ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 1991 - December 31, 1991

PROJECT TITLE: Morphological characterization of particulate matter emission from open burning of rice straw

PROJECT LEADER AND PRINCIPAL UC INVESTIGATORS:
B.M. Jenkins, Associate Professor
Agricultural Engineering Department
University of California, Davis

S.Q. Turn, Graduate Research Assistant
R.B. Williams, Graduate Research Assistant
Agricultural Engineering Department
University of California, Davis

COOPERATORS:
W. John
D. Scales
Air and Industrial Hygiene Laboratory (AIHL),
Department of Health Services, Berkeley, California

J. Paskind
J. McCormack
Air Resources Board, Sacramento, California

J.F. Williams, Farm Advisor, Sutter/Yuba Counties
S.C. Scardaci, Farm Advisor, Colusa County

LEVEL OF 1991 FUNDING: $19,275

OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES

1. Determine emission factor for biogenic silica fiber emitted during field burning of rice straw.

Laboratory experiments were conducted in the UC Davis combustion wind tunnel to determine the number of fibers emitted per unit mass of straw burned. As part of this objective, and the other objectives of the study, analytical protocols were developed by staff of the Air and Industrial Hygiene Laboratory (AIHL), Department of Health Services, for preparing filter samples and identifying fiber particles by transmission electron microscopy (TEM). No such protocol previously existed for biogenic silica fiber.

2. Perform area sampling for biogenic silica fiber emitted from field burning.

Field samples were collected from various locations during field burning of rice straw. These samples were used to qualitatively evaluate the wind tunnel results, and to assess the nature of other particulate matter emitted during field burns.

3. Collect ambient air samples from municipal areas in the Sacramento Valley on rice straw burn days.

Air samples were collected from a number of towns and cities throughout the lower Sacramento Valley during rice straw burning episodes. The purpose of collecting these samples was to investigate the potential exposure to biogenic silica fibers in more populous regions.

4. Perform area sampling in cooperation with other UC researchers for biogenic silica fiber emitted from rice harvesting operations.

Air samples were collected at the downwind field edge to compare with samples collected on equipment operators during rice harvesting.

SUMMARY OF 1991 RESEARCH BY OBJECTIVE:

Objective 1: Wind Tunnel Studies

Burning trials were conducted using the UC Davis combustion wind tunnel. This wind tunnel incorporates a unique fuel transport system which permits extended sampling, and was originally developed to obtain emission factors for pollutant species from a number of different crop and forest residues, including rice straw. Because fuel and air inlet conditions are controlled and known, the emission factor can be determined by direct mass balance, unlike the field where element balances (normally carbon balances) are necessary to estimate fuel consumption. Because of the large uncertainty in the element balances, field determined emission factors are normally subject to large errors.

Wind tunnel samples were initially collected during the first year of the project (1990) as shown in Table 1. These samples, coupled with early field samples (also shown in Table 1), were used by staff of the AIHL to develop the analytical protocol necessary to perform fiber counts by TEM analysis. Paired samples of 25 mm diameter 0.4 μm (1 μm = 0.00004 inch approximately) polycarbonate and cellulose ester filter cassettes were collected and delivered to AIHL to assess the quality of direct and indirect analytical methods for obtaining fiber counts. The direct method was preferred because it avoided potential loss of particles and potential contamination of samples, but required lightly loaded filter samples, which for the wind tunnel and many of the field samples led to poorer counting statistics and wider confidence intervals. A fibers was considered to be any particle with a length to diameter ratio, or aspect ratio, of three to one or greater. On wind tunnel samples, AIHL found two classes of particles, identified as class I and II particles in Table 2. Biogenic silica fibers were included under class II, and were either amorphous or crystalline, but most often amorphous. Wind tunnel samples were fairly heavily loaded with class I particles--small crystalline KCl particles. The source of these particles is not yet known, but is believed to be the straw itself, which contains high concentrations of K and Cl. Other sources, such as molds and fungi, may also contribute. Two other classes of particles, identified as class III and IV particles in Table 2, were not found in the wind tunnel samples, but were found in field samples as discussed later.

During 1991, following development of the preliminary analytical protocol, additional wind tunnel samples were collected (Table 1) and analyzed. Four of these samples were taken on 47 mm diameter 0.4 μm polycarbonate Nuclepore filters using a standard EPA/ARB method 17 in-stack sampling procedure at the wind tunnel stack. Total sample volumes were 2, 4, 10 and 100 L. A range of volumes was taken to test effects of filter loading. Silica fiber counts are shown in Table 4 for these four samples, identified by accession numbers UCRRB60 - 63. The 100 L sample was overloaded with total particulate, and could not be analyzed by the direct method. The 2, 4, and 10 L samples were analyzed. An additional sixteen samples taken at this time were collected on 3 mm TEM grids (effective sample diameter of 2.03 mm) using a point-to-plane electrostatic precipitator. Samples were collected from the flame region as well as from the stack.

Filters were prepared for TEM analysis by coating with carbon. Five pieces, each 3 mm x 3 mm were placed carbon-side up on 200-mesh copper grids, placed on filter paper in a Jaffe solvent washer and cleared in chloroform for 72 hours. The grid opening area was determined using a light microscope interfaced to a Kevex Delta Class Analyzer and running Kevex feature analysis software. The mean area from thirty grid openings was used to determine the number of grid openings to be scanned to maintain required sensitivity. Typical grid opening areas were in the neighborhood of 0.009 mm^2. Grids were scanned at 35,000X magnification using a Hitachi H-600/H-6010A microscope operated in transmitted electron image mode (TEM) viewed on a fluorescent screen. When a fiber (any particle of 3:1 aspect ratio or greater) was encountered, the microscope was switched to electron diffraction mode and the presence or absence of Bragg reflections was noted. The electron diffraction mode was used to determine whether the particle was amorphous or crystalline. The microscope was then switched to scanning transmitted electron mode (STEM) with the magnification set at 20,000X to record the approximate length and width of the particle. Particles were counted into two size categories separated at 5 μm length. A Kevex analyzer was used to acquire an x-ray fluorescence spectrum from which the elemental composition of the particle was obtained. Fiber concentrations were determined from the grid area scanned, the effective area of the filter, and the sample volume.

Confidence intervals (95%) were computed using a Poisson distribution. Because sample volumes for the wind tunnel samples were required to be small to avoid overloading, the confidence intervals were fairly wide.

For the three filter samples analyzed (UCRRB61-63), a total of two silica fibers were found. There were no fibers found on the 10 L filter, 1 fiber greater than 5 μm in length found on the 4 L filter, and 1 fiber less than 5 μm length on the 2 L filter. Computed fiber concentrations are shown along with the 95% confidence intervals in Table 4. There were no class III alumina-silicate fibers found (Table 5). The single fiber on each of the 2 and 4 L samples translates into a fiber concentration of 3 - 5 x 10^6 per cubic meter of stack gas. The confidence intervals yield a concentration range of 0.68 x 10^5 to 1.49 x 10^7 m^{-3} for the 4 L sample, and 1.36 x 10^5 to 2.98 x 10^7 m^{-3} for the 2 L sample. The null count on the 10 L sample does not necessarily imply a true zero concentration, as the confidence intervals are also quite wide. The particles were irregular in shape, and did not exhibit the straight, parallel sided morphology of mineral fibers.

Results for the electrostatic precipitator grids are given in Table 6. Three of the samples collected from the flame itself were overloaded and could not be analyzed. Another grid was lost in shipping and was not analyzed. Three fibers were found on the sample collected from the inlet flow ahead of the fire. These fibers would have originated from the fuel bed upstream of the sampling probe. Their presence indicates the potential for wind induced entrainment of silica fibers from rice straw alone. The presence of fibers in the upstream flow also indicates a background source of fibers independent of any combustion, although only one sample was analyzed. Samples collected from the flame were heavily coated with soot, and most could not be analyzed for this reason. Fibers were detected on samples collected immediately downstream and behind the flame, as well as in the flow above the flame tip. Two fibers were found on each of two samples taken from the stack. Under the conceivably poor assumption that all fibers in the sample flow were collected on the grids, the two stack samples yield stack fiber concentrations of approximately 2 x 10^5 m^{-3}, which is an order of magnitude lower than indicated by the filter samples. The assumption of complete fiber capture by the electrostatic precipitator is likely erroneous, and computed fiber concentrations would therefore be expected to be lower than those derived from filter samples. The total sample volumes for the electrostatic precipitator samples were also lower than for the filter samples, which may be reflected in the difference in concentrations.

An emission factor for silica fiber (class II fibers) was estimated from the wind tunnel results. The stack gas volume flow rate was 3.27 m^3-s^{-1} (6,928 cfm) at a fuel consumption rate of 6.25 g-s^{-1} (49.6 lb-h^{-1}) yielding a stack flow of 0.52 m^3-g^{-1} (8,380 ft^3-lb^{-1})of fuel burned. For a fiber concentration range of 2 x 10^5 to 5 x 10^6 m^{-3} (5,660 to 141,600 ft^{-3}) the emission factor ranges from approximately 1 x 10^5 to 2.6 x 10^6 fibers-g^{-1} (4.7 x 10^7 to 1.2 x 10^9 fibers-lb^{-1}) of straw. The 95% confidence intervals range from 10^4 to 10^7 fibers g^{-1}, indicating considerable uncertainty. This latter range translates into a release of 6 x 10^{10} to 6 x 10^{13} fibers-ha^{-1} (2 x 10^{10} to 2 x 10^{13} fibers-$acre^{-1}$), or 10^{16} to 10^{19} silica fibers (up to 16 μm length) released by the approximately one million tons of rice straw burned in California.

Objective 2. Sampling for biogenic silica fiber from field burning

Perimeter air sampling was done on five field burns (Table 1) in an effort to determine if biogenic silica fiber is emitted and to qualitatively compare field burning to the wind tunnel results. Additional field burn trials are to be conducted.

Four battery powered air samplers were used to collect upwind and downwind samples during field burns in rice straw as indicated in Table 3. A portable weather station was located on site to indicate wind speed, direction, air temperature, relative humidity, and solar radiation. The upwind sampler was placed so that at no time during the burn was it exposed to the plume. Two samplers were placed at the downwind edge of the field, and the fourth sampler was placed approximately 1.6 km (1 mile) downwind. The filters were placed at a height of approximately 2 m (6 feet), except for one filter located on a mast at a height of 5 m (16 feet) during the test of 4/12/91. For the last field trial (11/16/91, not shown in Table 3) a fifth sampler was used to acquire the filter sample on the mast, permitting two other samplers to collect ground level (2 m height) samples. Flow rates were generally set at the maximum the pumps could pull, which was between 8 and 10 L/min. With the exception of the first trial (10/5/90), all samples were collected on 0.4 μm polycarbonate filters in 25 mm diameter carbon filled polyethylene cassettes. Cassettes were run open without upstream particle size separation. The first field burn trial used 0.45

μm mixed cellulose ester because it was originally thought than an indirect analysis technique would be used. Because initial tests of the indirect method were less satisfactory than the direct method, only polycarbonate filters were used subsequently. The polycarbonate filters did suffer from a problem of plugging when located in the plume immediately downwind of the fire. Filters UCRRB37 and 38 were not analyzed for fiber count for this reason. Under microscopic inspection, the filter pores were seen to be open, indicating that the plugging was a result of moisture condensing on the filter, which evaporated prior to inspection. Laboratory experiments confirm that the polycarbonate filters are subject to plugging in high humidity environments, and that the water is held very tightly in the pores. The cellulose ester filters did not plug, nor were there problems of plugging with the polycarbonate filters on the upwind and far-downwind samplers. Further experiments are to be conducted in the field to reduce or eliminate the plugging problem with polycarbonate filters immediately downwind in the plume of the fire.

In addition to the four monitoring locations described above, several short exposure samples were collected by following the fire as it burned through the field, and taking samples (also on polycarbonate filters) in the plume 1 - 2 m (3 - 6 feet) behind the flame. These are described as "near flame" samples in Table 3. The total sample volumes for these filters are of the same order as those collected from the wind tunnel. The conditions in the plume near the fire were thought to be similar to the wind tunnel in regards to air dilution. However, the humidity of the gas sampled in the field was higher than in the wind tunnel, as extended sampling behind the fire in the field also resulted in filter plugging. For this reason, the flows were monitored and sampling stopped prior to or at the onset of plugging. The presence of water on the filters collected in the field may also be important for interpreting the concentrations of KCl particles observed. A smaller number were found on field samples compared to the wind tunnel, which may be a result of leaching by condensation. Other factors may also contribute.

Four classes of particles were identified by AIHL during the analysis of the field samples (Table 2). Particles in classes III and IV, which were not observed in the wind tunnel samples, most likely originated from the soil. Class IV particles are commonly observed on ambient air samples. The class III particles are alumina-silicates, most often crystalline, and are probably clay or other soil particles. Most fibers, like those from the wind tunnel , were irregular in shape.

Results of fiber analyses to date for the field samples are given in Tables 4 and 5. Table 4 shows only class II particles, most likely originating from the straw, while Table 5 shows results for class III particles displaying the characteristic presence of aluminum. One silica fiber was found on each of the upwind samples on two out of the three trials analyzed, yielding a fiber concentration of up to 27,000 m^{-3} (765 ft^{-3}) in each of the two size categories. Fiber concentrations for the far-downwind samples were similar. A larger number of alumina-silicate (class III) particles were found on the upwind and far-downwind samples (Table 5). Total concentrations ranged up to about 80,000 m^{-3} for both size categories combined.

Silica fibers (class II particles) were found on five of the eight near-flame samples. Alumina-silicate fibers (class III particles) were not detected within the grid areas scanned on these samples. A large number of silica fibers were found on sample UCRRB54. The total silica fiber concentration was almost 5×10^6 m^{-3}, similar to filter samples collected from the wind tunnel stack. Silica fiber concentrations on other near-flame samples ranged from 10^5 to 10^6 m^{-3}, which is of the same magnitude as samples collected by electrostatic precipitator in the wind tunnel. The low total sample volumes again result in wide confidence intervals.

The results from the downwind field edge have larger associated uncertainty because of the condensation and plugging problem. Only sample UCRRB59 did not plug, and it yielded the highest concentration of silica fibers (3.0×10^4 to 4.7×10^5 m^{-3}). Unlike the near-flame samples, class III alumina-silicate particles were detected on the field perimeter samples. Because the concentrations of class III particles were in many cases similar to those for the upwind samples, the source of these particles can not be explicitly defined. They may be background particulate matter carried in on the ambient wind, or they may be released from behind the fire, in which case they would not have been observed on the near-flame samples. The fact that no class III particles were detected on the near-flame samples suggests either the latter explanation, or that the sampling time for the near-flame filters was inadequate to observe such particles if carried on the ambient wind. The confidence intervals for class III fibers on the near flame samples are wide because of the low sample volumes.

Objective 3. Ambient air sampling in municipal areas during rice straw burning

Ambient air samples were collected on several days as shown in Table 1 in various cities and towns throughout the lower Sacramento valley. Total rice area burned was 7,300 ha (18,000 acres) on 10/22/91, 1,600 ha (4,000 acres) on 10/23/91, 3,200 ha (8,000 acres) on 10/25/91, and 1,200 ha (3,000 acres) on 10/28/91. Analysis of these samples has not yet been completed by AIHL, and no results are yet available. Additional sampling is to be conducted during non-burn days for rice to establish potential background levels for silica fiber.

Objective 4. Area sampling during rice harvesting

Air sampling at the field edge was conducted during rice harvesting operations in October, 1991 (Table 1). These experiments were done in association with a sampling program conducted by staff of the UC Medical School, who did personnel monitoring directly on the harvesters and bank-out wagons. Analysis of these samples has also not yet been completed by AIHL. Results will be reported at a later date. Earlier samples taken during 1990 were collected on cellulose ester filters, and were not analyzed due to the preference for the direct analysis method. These samples are to be analyzed by the indirect method, and results will also be reported later.

PUBLICATIONS OR REPORTS:

Jenkins, B.M. 1990. Morphological characterization of particulate matter emissions from open burning of rice straw. Annual Report, Comprehensive Rice Research, University of California, Davis.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

Silica fibers were detected on filter samples collected from both the field and the UC Davis wind tunnel during combustion of rice straw. Fibers containing aluminum in addition to silicon were found on field samples, but were not observed on wind tunnel samples. KCl particles were observed in both wind tunnel and field samples, although at much higher concentrations in the wind tunnel samples. Because of the absence of alumina-silicate particles in wind tunnel samples, these particles are believed to originate from the soil. The silica fibers and the KCl particles are believed to derive from the straw, although other sources may account for some of the KCl emission.

Fibers were identified as any particle with a length to diameter ratio (aspect ratio) of 3:1 or greater. Silica fibers from rice straw burning were irregular without exhibiting the straight, parallel sided morphology of mineral fibers. Fibers observed within the filter area scanned by electron microscopy were generally few in number, but represent concentrations of 10^4 to 10^7 m^{-3} (300 to 300,000 fibers per cubic foot) with typical values in the range of 10^5 to 10^6 m^{-3} (3,000 to 30,000 per cubic foot).

An approximate emission factor for silica fibers was derived from wind tunnel results. Rice straw at 6-10% moisture content generated 1×10^5 to 2.6×10^6 fibers-g^{-1} (45 million to 1 billion fibers per pound) of straw with 95% confidence intervals from 10^4 to 10^7 fibers g^{-1} (4.5 million to 4.5 billion fibers per pound). The wide range shows the considerable uncertainty which exists. This latter range translates into a release of 6×10^{10} to 6×10^{13} fibers-ha^{-1} (20 billion to 20 trillion fibers per acre), or 10^{16} to 10^{19} (10 - 10,000 quadrillion) silica fibers (up to 16 μm in length) released by the approximately one million tons of rice straw burned in California. An emission factor for alumina-silicate fibers can not be derived because they were not observed on wind tunnel samples. They did appear in field area samples, including both upwind and downwind samples, but were not found in short duration samples taken just behind the flame. Because no formal mechanism for the formation and entrainment of fibers from straw burning has been confirmed, quantitative results must be considered to be representative of the conditions tested. Results do not show, for example, whether fibers are emitted continuously or whether discrete processes may be effective in forming and transporting fibers. Nor do these results show whether all plant tissues contribute equally to silica fiber production. The estimate obtained by extrapolation of current results to total fiber emission from the entire rice crop should be considered to be highly uncertain.

Analyses of filters collected from municipal areas in the Sacramento Valley during permissible burn days have not been completed. Estimated exposures cannot yet be computed. Samples collected during rice harvesting have also not yet been analyzed. Results will be reported at a later date.

Table 1. Number and type of air samples collected.

Sampling Date	Sample Type	Number of Samples
5/2/90	Wind Tunnel	2
5/4/90	Wind Tunnel	8
9/28/90	Harvest	8
10/5/90	Field Burn	7
11/21/90	Field Burn	4
2/26/91	Field Burn	7
4/12/91	Field Burn	9
7/22/91	Wind Tunnel	20
10/4/91	Harvest	6
10/10/91	Harvest	6
10/11/91	Harvest	6
10/15/91	Harvest	6
10/22/91	Municipal Smoke Exposure	4
10/23/91	Municipal Smoke Exposure	4
10/25/91	Municipal Smoke Exposure	4
10/28/91	Harvest	3
10/28/91	Municipal Smoke Exposure	2
11/16/91	Field Burn	5
Total		111

Table 2. Particle classification scheme developed for air samples.

Class	Description
I	Very small (0.1 - 0.3 μm) background particulate consisting primarily of K and Cl
II	Larger (1 - 16 μm) particles consisting primarily of silicon
III	Particles consisting primarily of aluminum in combination with silicon
IV	Particles containing no silicon, most often containing Ca or S

Table 3. Specific locations and flows for smoke samples analyzed to date.

Sample ID	Date Sampled	Flow Rate (LPM)	Elapsed Time (min)	Total Flow (L)	Location
1990 Fall Field Burn					
UCRRB36	11/21/90	9.5	124	1,174	Upwind
UCRRB37	11/21/90	9.5	125	1,186	Downwind Edge #1
UCRRB38	11/21/90	9.5	127	1,203	Downwind Edge #2
UCRRB39	11/21/90	9.5	139	1,317	0.7 mi Downwind
1991 Spring Field Burn					
UCRRB44	2/26/91	10.0	174	1,740	Upwind
UCRRB45	2/26/91	10.0	159	1,590	Downwind, West
UCRRB46	2/26/91	10.0	172	1,722	0.7 mi downwind
UCRRB47	2/26/91	9.5	2	19	Near Flame
UCRRB48	2/26/91	10.0	94	936	Downwind, East
UCRRB49	2/26/91	5.0	2	12	Near Flame
UCRRB50	2/26/91	5.0	2	12	Near Flame
1991 Spring Field Burn					
UCRRB51	4/12/91	9.5	137	1,305	Upwind
UCRRB52	4/12/91	9.3	106	982	Mast downwind
UCRRB53	4/12/91	9.5	141	1,340	1.1 mi downwind
UCRRB54	4/12/91	2.0	3	5	Near Flame
UCRRB55	4/12/91	2.0	3	7	Near Flame
UCRRB56	4/12/91	2.0	3	5	Near Flame
UCRRB57	4/12/91	2.0	1	2	Near Flame
UCRRB58	4/12/91	2.0	2	4	Near Flame
UCRRB59	4/12/91	2.0	45	90	East side downwind
UCD Wind Tunnel					
UCRRB60	7/22/91			100	Stack
UCRRB61	7/22/91			10	Stack
UCRRB62	7/22/91			4	Stack
UCRRB63	7/22/91			2	Stack

Table 4. Silica fibers detected and silica fiber concentrations (95% confidence intervals given by particle size category).

Sample ID	Number of Silica Fibers Detected		Silica Fiber Concentration (fibers/cubic meter)		95% confidence intervals		95% confidence intervals	
	< 5 µm	>5 µm	< 5 µm	>5 µm	< 5 µm lower	< 5 µm upper	> 5 µm lower	> 5 µm upper
1990 Fall Field Burn								
UCRRB36	0	0	0	0	0	11,500	0	11,500
UCRRB37	not analyzed							
UCRRB38	not analyzed							
UCRRB39	2	0	6,460	0	780	23,300	0	11,900
1991 Spring Field Burn								
UCRRB44	0	1	0	5,000	0	18,400	100	27,800
UCRRB45	1	0	4,560	0	100	25,400	0	16,800
UCRRB46	0	0	0	0	0	15,600	0	15,600
UCRRB47	1	0	114,000	0	2,900	635,000	0	421,000
UCRRB48	0	0	0	0	0	17,200	0	17,200
UCRRB49	0	1	0	181,000	0	668,000	4,600	1,008,000
UCRRB50	0	0	0	0	0	668,000	0	668,000
1991 Spring Field Burn								
UCRRB51	0	1	0	4,800	0	18,000	100	27,000
UCRRB52	0	2	0	9,900	0	18,000	1,200	36,000
UCRRB53	1	0	4,600	0	100	26,000	0	18,000
UCRRB54	7	4	3,050,000	1,740,000	1,220,000	6,290,000	480,000	4,460,000
UCRRB55	1	0	310,000	0	7,900	1,740,000	0	1,150,000
UCRRB56	0	0	0	0	0	1,610,000	0	1,610,000
UCRRB57	1	0	1,090,000	0	28,000	6,080,000	0	4,030,000
UCRRB58	0	0	0	0	0	2,010,000	0	2,010,000
UCRRB59	2	4	48,000	97,000	5,900	180,000	26,000	250,000
UCD Wind Tunnel								
UCRRB60	overloaded							
UCRRB61	0	0	0	0	0	3,950,000	0	3,950,000
UCRRB62	0	1	0	2,678,000	0	9,882,000	68,000	14,917,000
UCRRB63	1	0	5,356,000	0	136,000	29,835,000	0	19,765,000

Table 5. Alumina-Silicate (Al-Si) fibers detected and fiber concentrations (95% confidence intervals given by particle size category).

Sample ID	Number of Al-Si Fibers Detected < 5 µm	>5 µm	Al-Si Fiber Concentration (fibers/cubic meter) < 5 µm	>5 µm	95% confidence intervals < 5 µm lower	< 5 µm upper	95% confidence intervals > 5 µm lower	> 5 µm upper
1990 Fall Field Burn								
UCRRB36	1	0	3,110	0	100	17,300	0	11,500
UCRRB37	not analyzed							
UCRRB38	not analyzed							
UCRRB39	0	0	0	0	0	11,900	0	11,900
1991 Spring Field Burn								
UCRRB44	1	1	5,000	5,000	100	27,800	100	27,800
UCRRB45	2	1	9,120	4,560	1,100	32,900	100	25,400
UCRRB46	3	2	12,700	8,460	2,600	37,100	1,000	30,500
UCRRB47	0	0	0	0	0	421,000	0	421,000
UCRRB48	2	0	9,300	0	1,100	33,600	0	17,200
UCRRB49	0	0	0	0	0	668,000	0	668,000
UCRRB50	0	0	0	0	0	668,000	0	668,000
1991 Spring Field Burn								
UCRRB51	1	4	4,800	19,000	100	27,000	5,200	49,000
UCRRB52	0	0	0	0	0	18,000	0	18,000
UCRRB53	0	0	0	0	0	17,000	0	17,000
UCRRB54	0	0	0	0	0	1,610,000	0	1,610,000
UCRRB55	0	0	0	0	0	1,150,000	0	1,150,000
UCRRB56	0	0	0	0	0	1,610,000	0	1,610,000
UCRRB57	0	0	0	0	0	4,030,000	0	4,030,000
UCRRB58	0	0	0	0	0	2,010,000	0	2,010,000
UCRRB59	0	3	0	73,000	0	89,000	15,000	210,000
UCD Wind Tunnel								
UCRRB60	overloaded							
UCRRB61	0	0	0	0	0	3,950,000	0	3,950,000
UCRRB62	0	0	0	0	0	9,882,000	0	9,882,000
UCRRB63	0	0	0	0	0	19,765,000	0	19,765,000

Table 6. Silica fiber counts and concentrations from electrostatic precipitator grids taken from flame and stack regions of wind tunnel.

Sample ID	Location	Number of Silica Fibers Detected		Silica Fiber Concentration (fibers/square mm)		Silica Fiber Concentration (fibers/cubic meter)		95% confidence intervals (fibers/cubic meter)		95% confidence intervals (fibers/cubic meter)	
		< 5 µm	>5 µm	< 5 µm	>5 µm	< 5 µm	>5 µm	< 5 µm lower	< 5 µm upper	> 5 µm lower	> 5 µm upper
UCRRB64	Inlet	0	3	0	38	0	475,556	0	577,778	97,893	1,377,778
UCRRB65	Flame	overloaded									
UCRRB66	Flame	overloaded									
UCRRB67	Flame	0	0	0	0	0	0	0	4,844,444	0	4,844,444
UCRRB68	Flame	overloaded									
UCRRB69	Post-flame	0	2	0	25	0	1,555,556	0	2,915,556	188,444	5,688,889
UCRRB70	Post-flame	0	2	0	25	0	314,160	0	582,222	38,200	1,155,556
UCRRB71	Afterburn	0	0	0	0	0	0	0	441,778	0	441,778
UCRRB72	Afterburn	0	1	0	25	0	238,000	0	441,778	3,022	666,667
UCRRB73	Flame tip	0	0	0	0	0	0	0	441,778	0	441,778
UCRRB74	Flame tip	1	0	12	0	114,222	0	3,022	666,667	0	441,778
UCRRB75	Plume	1	0	12	0	114,222	0	3,022	666,667	0	441,778
UCRRB76	Post-flame tip	1	0	12	0	114,222	0	3,022	666,667	0	441,778
UCRRB77	Post-flame tip	not analyzed									
UCRRB78	Stack	0	2	0	25	0	238,000	0	441,778	28,889	844,444
UCRRB79	Stack	2	0	25	0	182,649	0	22,209	662,222	0	339,000