



## Evaluation of a Tractor Cab Using Real-Time Aerosol Counting Instrumentation

Ronald M. Hall , William A. Heitbrink & Laurence D. Reed

To cite this article: Ronald M. Hall , William A. Heitbrink & Laurence D. Reed (2002) Evaluation of a Tractor Cab Using Real-Time Aerosol Counting Instrumentation, Applied Occupational and Environmental Hygiene, 17:1, 47-54, DOI: [10.1080/104732202753306159](https://doi.org/10.1080/104732202753306159)

To link to this article: <https://doi.org/10.1080/104732202753306159>



Published online: 30 Nov 2010.



Submit your article to this journal [↗](#)



Article views: 60



View related articles [↗](#)



Citing articles: 10 View citing articles [↗](#)

# Evaluation of a Tractor Cab Using Real-Time Aerosol Counting Instrumentation

Ronald M. Hall, William A. Heitbrink, and Laurence D. Reed

*Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio*

Aerosol instrumentation was used to evaluate air infiltration into tractor cabs that are used to protect the agricultural worker during pesticide applications. Preliminary surveys were conducted on three different manufactured agriculture enclosures. The results of these preliminary surveys indicated that aerosols are entering the cab through leak sources or are being generated inside the cab. These results identified the need for in-depth field evaluations of tractor cabs to identify any leak sources. To evaluate the ability of tractor cabs to reduce operator air contaminant exposure, field evaluations were conducted on two tractor cabs. Specifically, we evaluated: 1) the particle size distribution and the effectiveness of the filter system; and 2) air infiltration into the cab. These evaluations were also conducted to demonstrate the ease and practicality of using optical particle counters to evaluate the ability of cabin filtration systems. Pesticide particle size distribution during an air blast spray operation was also evaluated during the study. The field tests were conducted on a John Deere 7000 series tractor cab (tractor manufacturer's cab) and a Nelson spraycab (retrofit cab). Both cabs were equipped with high efficiency particulate air (HEPA) filter media which were assumed to be 99.97 percent efficient at removing the test aerosol, atmospheric condensation nuclei. Thus, the major source of aerosols inside the cab was assumed to be leakage around filters at the seals. Using a portable dust monitor (PDM), the ratio of the outside to inside aerosol measurements was used to calculate a cab protection factor. During the evaluations, one PDM was placed inside the tractor cab (near the tractor operator) and one PDM was placed outside (near the air intake) to count particles. During the evaluations, the instruments were switched to prevent instrument bias from affecting the findings. The ratio of the two measurements (i.e., protection factor = outside concentration ÷ inside concentration) was used to cal-

culate how efficient the tractor cab was at removing aerosols. The John Deere cab was more than 99 percent efficient at removing aerosols larger than 3.0  $\mu\text{m}$  in diameter and had protection factors greater than 260 for particles larger than 3.0  $\mu\text{m}$  (indicated by the PDM results). The Nelson cab was more than 99 percent efficient at removing aerosols larger than 3.0  $\mu\text{m}$  in diameter and had protection factors greater than 200 for particles larger than 3.0  $\mu\text{m}$  (indicated by the PDM results). For aerosols smaller than 1.0  $\mu\text{m}$  in diameter (indicated by a PortaCount Plus instrument), the John Deere cab provided a mean protection factor of 43 and the Nelson cab provided a mean protection factor of 16. The results from this study indicate that tractor cabs can be effective at removing different size aerosols depending on the seals and filters used with the enclosure. This study has also demonstrated the practical use of real-time aerosol counting instrumentation to evaluate the effectiveness of enclosures and to help identify leak sources. The method used in this study can be applied to various cabs used in different industries including agriculture, construction, and manufacturing.

**Keywords** Tractor Cabs, Enclosures, Pesticides, Aerosol Instrumentation

Agriculture is one of our nation's most hazardous occupations. Agricultural workers and their families experience a disproportionate share of injuries and diseases associated with numerous chemical, biological, and physical hazards.<sup>(1)</sup> In addition, agricultural workers experience a variety of respiratory diseases associated with a number of exposures.<sup>(2)</sup> These diseases include asthma, hypersensitivity pneumonitis, chronic and acute bronchitis, organic dust toxic syndrome, and interstitial fibrosis.

Pesticide application can create aerosols that pose a health risk to the workers. In orchards, air blast spraying creates skin exposures and the potential for respiratory exposures to pesticides. In air blast spraying, an applicator uses a tractor to pull a spraying rig through an orchard. Typically, a rig has a 1.9 m<sup>3</sup> (500 gallon) tank containing a dilute solution, emulsion, or suspension of a

This article is not subject to U.S. copyright laws.

pesticide. The diluted pesticide is pumped through nozzles at pressures less than 689 kilopascals (100 psi). The nozzles spray the pesticide at a direction normal to the dispersing air flow of about 44 to 67 m/sec (100 to 150 mph). Accelerating the liquid from zero velocity to the velocity of the air blast sprayer atomizes the liquid, creating an aerosol that can enter the worker's breathing zone. This causes detectable pesticide exposure via respiratory and skin exposure routes.<sup>(3-5)</sup> Dermal and ingestion exposures have been reported to cause fatalities.<sup>(6)</sup>

Pesticide labels specify the clothing and personal protective equipment that must be worn during pesticide handling activities. The U.S. EPA Worker Protection Standard (WPS) requires that applicators and workers must wear the personal protective equipment specified by the pesticide label.<sup>(7)</sup> The WPS allows applicators to reduce the amount of personal protective equipment worn when operating in an enclosed cab. For respiratory protection, a cab must provide protection that is equivalent to the respirator type specified by the pesticide label. To comply with the WPS, a government agency or manufacturer must declare in writing that the enclosed cab provides protection that is equivalent to the protection provided by a respirator.

The combined use of a respirator and chemical protective clothing will reduce the ability of the body to dissipate heat through the evaporation of sweat. In addition to the hazards posed by pesticides, handlers and workers are potentially exposed to excessive heat stress during warm weather. To protect the applicator from pesticide exposure, tractor cabs have been devised that offer protection from pesticide sprays and heat stress. A blower draws air through a preliminary filter, a higher efficiency particulate air filter, and a carbon filter to remove pesticide aerosols and vapors. The enclosure also includes air conditioning. In addition, some tractor cabs meet roll over protection structure (ROPS) standards.

In recent years, the California Environmental Protection Agency (Cal EPA), Department of Pesticide Regulation, has recognized certain enclosed cabs that provide adequate dermal and respiratory protection for pesticide application. Their criteria include field testing of the cab.<sup>(8,9)</sup> The test procedures require operation of the enclosure in an environment where the pesticide is being dispersed by air blast spraying. The pesticide concentration in the air inside and outside of an enclosed cab is measured. For a cab to be considered acceptable, the ratio of the concentration outside of the cab to the concentration inside the cab must be greater than 50. This ratio is termed the "protection factor." Frequently, pesticide concentrations outside a cab are not large enough to determine whether the cab offers a protection factor of 50. Given the low concentration of pesticides, such testing is difficult and needs to be repeated.

To avoid these problems, environmental cabs are evaluated by using the ambient aerosol and dust generated by the operation of the tractor as a challenge aerosol. Optical particle counters are used to measure aerosol concentration inside and outside the cab. Penetration is defined as the ratio of aerosol concentration inside the cab to the aerosol concentration outside the cab. This

approach has been used by the American Society of Agricultural Engineers (ASAE) to develop ASAE S525. The technique described in the ASAE consensus standard involves switching two identical optical particle counters between the inside and outside of an agricultural enclosure during routine operations.

The ASAE consensus standard specifies requirements for environmental enclosures that are used for controlling applicator exposure to pesticide spray mist.<sup>(10,11)</sup> Cabs, which are certified under this standard, may be used instead of respirators to meet the requirements of the Worker Protection Standard.<sup>(7)</sup> Three important specifications in the ASAE consensus standard describe the performance of these enclosures for particulate air contaminant:

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 for particles larger than 3  $\mu\text{m}$ ; and,
3. The filtration efficiency shall be at least 99 percent for particles larger than 3  $\mu\text{m}$ .

During this study, data were collected when driving tractors fitted with enclosures over unpaved surfaces. Because equipment manufacturers were interested in using particulate filters that address particulate larger than three micrometers aerodynamic diameter, pesticide spray distribution data were collected to evaluate the appropriateness of the particle size distribution assumptions inherent in the standard.

The data collected during this study predate the ASAE S525 and were collected to address the following objectives:

1. Evaluate the ability of these cabs to protect workers from particulate exposures.
2. Demonstrate the ease and practicality of using optical particle counters to evaluate the ability of cabin filtration systems.
3. Measure pesticide particle size distributions during an air-blast spray operation.

To evaluate the ability of cabs to protect pesticide applicators, the optical particle counters were used to measure aerosol penetration into the cab while the tractor was driven over unpaved surfaces at speeds of 3-5 k/hr. Due to concerns that the S525 standard addresses only particles larger than 3 micrometers, pesticide size distribution measurements were made to determine the proportion of particles smaller than 3 micrometers.

## METHODOLOGY

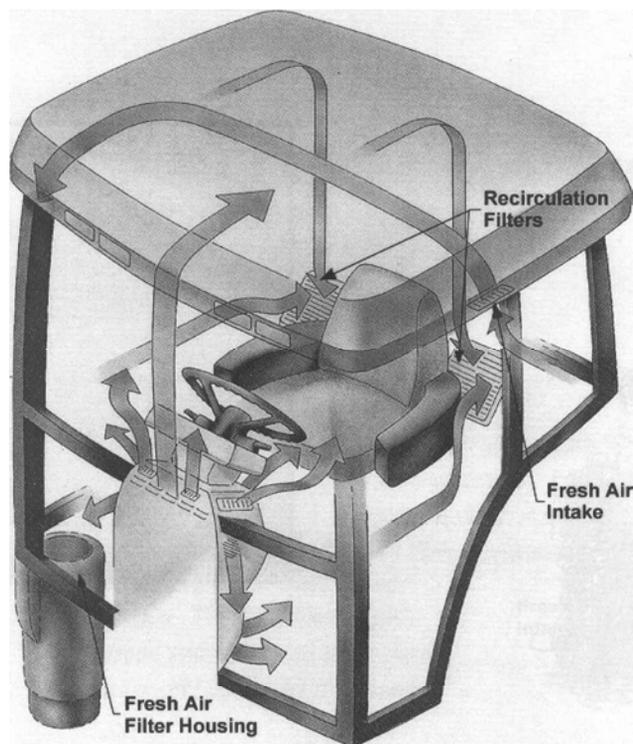
In the early stages of the project, preliminary surveys were conducted on three different manufactured agriculture enclosures. Two of these enclosures (made by two different manufacturers) met the California EPA protection criteria. The results of these preliminary surveys indicated that aerosols are entering the cab through leak sources or are being generated inside the cab. The results obtained during the preliminary surveys identified the need for field evaluations to identify the sources of

aerosols inside the cab. The field evaluations were conducted on a tractor manufacturer's cab (John Deere 7000 series tractor cab) and a retrofit cab (Nelson Spray Cab designed to fit on a Massey Ferguson 396 tractor). The tractor manufacturer's cab was designed and included as an integral part of the tractor during the manufacturing process. The retrofit cab is an after market cab that was not designed to be an integral part of the tractor during the tractor manufacturing process. Filter (HEPA) media were required in both cabs to remove the test aerosol (i.e., atmospheric condensation nuclei).

## Cab Design

### *Tractor Manufacturer's Cab*

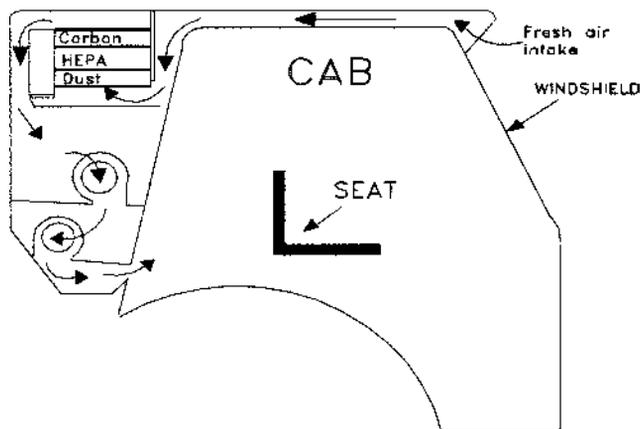
Figure 1 describes air flow in the tractor manufacturer's prototype cab.<sup>(12)</sup> The field evaluation was performed on a John Deere 7000 series tractor cab equipped with a HEPA filter inside the fresh air filter housing. The cab was also equipped with recirculation filters (paper pleated filters approximately 95% efficient at removing particles of 3  $\mu\text{m}$  in diameter) inside the cab. Fresh air enters the ventilation system from the top portion of



**FIGURE 1**

Diagram of air flow inside the Tractor Manufacturer's cab.<sup>(12)</sup>

Figure obtained from the following: American Journal of Industrial Medicine Supplement 1:75-76 (1999). Use of Ambient Aerosol for Testing Agricultural Cabs for Protection Against Pesticide Aerosol, William A. Heitbrink, Ronald M. Hall, Laurence D. Reed, and Dennis Gibbons. Wiley-Liss, Inc., a subsidiary of John Wiley & Sons, Inc.



**FIGURE 2**

Diagram of air flow through filters and into the retrofit cab.<sup>(13)</sup>

the cab above the door. The fresh air flows through ventilation ducts over the cab and down through the front right side structure beam (part of the ROPS) into the fresh air filter housing located beneath the right side of the cab. The fresh air is then pulled through the fresh air blower and transported through ventilation ducts to the evaporator/heater core housing. At this point the fresh air and recirculated air is pulled through the recirculation blower and transported to the outlet louvers inside the cab.

### *Retrofit Cab*

Figure 2 describes the air flow pattern in the retrofit cab.<sup>(13)</sup> This cab, a Nelson Spraycab, is designed to fit on a Massey Ferguson 396 tractor and also serves as a ROPS. The cab is designed to pull fresh air into the ventilation system from the front top portion of the cab. The fresh air flows through a filter system that consist of three separate filters. The first is a pre-filter (paper filter to remove larger particles) that is followed by a HEPA filter and an activated carbon filter. After the air passes through the filters it is then blown into the cab through louvers located behind the operator seat and maintains positive pressure inside the cab.

## Study Methods for Cab Evaluation

All measurements taken inside and outside of the cabs were collected while the tractors were driven in a dirt lot or in a tilled field. The tractors were driven in a dirt lot or field to assess how well the cab remains sealed and its ability to remove dust particulate in field conditions. A portable dust monitor (model 1.106, Grimm Technologies, Ainring, Germany) was used to measure dust number concentration inside and outside of the cabs. This instrument sizes the particles based upon the amount of light scattered by individual particles. It counts the individual number of particles in eight size channels between 0.4 and 6.5  $\mu\text{m}$ . Particles are sized based upon the amount of light scattered by individual particles. The portable dust monitor (PDM) operates at a flow rate of 1.2 Lpm. In addition, another optical particle counter and a condensation particle counter were used

to evaluate the cabs. Because the results from these instruments were consistent with the Grimm PDM results, the results from the other two instruments are not presented here. However, the complete results are available in survey reports, which are available from NTIS.<sup>(14,15)</sup>

During the evaluations, one PDM was placed inside the tractor cab near the tractor operator to count dust particles. Another PDM was placed directly outside the cab near the air intake. During the evaluations, the instruments were switched to obtain additional readings and avoid instrument-to-instrument variability biasing the results. That is, instruments located inside the cab were placed outside and vice versa. The PDMs were run for approximately 30 minutes and then switched. This process was repeated four times to collect enough data for analysis. The data collected from the PDMs were downloaded into a portable computer and placed in a spreadsheet for analysis. Size-dependent penetration into the cab was estimated as the ratio of the concentration measured inside the cab to concentration of particles outside the cab.

The air velocities into the fresh air inlet and out the exhaust of the louvers (inside the cab) were estimated with a velometer. An autozero digital micro manometer, MP series 4 (Solomat, a Neotronics company, Norwalk, CT), was used during the field test to measure air pressure inside the cab. A Metrosonic dl-3200 data logger (Metrosonic Inc., Rochester, NY) was used to record the data output of the digital micro manometer throughout the field evaluations.

### Pesticide Study Methods

Because of concerns over the size of pesticide aerosols generated during air blast spray operations, pesticide size distributions

were measured at a site on an orchard in California's central valley near Visalia. The pesticide size distribution portion of the study did not involve a tractor cab. An air blast sprayer directed a pesticide solution containing 1.5 gallons of chlorpyrifos in 500 gallons of water at instruments (located near the sprayer) used to measure aerosol size distributions. The aerosol size distribution was measured by an aerodynamic particle sizer (APS Model 33b, TSI, St. Paul, MN) and a micro-orifice uniform deposit impactor (MOUDI, MSP corporation, St. Paul, MN). Using the APS, individual particles are sized based upon their transit time as they are accelerated between two laser beams. As particles pass through the two laser beams, scattered light is detected by two photo multiplier tubes. The time difference between these two events is measured. The MOUDI is an eight-stage cascade impactor that was operated at a flow rate of 30 Lpm. This impactor is unique in that each stage rotates, allowing the collected material to be uniformly deposited on the filters. The pesticide spray mist was collected on aluminum substrates that were coated with vegetable oil (PAM). The 50 percent cut diameters for this impactor are: 18, 10, 6.2, 3.2, 1.8, 1.0, 0.32, and 0.18  $\mu\text{m}$ . The last impaction stage was not used. The impaction stages were backed up with a 0.8  $\mu\text{m}$  mixed cellulose ester membrane filter.

The impaction stages and the backup filter were analyzed by Datachem Laboratories, Inc. (Salt Lake City, UT) for the pesticide chlorpyrifos by a modification of *NIOSH Manual of Analytical Methods 5600*.<sup>(16)</sup> The pesticide was desorbed by rotating the aluminum substrates in 5 ml of isopropyl alcohol overnight. The filters were desorbed for one hour in 2 ml of a toluene and acetone (9:1) solution. The samples were analyzed using a gas chromatograph operated with a flame photometric detector in phosphorus mode. The conditions in the gas chromatograph

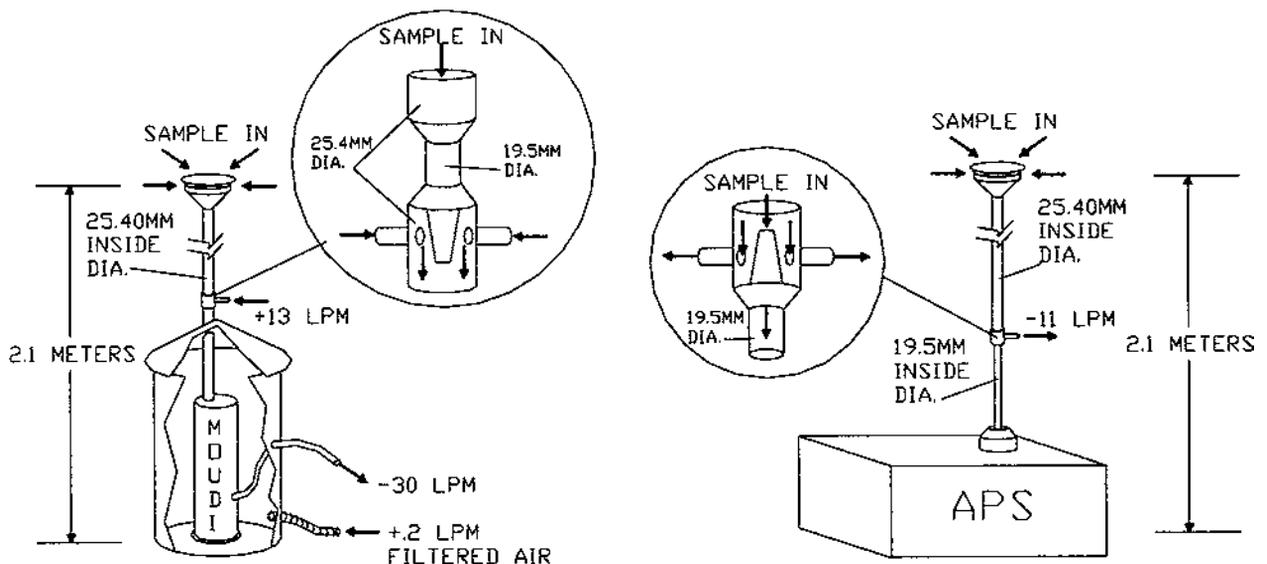


FIGURE 3

Schematic of equipment used to measure particle size distribution.

were as follows:

Column:	30 m × 0.53 mm fused silica capillary column coated internally with 1.5 μm DB-1
Oven conditions:	225°C isothermal for 8 minutes
Injectors:	5 μL into a 225°C injector

The limit of detection for this method was 0.1 μg per sample. For reasons that have yet to be determined, it was difficult to reproducibly spike the oil surfaces. Quality control spike recoveries varied from 84–96 percent. Media standards were used to correct for the variability.

Particle size measurements using the APS and MOUDI were not made at the same time. These instruments sampled air through the sampling train described in Figure 3. The inlet to this sampling train was the omnidirectional inlet from a PM<sub>10</sub> sampler (Anderson-Grasby). The design flow for the PM<sub>10</sub> sampler is 17 Lpm and the design flow for the MOUDI is 30 Lpm. Therefore, the sampling train was designed so that 17 Lpm could be pulled through the PM<sub>10</sub> sampler and an additional 13 Lpm of sheath air could be added after the sample inlet to supply a total of 30 Lpm to the MOUDI (see Figure 3). The MOUDI was enclosed in a positive pressure container to eliminate the possibility of small aerosols (generated by the air blast sprayer) leaking between the sample stages. The PM<sub>10</sub> sampler was also used in the sampling train with the APS. The APS operated at its design flow rate of 5 Lpm. In an effort to pull the air through the PM<sub>10</sub> sampler at its design flow rate an additional pump was used in the sampling train. The APS and the additional pump pulled air through the PM<sub>10</sub> sample inlet. The sampling train was designed so that the APS could collect isokinetic samples (see Figure 3).

Two 40-minute samples were collected using the MOUDI and one 20-minute sample was collected using the APS. The air blast sprayer (FMC) was used with orifices that had diameters of 0.12 and 0.23 cm. The air velocity near the nozzles was 54 m/sec (10,600 fpm) based upon a velocity pressure measurement.

## RESULTS

The PDM used in the field study counted aerosols in eight different size ranges from 0.4 to 6.5 μm. The apparent penetration into the cab, the upper 95 percent confidence limit on this penetration, and the standard deviation of penetration are plotted as a function of particle size (see Figure 4). The John Deere cab was more than 99 percent efficient at removing aerosols larger than 3.0 μm in diameter and had protection factors greater than 260 for particles larger than 3.0 μm. The Nelson cab was more than 99 percent efficient at removing aerosols larger than 3.0 μm in diameter and had protection factors greater than 200 for particles larger than 3.0 μm. For aerosols smaller than 1.0 μm in diameter, the John Deere cab provided a mean protection factor of 43 and the Nelson cab provided a mean protection factor of 16.

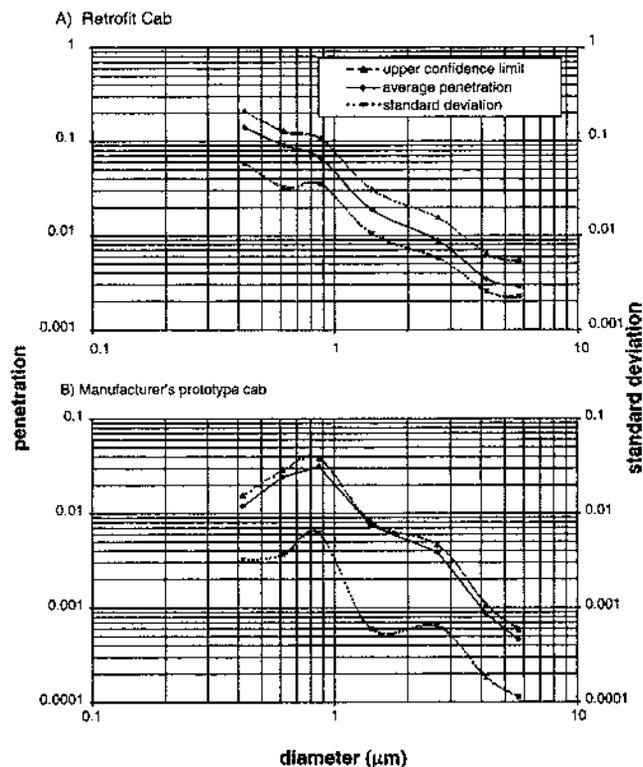


FIGURE 4

The penetration, upper confidence limit on penetration, and the standard deviation of penetration for two tractor cabs.

Penetration is the ratio of the concentration inside the cab to the concentration outside the cab. Manufacturer's prototype cab figure obtained from the following: American Journal of Industrial Medicine Supplement 1:75–76 (1999). Use of Ambient Aerosol for Testing Agricultural Cabs for Protection Against Pesticide Aerosol, William A. Heitbrink, Ronald M. Hall, Laurence D. Reed, and Dennis Gibbons. Wiley-Liss, Inc., a subsidiary of John Wiley & Sons, Inc.

## Ventilation

Ventilation measurements were taken at the top right corner of the tractor manufacturer's cab where the fresh air flows through the opening of the structure beam (part of the ROPS system). The area of the opening is 0.035 square feet. The average air velocity during the field evaluation was 2,000 fpm, which resulted in an air volume of 70 cfm for the tractor manufacturer's cab. Ventilation measurements were collected at the air louvers inside the retrofit cab. These air louvers are located in the back of the cab behind the operator. The area of the opening in the air louvers is 0.2 square feet. The average air velocity exiting these openings was 1,300 fpm, which resulted in an air volume of 260 cfm for the retrofit cab.

Pressure measurements inside both cabs were collected with an auto-zero digital micro manometer. The data output of the micro manometer was recorded with a data logger. The pressure remained positive inside both of the cabs during our evaluations.

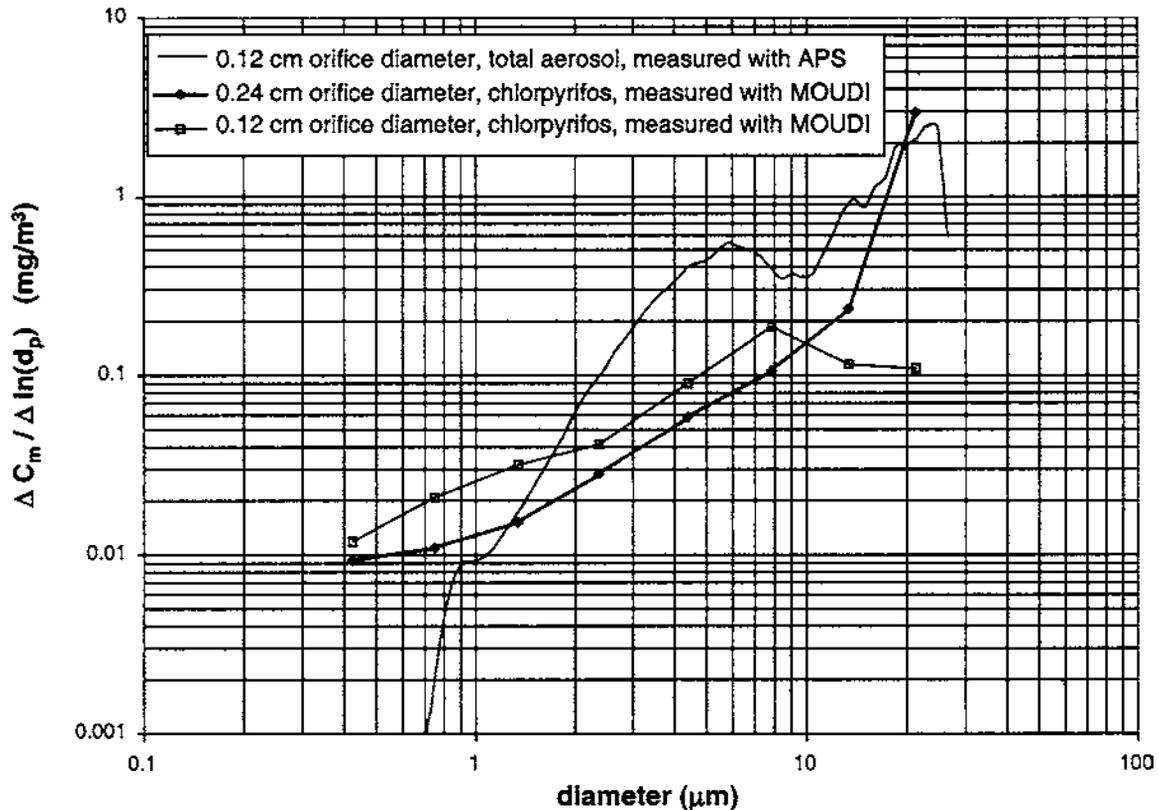


FIGURE 5

Pesticide particle size distributions measured with MOUDI and spray mist distribution measured with APS.

The average pressure reading inside the John Deere cab was 0.75 inches water gauge (wg) with a standard deviation of 0.12. The Nelson cab had an average pressure reading of 0.3 inches wg with a standard deviation of 0.04.

### Pesticide Study Results

Figure 5 presents measured size distribution results. The measured distributions indicate that there is a noticeable mass of aerosol in sizes less than  $3 \mu\text{m}$ . This is surprising in that most of the literature and pesticide sprays indicate that this spray is typically larger than  $100 \mu\text{m}$ . However, the spray concentration was 1.5 gallons of concentrate in 500 gallons of water. The concentrate was 50 percent petroleum distillate. When the water evaporates from the spray, a  $100 \mu\text{m}$  spray droplet will become an  $11 \mu\text{m}$  particle. (Note: The dried droplet size is proportional to the cube root of the mass fraction of the nonvolatiles.) This suggests that pesticide spray that does not deposit on the crop or on the ground could become a much smaller particle due to evaporation, thus explaining the generation of particles smaller than  $3 \mu\text{m}$ .

Table I presents concentration data obtained from the measurement of size distribution. Results for particles smaller than  $3 \mu\text{m}$  are presented because an American Society of Agricultural Engineers (ASAE) consensus standard specifies that agricultural

enclosures must have a 50-fold reduction in exposure for particles larger than  $3 \mu\text{m}$ . The results presented in Table I indicate a range of 3 percent to 23 percent of the chlorpyrifos aerosol mass was smaller  $3 \mu\text{m}$ . However, the mass concentration for these

TABLE I

Spray mist concentrations measured during size distribution measurements

Measurement	Total concentration (mg/m <sup>3</sup> )	Concentration smaller than $3 \mu\text{m}$ (mg/m <sup>3</sup> )
Chlorpyrifos concentration measured with a MOUDI. The spray nozzle had a diameter of 0.23 cm.	1.3	0.04
Chlorpyrifos concentration measured with a MOUDI. The spray nozzle had a diameter of 0.12 cm.	0.3	0.07
Total spray mist concentration measured with the APS. The spray nozzle had a diameter of 0.12 cm	1.9	0.07

particles was less than the American Conference of Governmental Industrial Hygienists (ACGIH<sup>®</sup>) Threshold Limit Value (TLV<sup>®</sup>) for chlorpyrifos, 0.2 mg/m<sup>3</sup>.<sup>(17)</sup>

## DISCUSSION

The results from this study indicate that tractor cabs can be effective at protecting against different size aerosols depending on the seals and filters used with the enclosure. As shown in Figure 4, the upper 95 percent confidence limit on the penetration of particles larger than 3  $\mu\text{m}$  was less than 0.02 for both cabs. These cabs also provide measurable exposure reduction for submicrometer-sized aerosol. The studied cabs provide at least a factor of 5 reduction in exposure for 0.3  $\mu\text{m}$  particles. This suggests that this technology has application in surfacing mining vehicle such as bulldozers and truck-mounted drills, where excessive crystalline silica exposures have been reported.<sup>(18)</sup> This study has also demonstrated the practical use of real-time aerosol counting instrumentation to evaluate the effectiveness of enclosures. The method used in this study can be applied to various cabs used in different industries including agriculture, construction, and manufacturing.

The pressure measurements collected inside the cabs indicate that they remained under positive pressure during our field evaluations. The positive pressure inside the cabs reduces the possibility of aerosols entering through leak sources other than around the filters and seals in the ventilation system. Therefore, any leakage of small particles ( $<3 \mu\text{m}$ ) into the cabs may be a result of these small particles penetrating around the seals used to hold the filters in place in the ventilation system. It is not likely that there is significant penetration of small particles through the filters themselves. There is also a possibility that some of the small aerosols (inside the cab) could be generated by the blowers or generated from the operator movement inside the cab.

During the pesticide measurement study, the air blast sprayer was directed at the samplers, which were some 4–5 meters from the sprayer. Therefore, the concentrations presented in Table I represent worst-case conditions. Even though the chlorpyrifos concentrations for particles smaller than 3  $\mu\text{m}$  were less than the ACGIH TLV, as much as 23 percent of the total pesticide aerosol concentration was smaller than 3  $\mu\text{m}$ . The ASAE standard S525 Part 1 specifies a factor of 50 reduction in exposure at 3  $\mu\text{m}$ .<sup>(11)</sup> The limited pesticide concentration and size data for particles smaller than 3  $\mu\text{m}$  suggest that the ASAE standard may need to specify some reduction in exposure to a smaller particle size.

The generation of spray particles smaller than 3  $\mu\text{m}$  is not surprising. Spray droplets are coarse and the mean droplet size is in excess of 100  $\mu\text{m}$ . Because the initial pesticide spray aerosol may contain approximately 0.1 percent active ingredient in water,<sup>(19)</sup> water evaporation could cause a factor 10 reduction in pesticide particle size. Womac reported that as much as 5–10 percent of the spray is smaller than 44  $\mu\text{m}$ .<sup>(20,21)</sup> Based upon Womac's data and droplet evaporation, 5–10 percent of the pesticide aerosol could be in particles smaller than 4  $\mu\text{m}$  particles.

In actual use, some applicators will inevitably apply pesticide under conditions that favor droplet evaporation, such as low humidity. This situation suggests that environmental cabs need to address exposures caused by particles smaller than 3  $\mu\text{m}$ .

## CONCLUSIONS

Environmental cabs can provide meaningful exposure reduction to particulate air contaminants and their use needs to be encouraged. Potentially, this technology can be used to control worker exposure to dusts generated by surface mining vehicles and outdoor construction equipment where silica exposures are a concern. Because of the potential for small particle penetration, consensus standards for these cabs should address particles smaller than 3  $\mu\text{m}$ .

## ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts and contributions of Barry Smith, Norm West (John Deere Manufacturing Co., Inc.), and Bob Nelson (Nelson Manufacturing Co., Inc.) who provided equipment and assistance for our surveys. We would like to acknowledge Dennis Gibbons (California EPA) for providing necessary contacts for our studies and assisting in field surveys, and we would also like to acknowledge Dan Watkins (NIOSH) for his technical support on the tractor cab evaluations.

## DISCLAIMER

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

## REFERENCES

- Novello, Antonia C.: Papers and Proceedings, Surgeon General's Conference on Agricultural Safety and Health, A Charge to the Conference. Papers and Proceedings of the Surgeon Generals Conference on Agricultural Safety and Health, Public Law 101-517, April 30–May 3, 1991, Des Moines, Iowa (1991).
- American Thoracic Society: Respiratory Health Hazards in Agriculture. *Am J Resp Crit Care Med* 158:s1–s76 (1998).
- Carman, G.E.; Iwata, Y.; Pappas, J.L.; O'Neal, J.R.; Guther, F.A.: Pesticide Applicator Exposure to Insecticides During Treatment of Citrus Trees with Oscillating Boom and Air Blast Units. *Arch Environ Contam Toxicol* 11:651–659 (1982).
- Wojeck, G.A.; Nigg, H.N.: Worker Exposure to Pesticides in Florida Citrus Operations. *Proc Fla State Hort Soc* 93:60–62 (1980).
- Lunchick, C.; Nielsen, A.P.; Reinert, J.C.: Engineering Controls and Protective Clothing: Second Symposium, STP 989, p. 605–610.: American Society of Testing Materials, Philadelphia (1988).
- Osoria, A.M.; Ames, R.G.; Rosenberg, J.; Mengle, D.C.: Investigation of a Fatality Among Parathion Applicators in California. *Amer J Indus Med* 20:533–546 (1991).
- Title 40 Code of Federal Regulations, Part 170.240. August 21, 1992.

8. Department of Pesticide Regulation: Criteria for Enclosed Cabs That Provide Respiratory Protection. February 28, 1995. State of California, California Environmental Protection Agency, Sacramento (1995).
9. California Department of Food and Agriculture: Compliance Strategy for Enclosed Cabs. Sacramento, CA, January 30, 1991.
10. Smith, B.L.: Environmental Cab Standard Development and Application. Presented at the 1998 ASAE Annual International Meeting, Orlando, FL, July 12–15, 1998. Paper Number 981001. ASAE, St Joseph, MI (1998).
11. American Society of Agricultural Engineers: Agricultural Cabs—Environmental Quality. Part 1: Definitions, Test Methods, and Safety Practices. Standard S525-1.1. ASAE, St Joseph, MI (1997).
12. John Deere 7000 Series Tractor Boucher, DKA 103 Litho in U.S.A. (94-04).
13. Nelson Manufacturing Co. Inc., Diagram of Air Flow into a Nelson Spraycab<sup>®</sup>, 2860 Colusa Hwy. Yuba City, CA 95993.
14. Hall, R.M.; Heitbrink, W.A.; McGlothlin, J.D.: In-depth Survey Report: Control Technology for Agricultural Environmental Enclosures at Nelson Manufacturing Co., Yuba City, California, October 9–11, 1996. NTIS Pub. No. PB 97-206262. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, OH (1997).
15. Hall, R.M.; Heitbrink, W.A.: In-depth Survey Report: Control Technology for Agricultural Environmental Enclosures at John Deere Manufacturing Co., Waterloo, Iowa, April 15–19 and August 5–9, 1996. NTIS Pub. No. PB 97-206288. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, OH (1997).
16. NIOSH: Manual of Analytical Methods, Method 5600, 4th ed., Vol. 2, DHHS (NIOSH) Publ. No. 84-100 Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health (1985).
17. American Conference of Governmental Industrial Hygienists: 1999 TLVs<sup>®</sup> and BEIs<sup>®</sup>. ACGIH: Cincinnati, OH (1999).
18. Tomb, T.F.; Gero, A.J.; Kogut, J.: Analysis of Quartz Exposure Data Obtained from Underground and Surface Coal Mining Operations. *App Occup Environ Hyg* 10(12):1019–1026 (1995).
19. Yeung P.; Cantrell, P.; Murdoch, A.; Rogers, A.; Apthorpe, L.; Vickers, C.; Coaty, G.: Exposure of Air Blast Applicators to Ethyl Parathion and Methyl Parathion in Orchards: A Comparison of Australian Conditions to Overseas Predictive Models. *App Occup Environ Hyg* 13(4):242–251 (1998).
20. Holmberg, M.: Defining Droplet Sizes—Tennessee Project Compares Drift Reducing Spray Tips. *Successful Farming*, October 1997, 95(10):52–54 (1997).
21. Womac, A.R.; Goodwin, J.C.; Hart, W.E.: Tip Selection for Precision Application of Herbicides—A Look-Up Table of Drop Sizes to Assist in the Selection of Nozzles. Bulletin 695. University of Tennessee Agricultural Experiment Station, Knoxville, TN (1997).