IN-DEPTH SURVEY REPORT:

CONTROL TECHNOLOGY FOR ENVIRONMENTAL ENCLOSURES
An Evaluation of In-use Enclosures.

AT

Nelson Manufacturing Company
Yuba City California

REPORT WRITTEN BY:
William A. Heitbrink, Ph.D., CIH
Ernest Moyer Ph. D.

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U.S. Department of Health and Human Services
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
4676 Columbia Parkway, Mailstop R-5
Cincinnati, OH 45226

NIOSH
Division of Respiratory Disease Studies
Morgantown WV

STUDY SITE: Nelson Mfg. Co.
2860 Colusa Highway
Yuba City, CA 95993

Employer Representatitve: Jim Bennett

SIC CODE: 3523

STUDY DATES: August 29-31 , 2000

STUDY CONDUCTED BY: William A. Heitbrink, Ph. D.; NIOSH
Ernest Moyer, Ph. D.; NIOSH

James Bennett, Nelson Mfg.

EMPLOYEE REPRESENTATIVE: No Union

DISCLAIMER

ABSTRACT

Optical particle counters were used to measure the aerosol concentration inside and outside of a modified Nelson Spray Cab. Testing was conducted to evaluate compliance with American Society of Agricultural Engineers Standard S525. For the S525 test, the tractor is driven over an unpaved surface for several hours to evaluate aerosol penetration into the cab. Two 8-channel optical particle counters are used to measure size-dependent dust concentrations inside and outside of the cab. This test is performed on a single cab. These test results were compared to a stationary test which could be performed on each cab. In the stationary test, the spray cab, which is mounted on a tractor, is set inside an enclosure. Aerosol, generated by burning incense sticks, is used to evaluate aerosol penetration into the cab. A single two-channel optical particle counter (model 227A Met One, Pacific Scientific, Grants Pass, Oregon) is used to measure the aerosol concentration outside and inside the cab. The stationary and mobile test gave different results. These results are thought to be caused by the aerosol generation inside the cab and a relatively low concentration of particles outside of the cab during field S525 testing. Also, some optical particle counter measurements were biased due to the excessive aerosol concentrations. This source of experimental error can be addressed by fabricating a diluter from a capsule filter.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential biological, chemical, and physical hazards.

The Engineering and Physical Hazards Branch (EPHB) of the Division of Physical Sciences and Engineering (DPSE) studies the engineering aspects relevant to the control of hazards in the workplace. Since 1976, EPHB has assessed control technology found within selected industries or used for common industrial processes. EPHB has also designed new control systems where current industry control technology was insufficient. The objective of these studies has been to document and evaluate effective control techniques (e.g., isolation or the use of local ventilation) that minimize risk of potential health hazards and to create an awareness of the usefulness and availability of effective hazard control measures.

One area identified for EPHB control studies is air contaminant penetration into environmental enclosures. Prior research conducted by EPHB has focused upon environmental enclosures used to protect workers from pesticide spray mist. NIOSH researchers conducted a field evaluation of tractor enclosures used for pesticide application by using optical particle counters to measure exposure reduction as a function of particle size.[1,2] To conduct the tests, the tractors equipped with environmental enclosures were simply driven over unpaved surfaces and the ambient aerosol and dust generated by the tractor were used to challenge the enclosure.

In an optical particle counter (OPC), air at a known volumetric rate is drawn into the sensing chamber of the OPC.[3] Air is drawn through the instrument and into a sensing chamber. A light beam from a laser, light-emitting diode or other source shines through the sensing volume. As each particle passes through the light beam, the particle scatters light which is detected by a photomultiplier tube. The instrument's electronics counts the number of light pulses and uses the amplitude of the light pulses to classify the particles into different particle sizes.

Environmental tractor cab enclosures can be used to protect heavy equipment operators from crystalline silica exposures during surface mining and other earthmoving operations.[4] During surface mining operations, many workers are positioned in cabs of earth moving equipment, rock-drilling equipment, and rock trucks. Excessive crystalline silica exposures are reported among surface mining workers.[5] Among surface miners, this is causing excessive cases of silicosis.[6] Appropriate cabin filtration and pressurization appear to have the potential for controlling worker exposure to respirable crystalline silica.[7] In addition, environmental enclosures are a potential means of controlling worker exposure to biosolids.[8]

These enclosures are generally constructed from impervious materials so that workers are protected from dermal and respiratory exposures. A fan is used to pull air through filters which efficiently remove air contaminants and pressurize the enclosure. Downstream of the fan, the air flows past an air-conditioning evaporator coil which can be used to temper the air. In these enclosures, a second fan can be used to re-circulate air through a second set of filters and the air conditioner evaporator coil. The air flows out of the enclosure through leaks or a vent port which is intended to allow air to leave the enclosure at a location which is shielded from the effects of the wind. These enclosures will have leakage due to the need for electrical and mechanical connections between these enclosures and the rest of the equipment.

Based upon the EPHB evaluation of tractor-mounted enclosures, the American Society of Agricultural Engineers (ASAE) has developed ASAE S525, which is a consensus standard. This standard specifies requirements for environmental enclosures that are used for controlling applicator exposure to pesticide spray mist.[9,10] Cabs, which are certified by California EPA under this standard, may be used in California instead of respirators to meet the requirements of Federal EPA's Worker Protection Standard for pesticide applicators.[11] Three important specifications in this consensus standard describe the performance of these enclosures for aerosols:

1. The static pressure in the enclosure must be at least 6 mm of water;
2. The penetration (ratio of concentration inside the enclosure to outside the enclosure) shall be less than 0.02 (1/50 or 2%) for particles larger than 3 μm; and,
3. The filtration efficiency shall be at least 99 percent for particles larger than 3 μm.

Aerosol penetration into the enclosure is evaluated by using optical particle counters to measure the concentration of particles in the 2-4 μm range inside and outside of the equipment. The testing is conducted by driving the vehicle mounted enclosure over an unpaved surface at 3-5 km/hr. This equipment can be tested and evaluated under relatively calm air conditions without regard to wind speed. In order to prevent the drift of pesticides, spray pesticide application is conducted when wind speeds are less than 16 km/hr.[12] In order to prevent wind from increasing air infiltration into an enclosure, the ASAE standard specifies that an enclosure must have a minimum pressurization of 6 mm water gauge.

The certification of cabs under the ASAE S525 standard is conducted on one cab and this certification evaluates whether the cab design and construction are adequate. This standard does not address the operation of quality control and maintenance programs that are needed to ensure that all cabs continue to be protective of workers. To evaluate the extent to which maintenance and quality control are affecting aerosol penetration into environmental enclosures, NIOSH researchers are evaluating in-use environmental enclosures.[13,14] The findings from these studies suggest that manufacturing quality control programs and user maintenance programs are needed. To develop such a plan, users and manufacturers need a quick test to evaluate whether the cab is performing adequately. During the study conducted at this site, NIOSH researchers demonstrated the use of a stationary test which could be used for evaluating cab integrity. This test involves placing the tractor in an enclosure constructed from studs and a polyethylene vapor barrier. Incense sticks were used as the aerosol source. A single, low priced optical particle counter was used to measure ambient aerosol concentration inside and outside of the enclosure and results were compared with measurements made with on 8-channel optical particle counter.

The Nelson spray cabs are mounted on the tractor by either the user or Nelson Manufacturing. A typical installation of a Nelson Spray Cab on a Massey Ferguson model 398 tractor is shown in Figure 1. During this study a Massey Ferguson model 4270 tractor was used. The air flow into this cab is illustrated schematically in Figures 2 and 3. Two fans move about 200 cfm through the air inlet above the front of the cab, through the stack of filters shown in Figure 3, past air conditioning coils and into the cab. The air flows out of the cab through various cracks and crevices where the cab is mounted on the tractor. In addition, this cab is designed to recirculate air from the cab through the filters and back into the cab. The cab contains a magnehelic static pressure gauge. This cab was certified by California EPA before the ASAE developed the S525 standard. Furthermore, the manufacturer has modified this manufacturing procedure so as to attach the cabs directly to the tractors frame thus minimizing leakage and increasing static pressure.

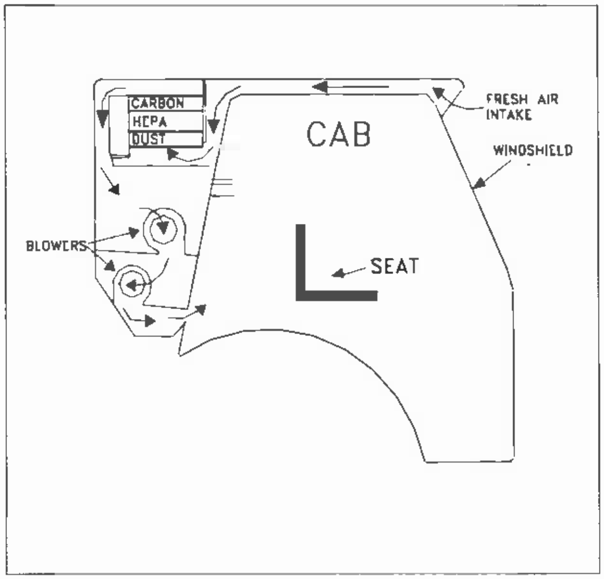

Figure 1. Schematic of Nelson cab air flow.

Figure 2. Photograph of cab setting on top of a tractor. This photograph was taken during another survey. However, the same sampling location outside of tractor was used during this study.

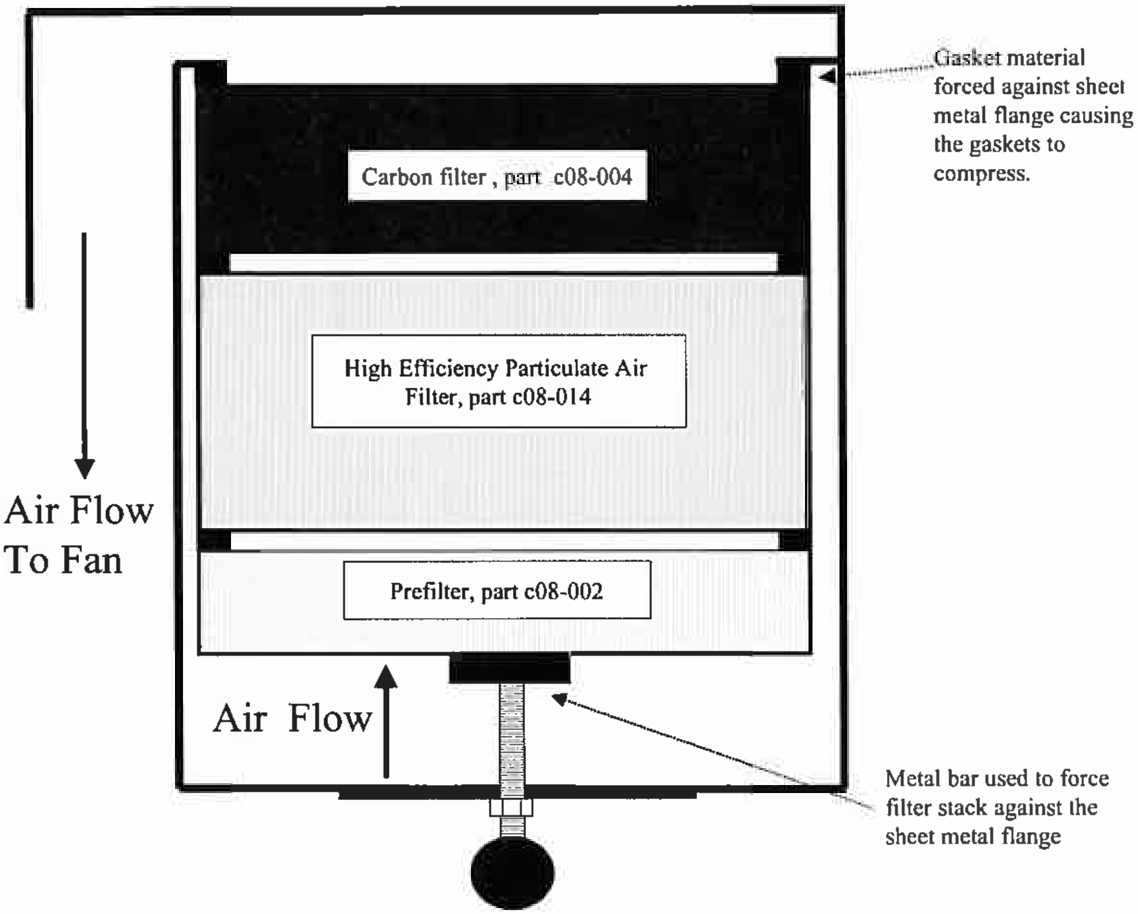

Figure 3. Schematic cross-sectional view of filters and mechanism for seating the filter.

Procedures

Before evaluating aerosol penetration into a tractor, the air flow into the cab was measured using a velometer (Velocicalc, TSI Inc., St. Paul MN). Air velocities were measured at the inlet. The air flow volume was estimated as the product of the average velocity and the cross sectional area of the inlet. Enclosure static pressure was recorded using the static pressure gauge in the enclosure.

Mobile test

The aerosol penetration into the cab was evaluated while an operator drove the tractor around the perimeter of a flat, unpaved field on the Nelson Manufacturing facility in Yuba City, CA. The operator ran the tractor in its lowest gear.(**Figure 4**) This gave a tractor speed which appeared to be between 2 and 5 kilometers/hr. Aerosol penetration into the cab was obtained by measuring the aerosol concentration inside and outside the spray cab with optical particle counters. Penetration is the ratio of particle concentration inside the cab to particle concentration outside the cab. Two optical particle counters (Grimm PDM, model 1106, Ainring Germany) were used to measure aerosol concentration inside and outside the cab. One was attached with bungie cords to the engine cowling. The second Grimm PDM was placed in the cab near the driver. These instruments were used with an impactor as sampling inlets. The Grimm PDM counts individual particles and sizes each particle, based upon the amount of light scatted, into one of eight channels. Aerosol penetration into the cab was the ratio of the concentration inside the enclosure to the concentration outside of the enclosure. The field tests of the cab were made in a sets of four measurements or replications which were about 30 minutes in length. The location of the optical particle counters was switched after each measurement.

During the field tests, the Grimms were operated with an impactor (PEM 200-2-2.5, MSP Corporation, Minneapolis MN) used as a pre-selector. These impactors were operated at a flow rate of 1.2 lpm and 2 of the 10 impaction orifices were covered with duct tape. Instead of having a cut diameter of 2.5 µm, the impactors had an estimated cut diameter of 4.08 µm. The impactors were operated with a jet Reynolds number of 194. The 50 % cut diameter, d_p, the particle size at which the impactor is 50% efficient can be computed as follows[15]:

$$d_p = \sqrt{\frac{Stk 9 \pi \eta w^3}{4Q}}$$

Where;

Stk = stokes number, At a Reynolds number of 200, the stokes number is 0.25
w = jet diameter (cm)
Q = air flow through each impactor jet (cm^3/sec)
η = viscosity of air (poise)

d_p= particle diameter in cm.

The impactor should eliminate practically all of the particles larger than 4.08 μm, aerodynamic diameter.

Stationary Test

A second method was used for screening the environmental cab performance. This screening method consisted of measuring aerosol concentration inside and outside the environmental cab when stationary but while the tractor and cab were operating at normal settings (RPM and flow commonly used during field conditions). The tractor was parked in an enclosure constructed of wood studs and polyethylene vapor barrier (**Figure 5**). One or two incense sticks (Endar Corp Temecula, Ca 92590) were placed in cracks in the concrete floor and the incense sticks were burned to create smoke (**Figure 6**). The entrance to this enclosure consisted of a roll of polyethylene vapor barrier which could be raised or lowered to adjust the aerosol concentration in the test chamber (**Figure 7**). The enclosure is 15' long, 8' feet wide and 8' feet high.

The procedure consisted of using one MetOne Model 227A optical particle counters (Pacific Scientific Instruments, Grants Pass, Oregon) for measuring the aerosol concentration inside and outside the environmental cab. Sampling lines of equal length were positioned with one at the air flow inlet to the cab and the other inside the enclosed environmental cab. The cab was closed and the tractor operated at 1800-2000 RPM. A five-minute period was used for warmup and cab equilibration at operating conditions. Subsequently, one or two minute Met One samples were obtained from inside and outside the cab at particle sizes of 0.5 and 0.7 micrometer (two replications) using the optical particle counter to sample through the different sampling lines. The sampling lines had an inside diameter of 0.125 inches. The sampling hose was about 7 feet long on both the inside and outside. One sampling line was placed on the tractors wind shield and the other sampling line inlet was on the tractors steering wheel. The latter sampling line was fed through a very small vacated bolt hole between the body of the tractor and the cab. The Met One Model 227A simultaneously counts two particle size ranges. We selected 0.5μm and 0.7 μm interval. The inside/outside particle count ratio was calculated for particles in the 0.5 to 0.7 μm interval and particles larger than 0.7 μm.

During the stationary tests, the particle number concentrations measured by the Met One were above the concentration for a 5% loss of particle counts due to coincidence. In an optical particle counter (opc) coincidence occurs when more than 1 particle is in the sensing volume at the same time. This causes the optical particle counter to interpret these particles as one larger particle. The instrument manual indicates that a 5% particle loss due to coincidence occurs at particle concentration of 71 particles/cm^3. To reduce the particle loss due to coincidence, a diluter was fashioned from a capsule filter (Gelman part 12144, Ann Arbor MI). As the air flows into this capsule filter, it flows around a flat piece of plastic which seals the end of the filter cartridge. A nominal 1/8" hole was drilled in this plastic to allow some of the air to flow around the filter instead of through the filter.

Figure 4. Tractor being driven during the mobile test. This test was conducted on the unpaved surfaces in the Nelson Manufacturing Company back lot.

Figure 5. Enclosure used for testing the environmental enclosures.

Figure 6. Burning incense stick used to create the test aerosol for the stationary testing.

Figure 7. Tractor in the test enclosure for the stationary testing. A roll of polyethylene was raised or lowered in an effort to control the incense aerosol concentration in the enclosure. Note, the flexible metal duct was used to transport engine exhaust out of the enclosure.

Results

The ventilation and air flow measurements are summarized in the following table. Approximately 25% of the air flow into the cab is recirculated.

ventilation summary and tractor data		
static pressure	17	mm of water
air flow into cab at front of cab	196	cfm
air flow from exhaust louvers	253	cfm
air flow into recirculation port	72	cfm
engine rpm during S525 test	1800	rpm
cab serial number	nctl001121	
tractor model number	4270	

The raw data is summarized in the data appendix. This data is summarized in Figures 8-11. **Figure 8** summarizes the aerosol penetration into the cab for the stationary and mobile tests. The results in this figure indicated that the penetration into this cab is acceptable from the perspective of the ASAE S525 standard. The stationary test results for the Grimm PDM 1106 and the Met One Optical particle counter are in agreement. The mobile and stationary test results for the Grimm PDM 1106 differed. At the smaller particle size, the stationary test results indicated lower penetration into the cab. The number concentration of the particles inside the cab during the stationary and mobile tests were nearly the same (See **Figure 9**). This suggests that there is a background of aerosol being produced in the cab which is noticeable in relation to the environmental variability. Possibly, there was an insufficient concentration of ambient aerosol during the ASAE S525 test to characterize penetration into the cab for particles smaller than 1 µm. This problem has been reported elsewhere.[16]

Figure 10 shows that observed protection factor (1/penetration) measured with the Met One decreases with increasing measured particle concentration. The results in this figure can be explained by coincidence. When more than one particle is simultaneously present in the sensing volume, an OPC can misinterpret these smaller particle as a single, larger particle.[3, 16] As a result, the particle concentration outside measured outside the cab decreases. As particle concentration increases above 100 particles /cm^3, the measured penetration into the cab increases. This indicates that coincidence is causing an overestimation of the penetration into the cab. **Figure 11** shows the size distribution of aerosol generated by burning the incense stick. Essentially, burning an incense stick provides a useful test aerosol for particles smaller than 1µm.

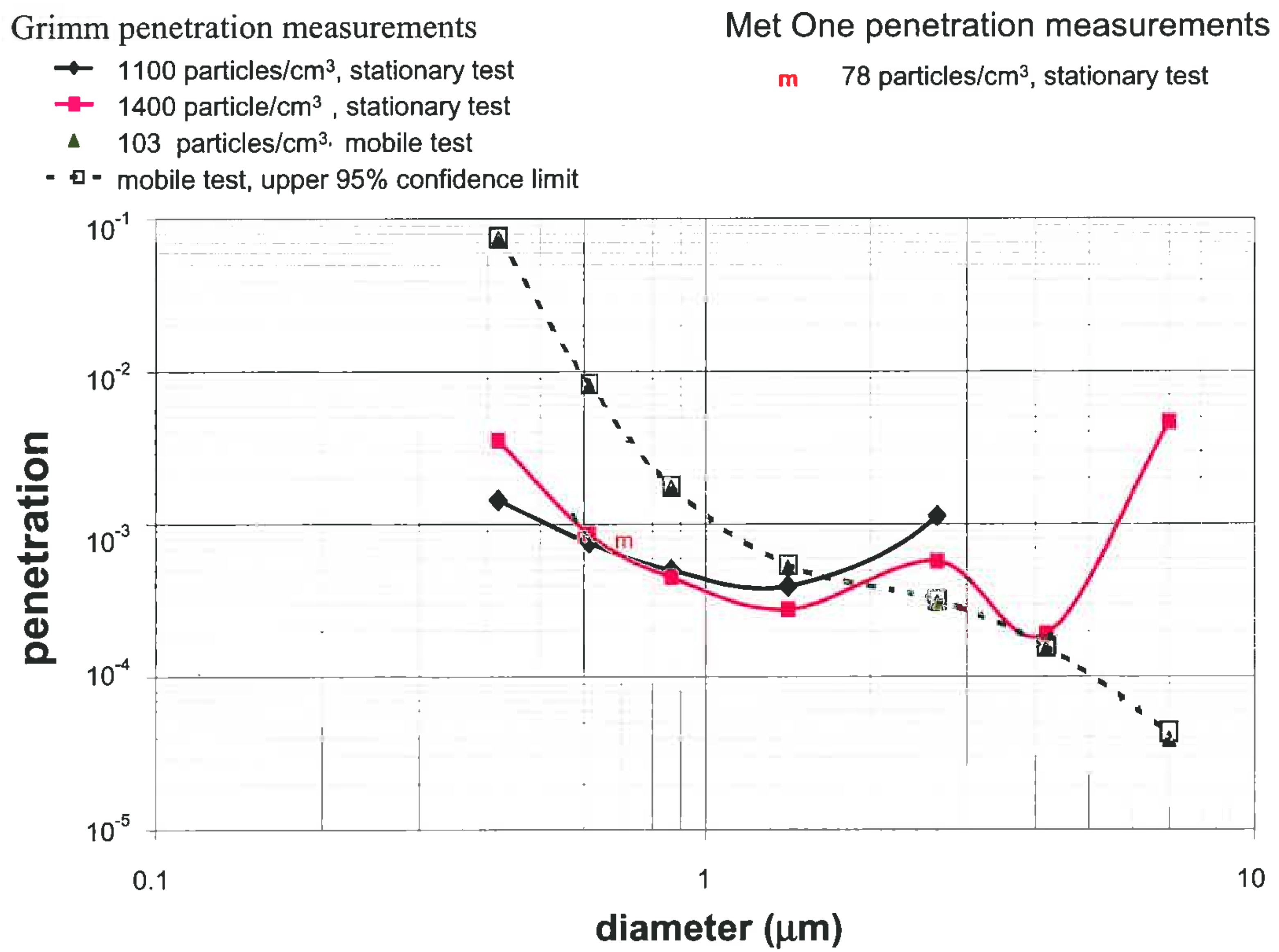

Figure 8. Aerosol penetration into the cab measured with the Grimm PDM 1106 and the Met One optical particle counter

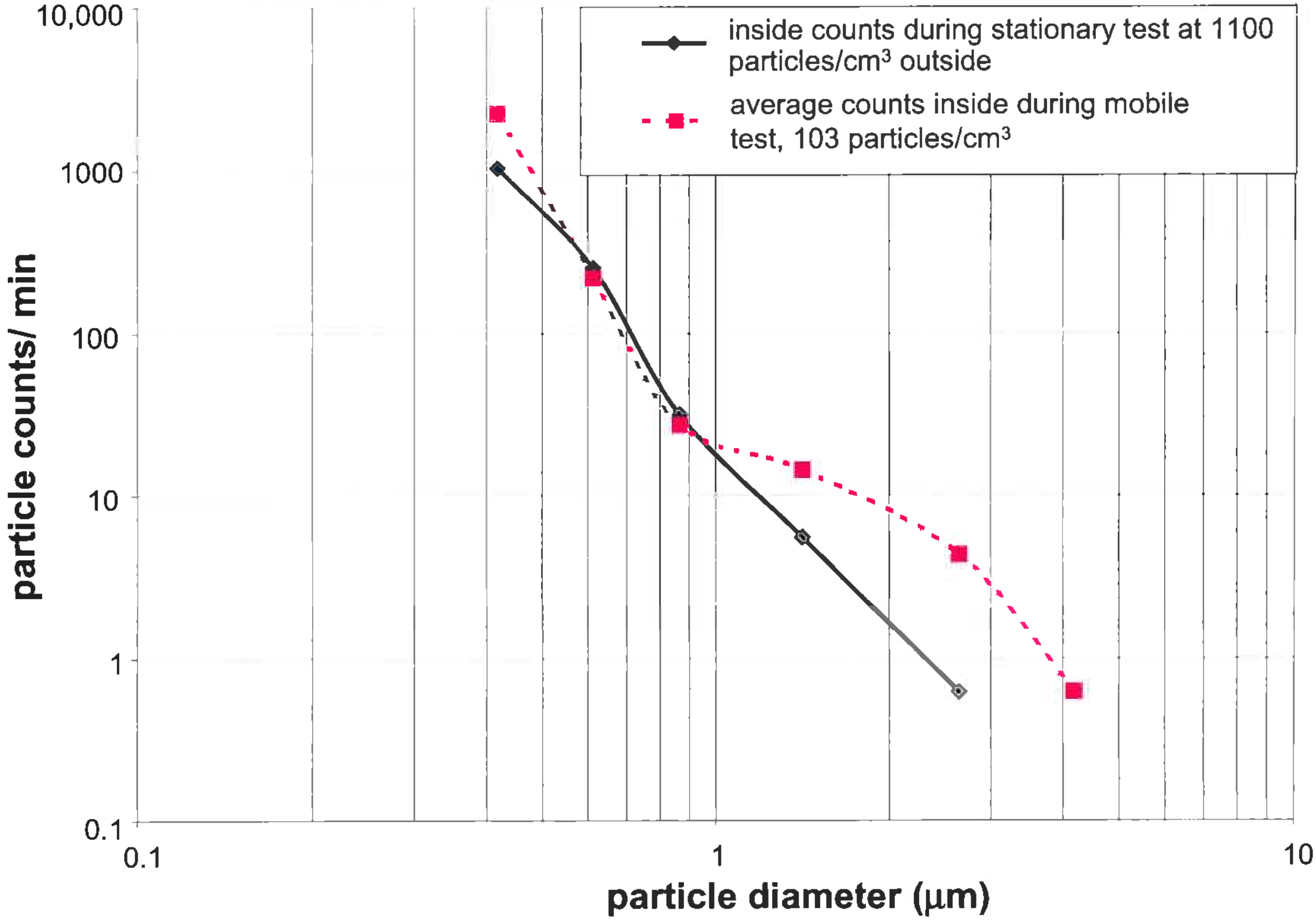

Figure 9. Average size-dependent particle count rate from Grimm PDM 1106s for stationary and mobile tests. These test results indicate the particle concentration inside the cab is the same for the stationary and mobile tests.

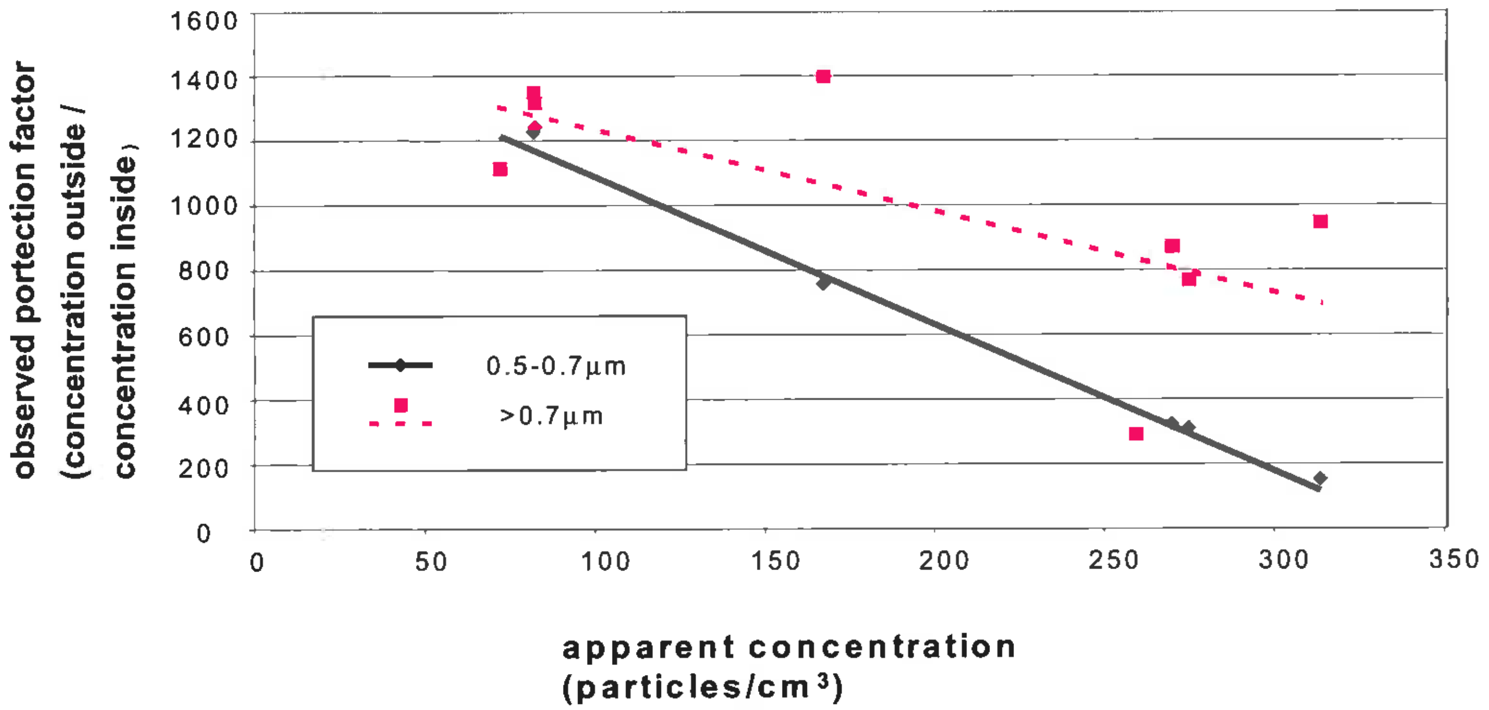

Figure 10. Measured protection factor decreases with increasing apparent concentration. Protection factor (1/penetration) is noticeably biased for measured number concentrations in excess of 100 particles/cm^3.

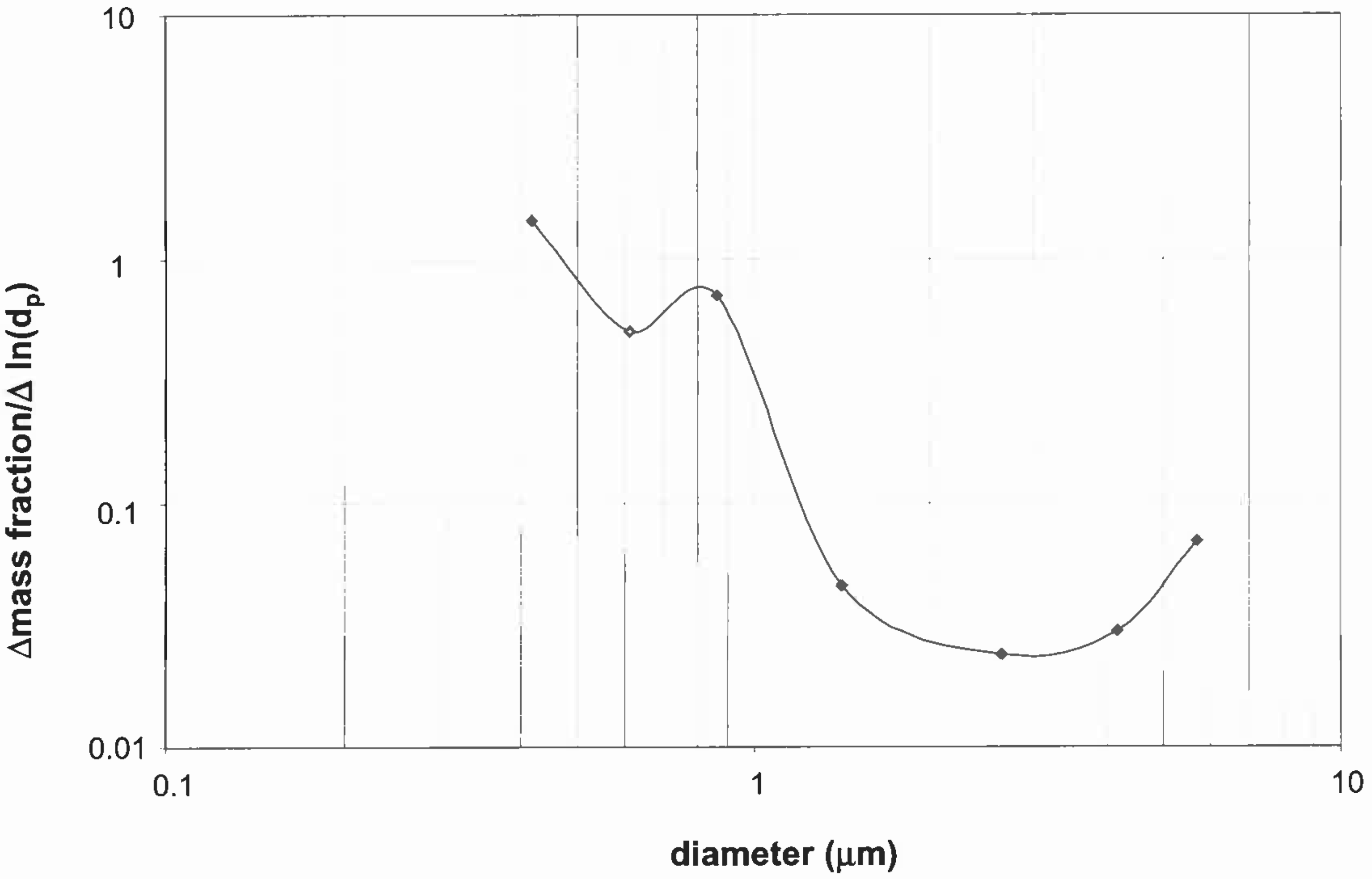

Figure 11 Size distribution measured during stationary test. The size distribution was measured withe the Grimm PDM 1106.

Conclusions

Stationary testing of cabs can be conducted with the Met One optical particle counter to verify the performance of each cab. In conducting this testing, a diluter is needed to make sure that coincidence is not biasing test results. Additional data is needed to show that there is a correlation between stationary and mobile tests. In this effort, the stationary and mobile tests did not agree for the smallest size particle size. This result may be explained by a low ambient aerosol concentration during the ASAE S525 test and the presence of aerosol generation in the cab.

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Data Appendix

incense stick 8/31/200, number of particles counted by Met One Optical Particle counter

treatment	sample time	outside		inside counts		penetration		particles/cm3, > 0.5 (µm)
	Minutes	>0.5 (µm)	>0.7 (µm)	>0.5 (µm)	>0.7 (µm)	0.5-0.7 (µm)	>0.7 (µm)	
no dilution	2	1756011	1249871	4643	1320	0.006565	0.001056	314
dilution	2	936067	422091	980	302	0.001319	0.000715	167
no dilution	2	457698	175604	360	130	0.000815	0.00074	82
dilution	2	1511602	944784	2841	1084	0.0031	0.001147	270
no dilution	1	769716	483183	1554	629	0.003228	0.001302	275
dilution	1	229865	88290	181	67	0.000805	0.000759	82
carbon filter last								
no dilution	2	1452682	880655	3252	1291	0.003428	0.001466	259
dilution , before inside measurement	2	439563	165824					78
dilution, after inside measurement	2	365881	134384					65
average before and after	2	402722	150104	364	137	0.000899	0.000913	72
new hepa from different supplier								
dilution	2	424960	160345	1035	287	0.002827	0.00179	76
dilution	2	441537	166709	1051	274	0.002827	0.001644	79

Particle number concentrations (particles/liter) , Data Collected with Grimm PDM 1.106 During ASAE S525 Testing

channel number	1	2	3	4	5	6	7	8	
lower limit on channel size (μm)	0.35	0.5	0.75	1	2	3.5	5	>6.5	
root mean diameter for channel (μm)	0.42	0.61	0.87	1.41	2.65	4.18	5.70		
run number	average particle concentration inside the tractor								time (minutes)
1	2010.9	181.8	22.2	13.6	3.6	0.5	0.0	0.0	24
2	1848.3	188.4	25.3	14.4	4.9	0.5	0.0	0.0	28
3	1935.4	188.0	20.1	9.7	3.3	0.7	0.0	0.0	31
4	1678.0	173.2	23.5	10.0	2.7	0.3	0.0	0.0	21
	average particle concentration outside enclosure								
1	19416.5	16993.4	11063.2	20732.1	10831.4	2751.5	298.8	74.5	
2	26126.5	22766.4	12047.4	21153.3	10583.1	3175.6	478.2	195.0	
3	28636.5	25793.4	15683.4	27667.8	16357.5	4534.9	387.8	85.8	
4	31955.7	29408.1	15537.6	24986.6	11991.6	3165.7	348.0	93.8	
	average penetration during each run								
1	1.0E-01	1.1E-02	2.0E-03	6.6E-04	3.3E-04	2.0E-04	0.0E+00	0.0E+00	
2	7.1E-02	8.3E-03	2.1E-03	6.8E-04	4.6E-04	1.5E-04	7.2E-05	1.8E-04	
3	6.8E-02	7.3E-03	1.3E-03	3.5E-04	2.0E-04	1.6E-04	8.3E-05	0.0E+00	
4	5.3E-02	5.9E-03	1.5E-03	4.0E-04	2.3E-04	1.0E-04	0.0E+00	0.0E+00	
average penetration	7.4E-02	8.0E-03	1.7E-03	5.2E-04	3.1E-04	1.5E-04	3.9E-05	4.4E-05	
upper 95% confidence interval on penetration	7.6E-02	8.2E-03	1.8E-03	5.4E-04	3.2E-04	1.6E-04	4.3E-05	5.3E-05	

Particle number concentrations (particles/liter)Stationary Test With Grimm PDM 1.106 Using Incense on 8/31/200

channel number	1	2	3	4	5	6	7	8	
lower limit on particle size for channel (µm)	0.35	0.50	0.75	1.00	2.00	3.50	5.00	6.5	Run time (minutes)
root mean channel diameter (µm)	0.42	0.61	0.87	1.41	2.65	4.18	5.70	0	
run number	outside the enclosure								
1	1126424.0	552771.4	117463.1	37485.8	2079.3	32.9	2.7	1.1	2.1
2	567886.3	189065.2	34879.5	10310.3	521.5	4.3	0.8	0.0	3
3	539462.6	257061.7	65575.0	19813.8	1364.3	66.9	11.0	2.5	2.2
4	550191.4	249117.3	61620.0	17970.7	1239.6	94.6	12.9	11.9	3.1
inside the enclosure									
1	1426.71	302.35	33.81	6.19	0.77	0.0e+00	0.0e+00	0.0e+00	3.1
2	773.81	168.45	31.32	9.10	1.55	2.6e-01	2.6e-01	0.0e+00	3.1
3	863.97	210.23	26.42	4.65	0.52	0.0e+00	0.0e+00	0.0e+00	3.1
4	830.22	196.59	26.13	5.28	1.00	2.5e-01	0.0e+00	0.0e+00	3.1
penetration									
1	1.3e-03	5.5e-04	2.9e-04	1.7e-04	3.7e-04	0.0e+00	0.0e+00	0.0e+00	
2	1.4e-03	8.9e-04	9.0e-04	8.8e-04	3.0e-03	6.0e-02	3.2e-01	0.0e+00	
3	1.6e-03	8.2e-04	4.0e-04	2.3e-04	3.8e-04	0.0e+00	0.0e+00	0.0e+00	
4	1.5e-03	7.9e-04	4.2e-04	2.9e-04	8.1e-04	2.6e-03	0.0e+00	0.0e+00	
average	1.4e-03	7.6e-04	5.0e-04	3.9e-04	1.1e-03	1.6e-02	8.1e-02		
standard deviation	1.5e-04	1.5e-04	2.7e-04	3.3e-04	1.2e-03	3.0e-02	1.6e-01		

Particle number concentrations (particles/liter) Incense data on 8/29/2000 collected with the Grimm Portable Dust Monitor 1.106

channel number	1	2	3	4	5	6	7	8	time (minutes)
lower limit on particle size for channel (µm)	0.35	0.5	0.75	1	2	3.5	5	6.5	
root mean channel diameter (µm)	0.42	0.61	0.87	1.41	2.65	4.18	5.70		
run	outside the enclosure								
1	833453.6	383343.5	80580.85	29262.85	2571.92	324.23	68.92	12.46	1.3
2	933452.7	432500.9	89594.61	31131.46	2505.00	216.52	8.94	2.22	5.4
	inside the enclosure								
1	3275.7	353.2	39.34	8.25	1.25	0.00	0.00	0.00	3.1
2	2957.9	349.8	37.20	8.55	1.67	0.08	0.08	0.00	9.6
	penetration								
1	3.9e-03	9.2e-04	4.9e-04	2.8e-04	4.9e-04	0.0e+00	0.0e+00	0.0e+00	
2	3.2e-03	8.1e-04	4.2e-04	2.8e-04	6.7e-04	3.9e-04	9.3e-03	0.0e+00	
average	3.5e-03	8.7e-04	4.5e-04	2.8e-04	5.8e-04	1.9e-04	4.7e-03	0.0e+00	