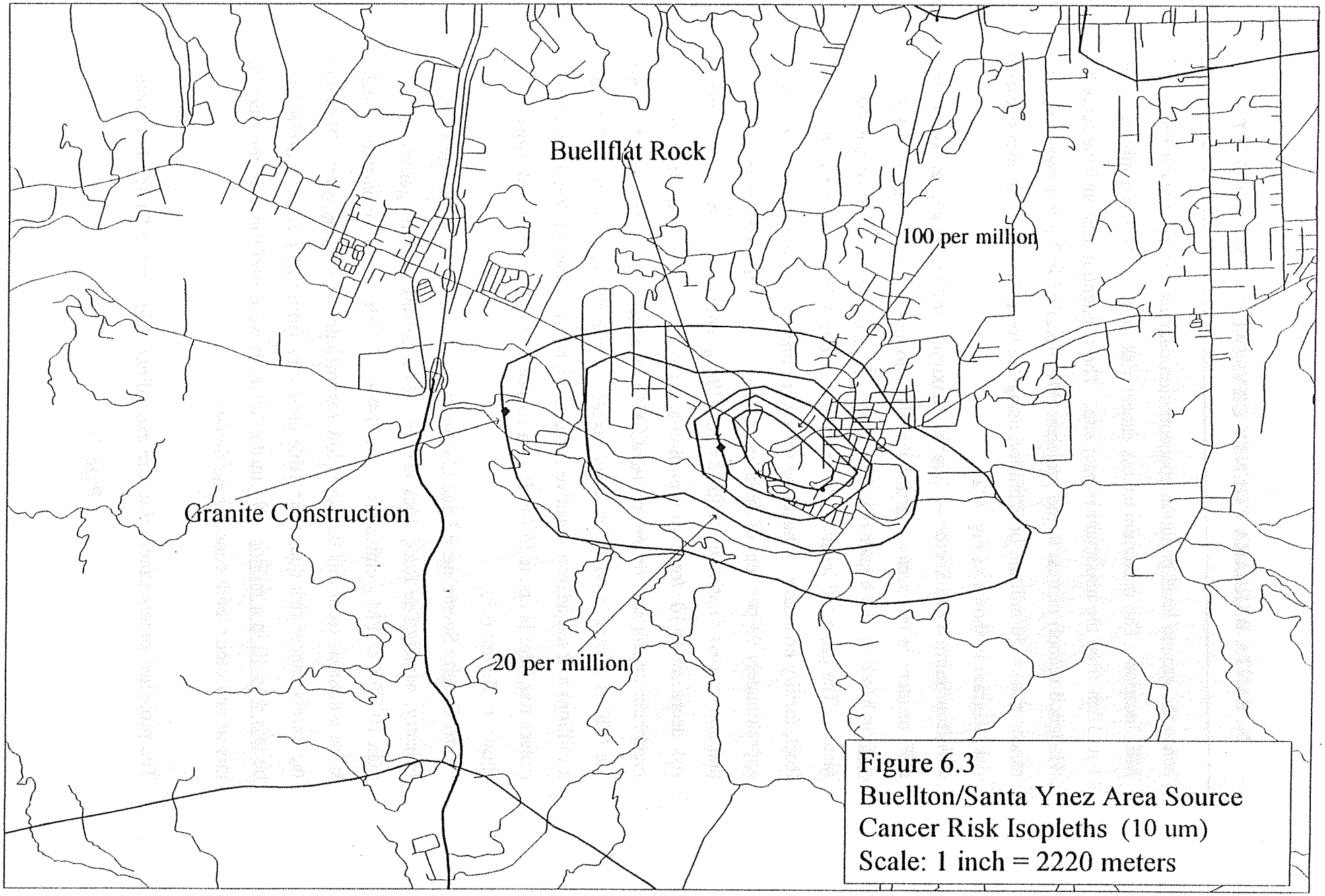

Figure 6.3
Buellton/Santa Ynez Area Source
Cancer Risk Isopleths (10 um)
Scale: 1 inch = 2220 meters

hence the ground level pollution concentration decreases steeply away from the MEI location. The maximum excess cancer risk drops to 100 in a million within 1 to 3 km from the maximum impact site. The residential area and the school (Hapgood school) nearest to the projected MEI location is 2.5 km away (excess cancer risk = 50/million, or 7/million using the lower factor). An excess cancer risk diagram is shown in Fig. 6.2.

Buellton/Santa Ynez Sector -- Highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) is estimated at 129 in a million based on the higher risk factor, and 20 in a million based on the lower factor. The projected location of the MEI is about 0.75 km from the BuellFlat Rock facility boundary. This close proximity impact results from the data that approximately 98 per cent of the ambient level contribution comes from process and non-process fugitive crystalline silica (PM_{10}) emissions. The excess cancer risk decreases to 10 (or 2) in a million at a distance of 1 to 5 km from the maximum impact spot or the projected MEI location. The nearest residence from the MEI is located about 1 km away (excess cancer risk here is about 20 (or 3) in a million) and the nearest sensitive receptor (school) is about 2 km away (excess cancer risk here is about 15 (or 2) in a million). Excess cancer risk isopleths are shown in Figure 6.3.

South County Sector near Lake Cachuma -- Only one south county zone industry, namely Bee Rock (rock and gravel processing) facility generated more than 10 TPY of PM_{10} emissions in CY 1989 (cf: Table 3.1). Inhalable crystalline silica emissions from this facility is low (estimatedly 86 pounds/year). Therefore, the excess cancer risk due to inhalable emissions from this facility is projected to be less than 10 in a million. No further analysis were performed in the study for this or any other south county zone facilities.

The projected excess cancer risks are exceedingly high in the Santa Maria sector.

In each of the other two north county sectors also the projected risk exceeds 100 in a million level. These estimated high levels can be traced to three factors, namely -- (a) the screening cancer risk value used in the study [$2.9 * 10^{-4}$/ $(\mu g/m^3)^{-1}$] may be too high; (b) the conservative emission factors from EPA's AP-42 used in this study overestimate the emissions; and, (c) the estimated crystalline silica fraction in the non-process fugitive emissions may actually be much lower. Thus, the results presented here need future verifications.

4. Excess Cancer Risk due to "Respirable (Fine)" Crystalline Silica

Maximum individual excess cancer risks were computed for CY 1989, using actual crystalline silica emissions data and for the fine (2.5 μm MMAD or less) particulates. This computation is important since fine particulate emissions were noted to be about 28 to 39 per cent of the inhalable emissions from the individual facilities, and thus the risks are proportionately lower. Results for the three north county sectors are listed below arranged in the order of decreasing excess cancer risks.

Santa Maria sector -- Highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) is found to be 1,724 in a million based on the higher risk factor, and 267 in a million based on the lower factor. The projected location of the MEI is about 0.1 km from the Coast Rock/Union Asphalt plants' boundary. The excess cancer risk decreases to 100 (or 15) in a million at a distance of 2 to 5 km from the maximum impact spot (projected MEI location). The nearest residence from the MEI is located about 1.5 km away (excess cancer risk here is about 40 (or 6) in a million) and the nearest sensitive receptor (Blockman school) is about 3.5 km away (excess cancer risk here is about 20 (or 3) in a million). An excess cancer risk isopleth diagram

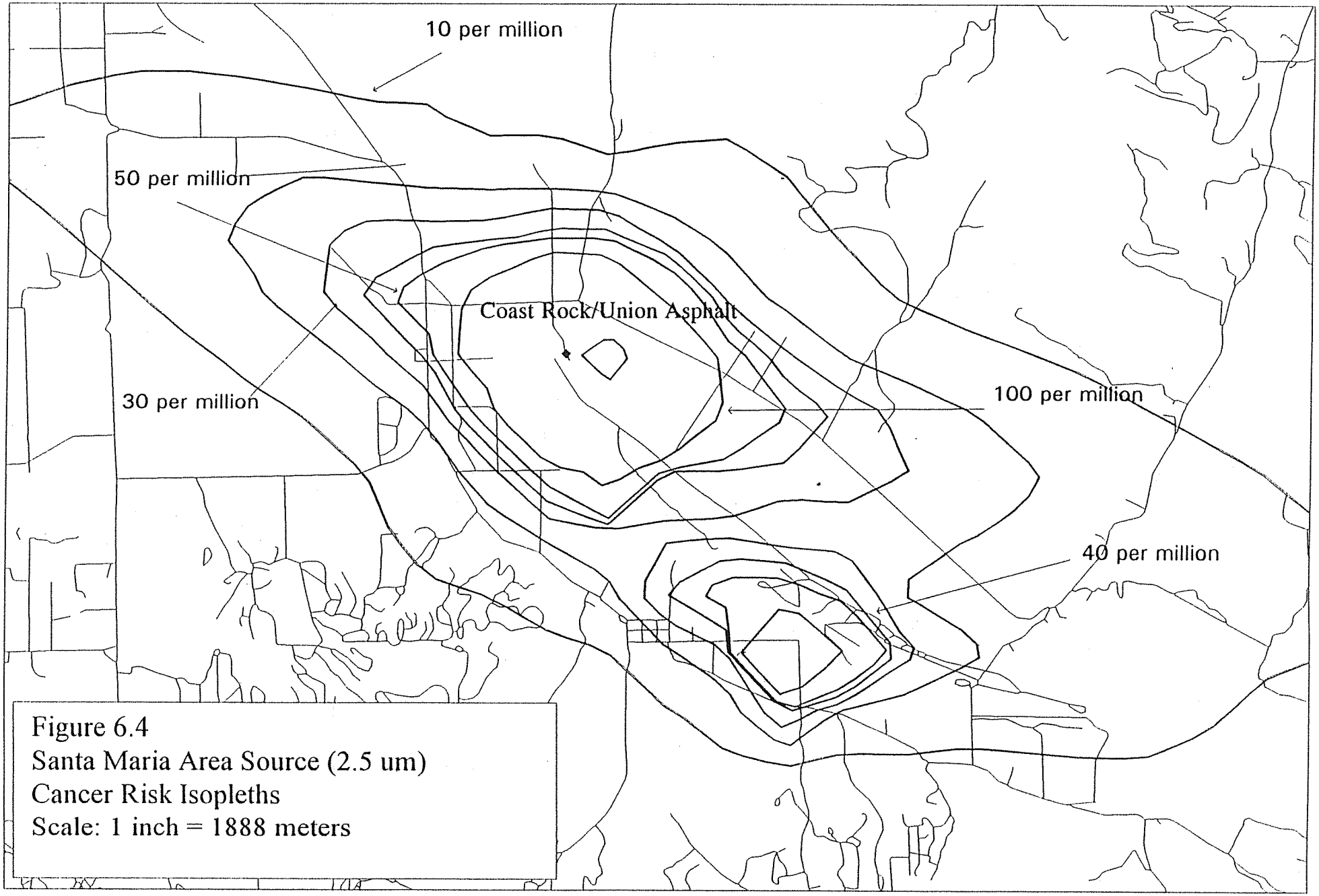

Figure 6.4
Santa Maria Area Source (2.5 um)
Cancer Risk Isopleths
Scale: 1 inch = 1888 meters

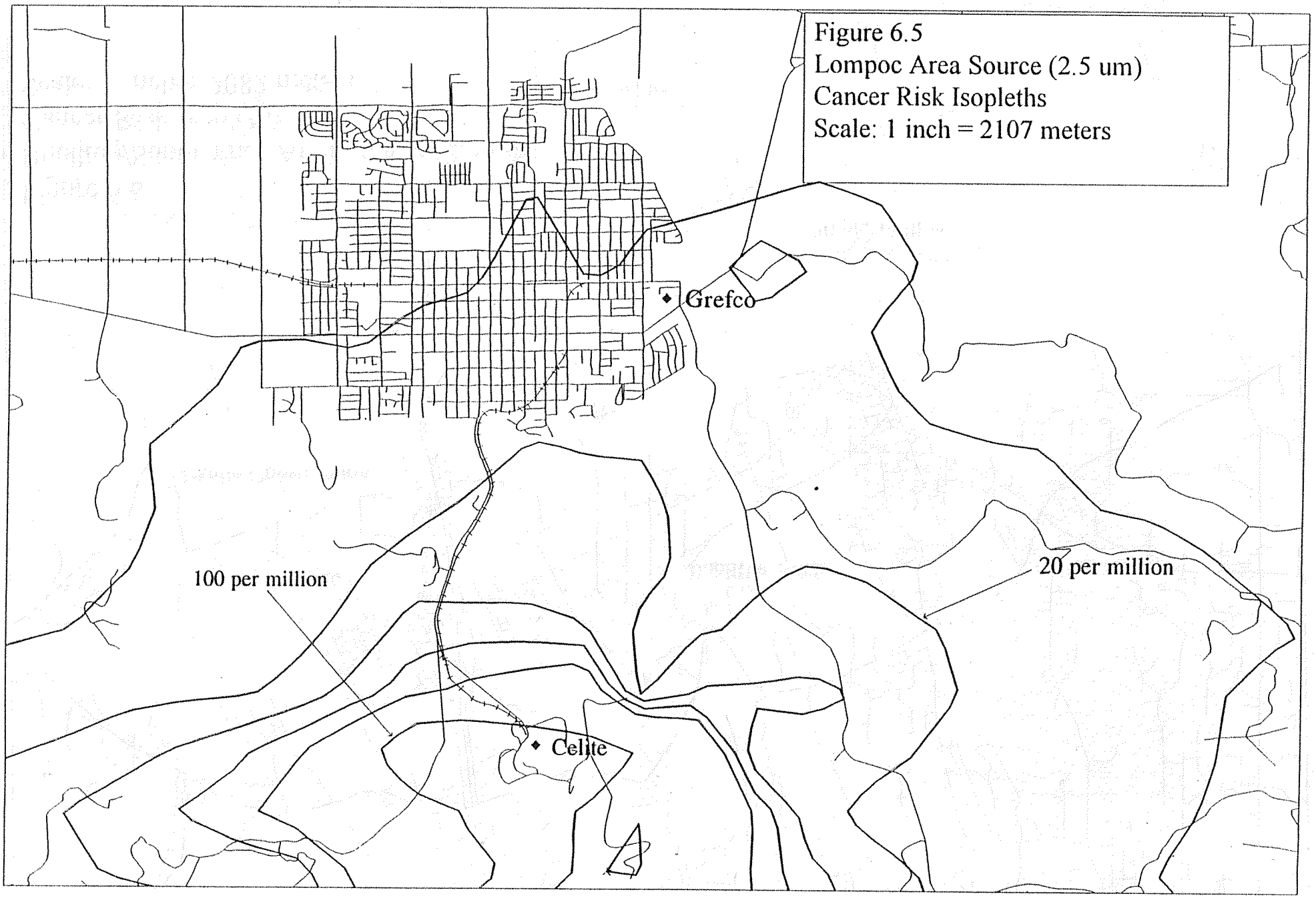
Figure 6.5
Lompoc Area Source (2.5 um)
Cancer Risk Isopleths
Scale: 1 inch = 2107 meters
Grefco
100 per million
20 per million
Celite

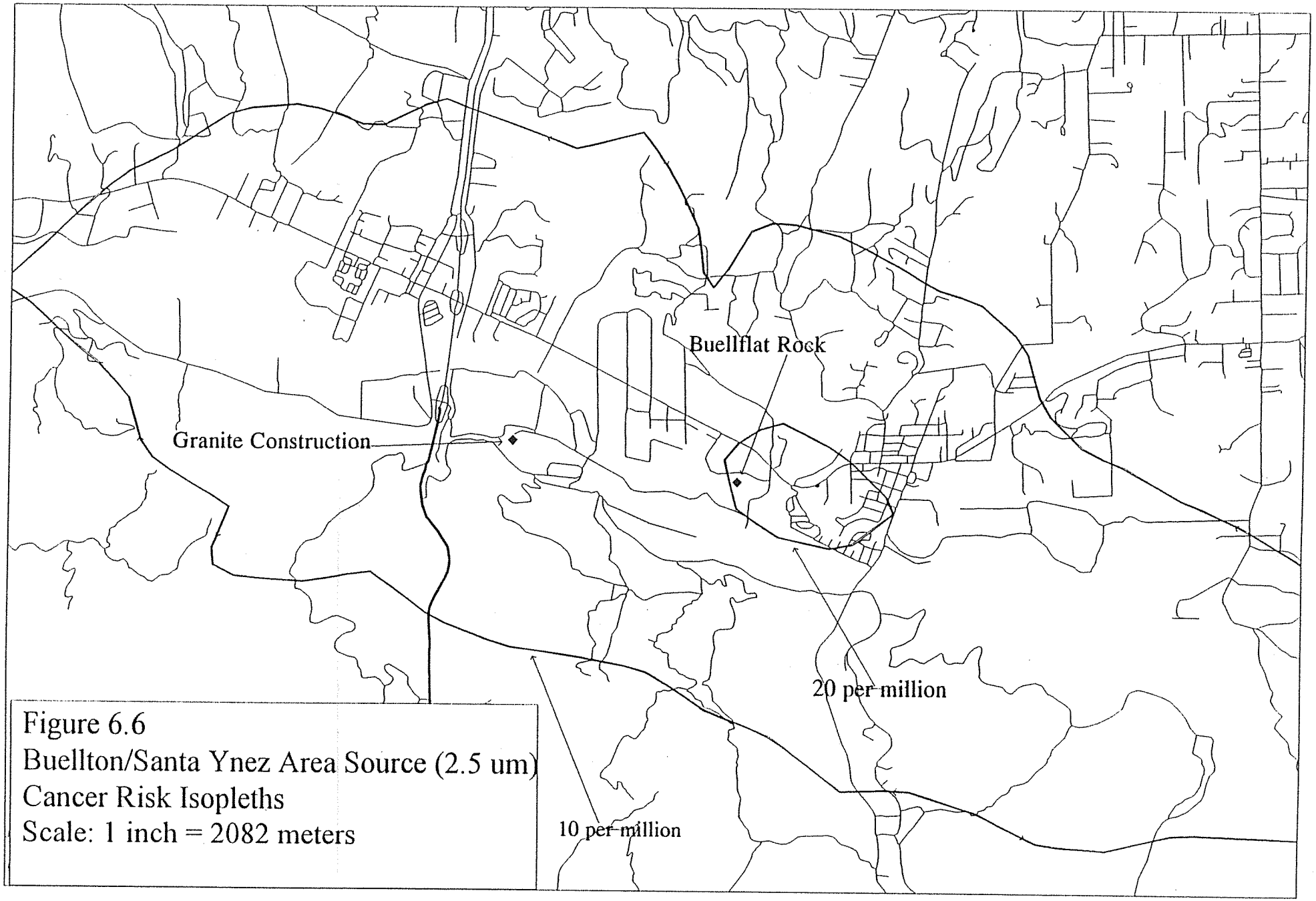

Figure 6.6
Buellton/Santa Ynez Area Source (2.5 um)
Cancer Risk Isopleths
Scale: 1 inch = 2082 meters

is presented in Figure 6.4.

Lompoc Industrial Sector -- Highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) amounts to 191 in a million based on the higher risk factor and 30 in a million based on the alternate risk factor. The projected location of the MEI is about 0.2 km from the Celite plant. The maximum excess cancer risk drops to 100 in a million within 0.2 to 2 km from the maximum impact site. The residential area and the school (Hapgood school) nearest to the projected MEI location is about 3.5 km away (excess cancer risk is about 20 (or 3) in a million). An excess cancer risk diagram is presented in Fig. 6.5.

Buellton/Santa Ynez Sector -- Highest maximum individual cancer risk to the MEI resident in this sector (outside the plant boundaries) is estimated at 37 in a million based on the higher risk factor and 6 in a million based on the lower risk factor. The projected location of the MEI is about 0.75 km from the BuelFlat Rock facility boundary. The excess cancer risk decreases to 10 (or 2) in a million at a distance of 1.5 to 5.5 km from the maximum impact spot (projected MEI location). The nearest residence from the MEI is located about 1 km away (excess cancer risk here is about 20 (or 3) in a million) and the nearest sensitive receptor (school) is about 1.5 km away (excess cancer risk here is 15 (or 2) in a million). An excess cancer risk isopleth diagram is presented in Figure 6.6.

Once again, the projected excess cancer risks are exceedingly high in the Santa Maria sector. In another north county sector (Lompoc industrial sector) also, the projected risk exceeds 100 in a million level. These estimated high levels can also be traced to the three factors discussed earlier for inhalable particulates impact.

5. **Non-cancer Chronic Adverse Health Effects**

Crystalline silica is not known to cause any non-cancer **acute** (adverse) health effects. Regulatory guidelines[38] indicate the possibility of non-cancer **chronic** (adverse) health effects only. They also list an acceptable chronic (i.e., annual) exposure level of 1.2 $\mu g/m^3$ of cristobalite only. Hence, the study focussed on the chronic health effects of crystalline silica in the north county zone. The **chronic adverse** health effect is expressed in terms of a "**hazard index (HI).**" The index is computed based on the projected annual ambient concentrations at any receptor of cristobalite divided by the acceptable exposure level of 1.2 $\mu g/m^3$ (based on exposure to **cristobalite only**). The projected **maximum** hazard index for the different areas at their MEI locations are listed below.

Inhalable Particulate Emissions Effect

Santa Maria Area -- For the Santa Maria area, the maximum hazard index at the MEI location is initially model-computed to be 14.37. However, this value is computed on the assumption that all emissions of crystalline silica occurs as cristobalite. In reality, the cristobalite emissions from the contributing facilities amounted to about 1/20th of the total emissions (see Coast Rock emissions data in Appendix B). **Therefore, the actual maximum hazard index for this MEI location is 14.37/20, or, about 0.72.** The index drops to below 0.1 within 1 km of the MEI location.

Lompoc Area -- In Lompoc area, the initially computed maximum hazard index at the MEI location is 1.26. **Once again, the cristobalite fraction is only about half of the total emissions (see Celite emissions data in Appendix B); and, thus the actual maximum hazard index is 1.26*0.52, or about 0.66.** The value decreases to less than 0.25 within 2 km of the Celite plant boundary.

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[38] Ibid.

Buellton/Santa Ynez Area -- In Buellton/Santa Ynez area, the initial model-computed maximum hazard index is 0.37, assuming the entire emissions to be cristobalite only. Since the BuellFlat Rock emissions show (see Appendix B) that the ratio of cristobalite-to-crystalline silica is about 1/20, **the actual index is 0.37/20, or, about 0.02**. The index decreases to 0.001 within 1 to 2 km of the MEI location.

Respirable/Fine Particulate Emissions Effect

Santa Maria Area -- For the Santa Maria area, the maximum hazard index at the MEI location translates to 0.25. The index drops to below 0.1 within 1.5 km of the MEI location.

Lompoc Area -- In Lompoc area, the adjusted worst hazard index at the MEI location is 0.25 and this value decreases to less than 0.1 within 1.5 km of the Celite plant boundary.

Buellton/Santa Ynez Area -- Finally, in Buellton/Santa Ynez area the final adjusted maximum index is 0.01 which decreases to 0.001 within 1 to 2 km of the MEI location.

In summary, the hazard index remains well below the health standard level of 1.0 in all residential areas and well below 0.5 at sensitive locations such as schools and hospitals for all three locations reviewed in this report. Thus, **the chronic adverse health effects** due to crystalline silica emissions in the north County may be assumed to be **negligible**.

CHAP. VII CONCLUSIONS AND RECOMMENDATIONS

1. Summary Findings

Findings of this study are restricted to three different areas, as follows:

(a) Crystalline silica emissions in the north county zone;

(b) Projected and observed crystalline silica levels in north county; and,

(c) Estimated adverse health effects of crystalline silica in north county.

Prior to this study, air quality management data were not available in either of the three sectors for any decision-making by the county regulatory agencies. Summary findings for all the three areas will attempt to provide inputs in that respect.

2. Basic Summary

A. Crystalline Silica Emissions in north County

Estimated **inhalable** crystalline silica emissions in the north county zone exceed 104 tons annually. Approximately 73 per cent of the emissions are generated by process operations, and about 23 per cent of the process operation emissions do not exhaust through a PM control device. Also, most of the non-process operations emit fugitive emissions (27 per cent of total) including dust from unpaved road traffic or from storage pile erosion.

Total **respirable/fine** crystalline silica emissions are estimated to be about 28 tons annually, i.e., about 27 per cent of total **inhalable** emissions. Point source emissions (15 TPY) comprise nearly 54 per cent of total emissions. These emissions consist mainly of controlled emissions (often using baghouse etc., to reduce emissions by 98 per cent or more). Annual fugitive emissions (process and

non-process) amount to about 13 tons. Most of these (about 70 per cent) occur just outside of Santa Maria, and a significant fraction of these emission can be attributed to storage pile dust and road dust generated by industrial traffic.

B. Population Exposure

Projected Inhalable Emissions Exposure -- Fugitive process emissions and industrial vehicular traffic emissions at plant sites were significant for all the rock and gravel processing facilities. One of these projected high ambient concentrations (about 17 $\mu g/m^3$) of crystalline silica at or just beyond the plant boundaries. The two diatomaceous facilities also projected about 1.5 $\mu g/m^3$ levels of the toxic substance at about 1.5 km from the plant sites, mainly caused by the low-level dust generation by the mining traffic. The exposure levels declined steeply from the point of estimated maximum impact. Since all the industrial facilities were located at considerable distances away from the central business districts and sensitive receptors, the estimated impact of the industrial emissions at these key locations were often below the ACGIH/NIOSH stipulated "permitted exposure levels (PEL)" and in some cases even below the "1-in-a million excess cancer risk" levels.

Projected Fine/Respirable Emissions Exposure -- Fugitive process emissions at plant sites were significant for rock and gravel processing facilities. High ambient concentrations (5.9 $\mu g/m^3$ annually) of crystalline silica were predicted just beyond the plant boundary for one facility. Respirable emissions from the two diatomaceous facilities resulted in an estimated annual concentration of 0.7 $\mu g/m^3$ of crystalline silica at about 0.5-1 km from the plant boundaries. These exposure levels declined steeply from the point of estimated maximum impact. For all sectors, the estimated impact of the industrial emissions at key/sensitive locations

(e.g., schools and hospitals) were mostly below the ACGIH/NIOSH stipulated "permitted exposure levels (PEL)." In general, the respirable particulate exposures were below the "1-in-a million excess cancer risk" levels.

Actual Observed PM_{10} Monitor Data -- Review of PM_{10} monitor data and extracted crystalline silica data at these samplers yields an interesting composite outline. First, the monitors do not seem to be affected by the emissions from the relatively distant industrial facilities. On the other hand, the monitors may be significantly affected by re-entrained dust plumes from road traffic. Overall, the data base available is not comprehensive, and does not provide any conclusive evidence of deleterious ambient levels of crystalline silica at the monitors studied.

C. Adverse Health Effects

Inhalable Emissions -- In Santa Maria sector, the highest individual cancer risk to the MEI resident is estimated to be 5,000 (or 776) in a million. The projected location of the MEI is about 0.1 km from the Coast Rock/Union Asphalt plants' boundary. In the Lompoc sector, predicted maximum individual cancer risk to the MEI resident amounts to 438 (or 68) in a million. The projected location of the MEI is about 1.5 km from the Celite plant. In Buellton/Santa Ynez sector, the maximum individual cancer risk to the MEI resident is estimated at 129 (or 20) in a million. The projected location of the MEI is about 0.75 km from the BuellFlat Rock facility boundary.

Respirable/Fine Emissions -- In Santa Maria area, the estimated maximum individual cancer risk to the MEI resident drops to 1,701 (or 267) in a million. The projected location of the MEI is about 0.1 km from the Coast Rock/Union Asphalt plants' boundary. In Lompoc area, the highest individual cancer risk to

the MEI resident amounts to 191 (or 30) in a million. The projected location of the MEI is about 0.2 km from the Celite plant. In Buellton/Santa Ynez, the maximum individual cancer risk to the MEI resident is estimated at 37 (or 6) in a million. The projected location of the MEI is about 1 km from the BuellFlat Rock facility boundary.

Hazard Index -- The hazard index at all locations, including the MEI location, computes to less than 0.5, compared to the health standard allowable maximum index of 1.0. Thus the chronic adverse health effects may be assumed to be negligible.

3. Analytical Discussion of Summary

(a) **Emissions Inventory** -- The compilation of emission inventory uncovered four potential limitations. First, compilation of an accurate emission inventory for all crystalline silica sources requires vast resources and, thus, is not practically feasible. The solution was to address only the significant industrial sources. Second, the $PM_{2.5}$ and PM_{10} emission factors for the industry source categories involved, e.g., rock and gravel processing, were based on limited studies. Also, most of the EPA emission factor studies focussed on limestone or phosphate rock processing whereas the Santa Barbara county plants processed mainly granite rocks and diatomaceous earth. Thus, a number of PM emission computations are tentative, particularly for respirable dust emissions. Finally, fugitive crystalline silica emission computation for industry sources was often based on the assumption that the fraction of the crystalline silica present in the process line grab sample accurately represented the actual fraction of crystalline silica present in all fugitive emissions. This is very plausible, but could not be conclusively proved. Thus a good possibility exists that this assumption may have led to a significant

ovrestimation of some of the fugitive emissions, e.g., traffic-generated emissions at plant sites. Interestingly, the industry operators agreed with this District assumption; and, did not provide additional data that could refute or confirm this assumption when requested to do so.

(b) Population Exposure -- Two different types of results related to population exposure to ambient crystalline silica are reviewed in this study. First, the ambient monitor data for "inhalable" crystalline silica indicates that reentrainment can be a major factor in causing discernible (though not deleterious) ambient crystalline silica impact. It also shows a need to obtain a more comprehensive data base for ambient crystalline silica levels near major industrial sources. Next, computer projections show that the ambient impact caused by industrial emissions of "inhalable" crystalline silica can be significant, albeit in remote non-residential (and non-inhabited) areas. Even, if the results for "total" or "inhalable" particulates are ignored based on the inability of these particulates to penetrate the lung, the projections for the "respirable" particulates point to the need of establishing $PM_{10}/PM_{2.5}$ monitors in Santa Maria and Lompoc areas.

(c) Adverse Health Effects -- Computations of adverse health effects are based on projected population exposure to respirable crystalline silica, and not on actual observed ambient levels. Since both the air quality and the health effect models are health-wise "conservative", the projections may be over-amplified.
For example, the tentative "cancer risk factor" listed by California health agencies as a "screening factor" only for use in health effect models (and used in this study for lack of any other useable factor) may have caused high predictions. Health officials at the state and federal levels are currently working to obtain a substantiable "cancer risk factor" for crystalline silica, and are expected to provide some data before the end of this year (1993). It is suggested that no definitive

cancer risk conclusions be drawn from results of this study until the health scientists finally decide on the numerical value for the cancer risk factor. If an accepted value of the cancer risk factor becomes available soon, then this study results should be revisited for a final strategy decision. The health risk effects are summarized in the table below:

"Inhalable" Emissions

Receptor Type	Santa Maria Area		Lompoc Area		Buellton Area	
	Cancer Risk*10^{-6}	Hazard Index	Cancer Risk*10^{-6}	Hazard Index	Cancer Risk*10^{-6}	Hazard Index
MEI	5000/776	0.72	438/68	0.66	129/20	0.02
Residence	100/15	<0.1	50/7	<0.25	20/3	<0.001
Sensitive	15/2	<0.1	50/7	<0.25	15/2	<0.001

* -- High/low values, based on risk potency values

Respirable ("Fine") Emissions

Receptor Type	Santa Maria Area		Lompoc Area		Buellton Area	
	Cancer Risk*10^{-6}	Hazard Index	Cancer Risk*10^{-6}	Hazard Index	Cancer Risk*10^{-6}	Hazard Index
MEI	1724/267	0.25	191/30	0.25	37/6	0.01
Residence	40/6	<0.1	20/3	<0.1	20/3	<0.001
Sensitive	20/3	<0.1	20/3	<0.1	15/2	<0.001

* -- High/low values, based on risk potency values

(d) Regulatory Impact -- The industrial sources addressed in this study annually

emitted about 500 tons of PM_{10} (and 104 tons of inhalable crystalline silica). If, (i) this figure is compared to a annual county-wide primary PM_{10} emissions of about 18,600 tons; and, (ii) it is assumed based on monitored PM_{10} data review that the rest of the sources do not contribute significantly to north county crystalline silica impact, then, it is apparent that only a small fraction of PM_{10} sources contributes to the north county crystalline silica burden. **Thus, instead of a county-wide PM emissions reduction strategy, source-specific emission reduction measures need to be considered.**

4. Recommendations

The following "contingent" steps are recommended based on this study:

A. In future, if health scientists project a crystalline silica "cancer risk factor," then the data compiled for this study be revisited for a final analysis.

B. Estimates of crystalline silica fraction in the fugitive PM emissions should be improved through multiple, actual on-site sampling process, particularly for secondary emissions such as traffic-generated emissions.

C. Ambient monitoring data for crystalline silica would be helpful along with any source-specific data obtained for non-process fugitive emissions. We suggest that future studies should consider setting up suitable PM_{10} and dichotomous samplers within 1 km or less from **major** industrial sources to better assess the $PM_{10}/PM_{2.5}$/crystalline silica emission factors.

D. Any future PM_{10}/crystalline silica regulatory strategy should pursue source-specific emission reduction conditions rather than county-wide emission reduction measures.