IN-DEPTH SURVEY REPORT:

CONTROL TECHNOLOGY FOR ENVIRONMENTAL ENCLOSURES – AN EVALUATION OF IN-USE ENCLOSURES

AT

SUN PACIFIC BAKERSFIELD, CALIFORNIA

REPORT WRITTEN BY
William A Heitbrink, Ph D , C I H
Ernest Moyer, Ph D

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U S Department of Health and Human Services
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Division of Applied Research and Technology
4676 Columbia Parkway, Mail Stop R5
Cincinnati, OH 45226

STUDY SITE	Sun Pacific 33374 Lerdo Highway Bakersfield, California 93308
EMPLOYER REPRESENTATIVE	Frank Wisehardt Grape Manager
CONTACT AT JOHN DEERE	Norm West John Deere Product Engineering Center P O Box 8000 Waterloo, Iowa 50704-8000 Lewis Beggs North Kern Machinery P O Box 8000 Delano, California 93216
SIC CODE	0172
STUDY DATES	October 27, 1999
STUDY CONDUCTED BY	William A Heitbrink, Ph D , NIOSH Ernest Moyer, Ph D , NIOSH
EMPLOYEE REPRESENTATIVE	No Union
MANUSCRIPT PREPARED BY	Debra A Lipps

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ABSTRACT

A tractor equipped with an environmental enclosure for pesticide application (John Deere Model 6410) was evaluated after it had been in use for about one year Optical particle counters were used to measure the particle number concentration inside and outside of the cab during a discing operation The evaluation was conducted with old filters which had about 700 hours of service and with new replacement filters Changing the filters did not greatly affect the exposure reduction offered by the filters The exposure reduction and static pressure in the cab were acceptable in terms of American Society of Agricultural Engineers Standard S525 However, the dust concentration in the cab increased as the testing was conducted The reason for this increase and its significance are unclear

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 Applied Research and Technology (DART) studies the engineering aspects relevant to the control of hazards in the workplace Since 1976, the engineering component of 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 being 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 The ratio of inside to outside enclosure concentrations was measured to evaluate aerosol penetration into the cab

Such enclosures can be used to protect heavy equipment operators from crystalline silica exposures during surface mining and other earth-moving operations [3] 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 [4] Appropriate cabin filtration and pressurization appear to have the potential for controlling worker exposure to respirable crystalline silica

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 to 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 recirculate 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 [5,6] 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 [7] Three important specifications in this consensus standard describe the performance of these enclosures for particulate air contaminants

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 concentration 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% for particles larger than 3 μm

Aerosol penetration into the enclosure is evaluated by using optical particle counters (OPCs) to measure the concentration of particles in the 2- to 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 to 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 [8] 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's design and construction are acceptable 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

Sun Pacific uses John Deere Model 6410 tractors equipped with filters for pesticide application This tractor was less than a year old This particular model had been certified under ASAE Standard S525 The pressure gauge on the tractor indicated that this tractor was maintained at a static pressure of 0 3 inches of water The ventilation system for John Deere Cabs uses two blowers A pressurization blower draws air through filters and discharges air into a mixing plenum A second fan draws air from the cabin and discharges the air into this mixing plenum The combined air flows passes through heat exchangers for air-conditioning and heating and into the cab

PROCEDURES

Before evaluating aerosol penetration into a tractor, the air flow into the cab was measured using a rotating vane anemometer (Model HTA4200, Pacer Industries, Chippewa Falls, Wisconsin) Air velocities were measured at the inlet The airflow volume was estimated as the product of the average velocity and the cross-sectional area of the inlet Enclosure static pressure was recorded using an electronic manometer (Model MP20SR, Neutronics, Herts, United Kingdom)

The aerosol penetration into the cab was evaluated while an operator disced a grape orchard to mix harvesting debris into the soil 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 simulated cab One Grimm PDM was placed in the cab near the driver This instrument was used with the omni-directional sampling inlets One was attached with elastic cords to the metal ledge above the tractor's power take off The omni-directional inlet to this optical particle counter was replaced with an impactor (PEM 200-2-10, MSP Corporation, Minnesota) 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 Grimm PDM outside the tractor was used with an impactor (PEM 200-10-2, MSP Corporation, Minneapolis, Minnesota) instead of the omni-directional inlet This impactor was designed to be operated at 2 Lpm to have a 50%-cut diameter of 10 µm This impactor was operated at a flow rate of 1 2 Lpm Instead of having a cut diameter of 10 µm, the impactors had an estimated cut diameter of 14 µm The 50% cut diameter, d_p, the particle size at which the impactor is 50% efficient can be computed as follows[9]

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

Where

Stk = stokes number, at a Reynolds number of 200, the stokes number is 0 25
w = jet diameter (0 29 cm)
Q = air flow through each impactor jet (cm^3/sec)
η = viscosity of air (poise)
d_p = particle diameter in cm

The impactor was used to protect the Grimm PDM from an excessive amount of dust which was generated by driving the tractors through grape vineyards which had not received noticeable rain in over a month Under each of the impaction jets, there was a 0 2- to 0 3-cm thick pile of dust

The Grimm PDMs were used to measure aerosol penetration into the cab while the tractor was discing the vineyard During discing, an implement with a number of metal discs ranging from 30 to 60 cm in diameter are dragged behind the tractor to work debris from the harvest into the soil and to leave flat, smooth soil between the rows of grapes During the first two runs, data was collected with the old filters in the tractor The Grimm PDMs were switched between runs to minimize instrument-induced bias Then, the Grimm PDMs were used to measure the aerosol concentration inside and outside the stationary tractor The main filters and the recirculation filters in the tractor were replaced During the next two experimental runs, the optical particle counter data was collected while the tractor disced the vineyard Between the experimental runs, the Grimm PDMs were switched to minimize between-instrument bias After the tractor had stopped, the stationary measurements were made with the Grimm PDMs

RESULTS AND FINDINGS

Table 1 lists identifying marks on the tractor and ventilation measurements made on the tractor's ventilation system The flow rate into the cab of 37 cfm and the static pressure in the cab of 0 3 inches of water exceed the ASAE standard specification of 25 cfm for a flow rate and 0 25 inches of water static pressure [6] Figure 1 shows aerosol penetration into the cab measured when the tractor was discing the vineyard The aerosol penetration into the cab remains below 0 02 for nearly all particle sizes In the data appendix, Tables 2 and 3 list the penetration into the cab and the raw optical particle counter data for each experimental run There is little difference between the efficiency of the old and new filters for particles smaller than 2 to3 µm For particles larger than 3 µm, the new filters apparently allow more penetration

Table 1 Tractor Specifications and Measurements

Specification	Number	Dimension
John Deere Model No.	**6410**	
Tractor Number	**2248**	
Frame Number	238618L	
Total cfm	37	cubic feet per minute
Static Pressure	0 3	inches of water
Time Filters in Use	703	hours

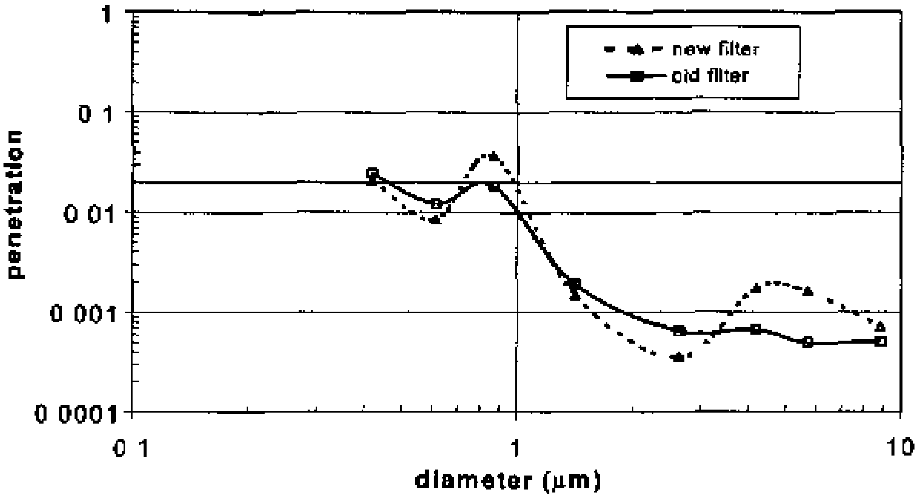

Figure 1 Aerosol penetration into cab with new and used filters The filters had 700 hours of use

When the filters were changed, about 2 to 3 kg of dust appeared to fall out of the filter holder This suggests that the filters were overloaded and the airflow rate into the cab was reduced

The dust concentration outside and inside the tractor were computed using the following formula

$$C_m = \sum_{i=1}^{8} \frac{1}{6} \pi d_i^3 \rho C_i$$

where

- C_m = mass concentration
- C_i = number concentration in a channel
- d_i = root mean diameter of the channel
- ρ = particle density

The formula assumes that the dust has a density of 1 gram/cc Dust concentrations inside the cab are shown in Figure 2 and in Table 4 which is in the appendix Figure 2 shows that the dust concentration in the cab increased with run number Linear regression between inside

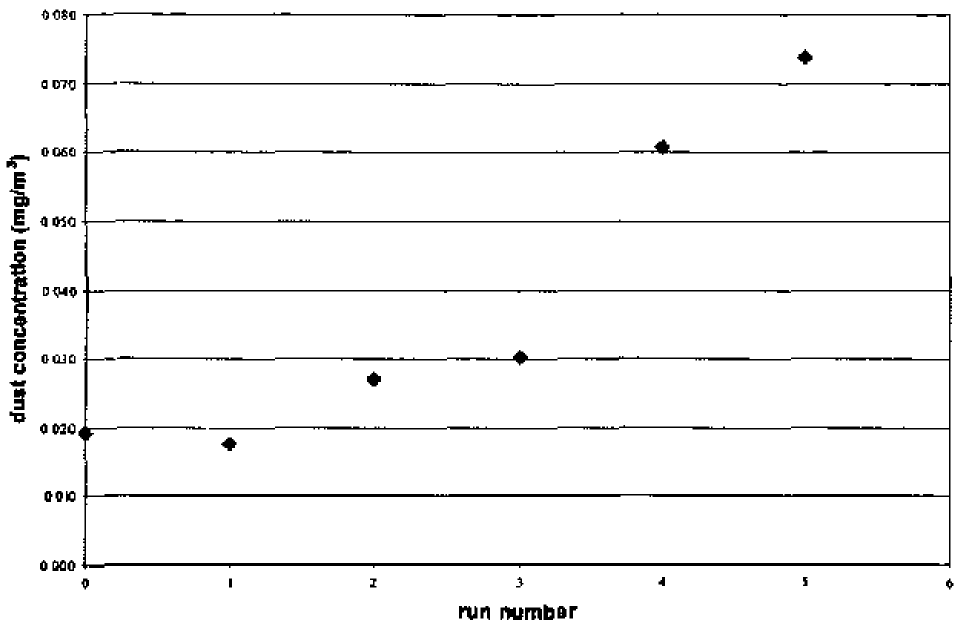

Figure 2 Dust concentration in the cab increased during the experimental runs

concentrations and run number showed that this relationship was significant (p=0 001 with an R^2 of 0 8) The dust concentrations outside of the tractor during discing were estimated to be as much as 60 mg/m^3 The highest dust concentration in the cab occurred during the last stationary measurements which was the last measurement During this period, the dust concentration reached 0 074 mg/m^3 in the cab In contrast, the concentration outside the cab was 0 28 mg/m^3

DISCUSSION

The tractor's cabin filtration system appears to be functioning very well and the spray cabs performance appears to have remained acceptable in terms of ASAE S525 However, the filters should be changed more frequently as specified by John Deere's recommendations The airflow rate though the filters may have been reduced due to the increased loading of the filters

The increase in particulate concentrations reported in Figure 2 is somewhat troubling In Figure 2, the dust concentration increased with run number and did not appear to reach steady-state This suggests that unacceptable amounts of dust could eventually accumulate in the cab This could cause excessive exposure to pesticide which might be on the dust or to respirable crystalline silica, a naturally occurring component of soil In some farming operations, occupational exposure to crystalline silica is a reported concern [10,11] The reason for this dust generation is unclear There are several possible explanations

1. Perhaps, the surface of the air-handling system downstream of the filter has become contaminated This could occur due to dust spilled during filter change Tractor vibrations could resuspend this dust

2. During the testing, the worker was in and out of the cab Perhaps, the interior surfaces of the cab are being contaminated with dust from the worker's clothing and shoes Then the motion of the tractor causes the dust to be resuspended

3. The recirculation filters are inadequate Perhaps using a more efficient recirculation filter would control the dust generated in the cab

A follow-up study could further evaluate this problem

CONCLUSION

The cabin filtration for the tested tractor only allowed a penetration 0 0245 for particles in the 0 035-0 5 µm when old filters were tested For particles larger than 3 µm, the particle penetration was under 0 01 Thus, the tractor's cabin filtration system on this tractor continued to the meet the specifications of ASAE S525 in terms of collection efficiency, flow rate, and pressurization However the filters should be changed every 500 hours as specified by the manufacturer During testing, the dust concentration in the cab increased from 10 to 70 $\mu g/m^3$ during the course of the testing The health consequences and the sources of this air contamination are unclear

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APPENDIX

Data Tables

APPENDIX - DATA TABLES

Table 2. Aerosol Penetration into Cabs								
Run Number	Lower Limit on Particle Size in a Channel (µm)							
	0 35	0 5	0 75	1	2	3 5	5	6 5
Old Filters								
0	0 0219	0 0129	0 0258	0 0023	0 0010	0 0016	0 0004	0 0004
1	0 0271	0 0121	0 0102	0 0017	0 0005	0 0007	0 0006	0 0007
New Filters								
3	0 0190	0 0090	0 0089	0 0017	0 0005	0 0019	0 0014	0 0005
4	0 0197	0 0087	0 0422	0 0017	0 0004	0 0015	0 0012	0 0007
Average Penetration								
new filter	0 0209	0 0083	0 0367	0 0015	0 0004	0 0017	0 0016	0 0007
old filter	0 0247	0 0121	0 0185	0 0019	0 0006	0 0007	0 0005	0 0005
Penetration Measured in a Stationary Mode								
2, old filter	0 01713	0 012785	0 01148	0 028267	0 130923	0 228623	0 25859	0 284992
5, new filter	0 02358	0 01764	0 020135	0 059582	0 157739	0 205757	0 22410	0 335884

Table 3 Number Concentration (Particles per Liter) During Penetration Measurements

				Lower Limit on Particle Size in a Channel (µm)							
Run	Grimm	Run Times	Location	0 35	0 5	0 75	1	2	3 5	5	6 5
Old Filters, Tractor Moving											
0	63	10 51-11 13	out	112759 6	76686 7	13406 4	100411 8	121743 6	98379 0	54268 0	92794 0
	64		in	2466 1	986 2	345 7	231 7	125 3	158 0	21 8	32 6
1	63	11 24-11 47	in	2514 4	991 4	317 0	243.7	105 7	79 4	32 4	53 3
	64		out	92745 6	82182 1	31162 8	140112 9	220753 9	110843 2	52756 6	73407 0
Stationary Tractor, Old Filters											
2	64	10 19-10 23	in	2666 2	826 8	233 4	168 2	95 6	75 4	28 6	33 8
	63		out	155609 6	64668 2	20324 4	5950 4	730 2	329 8	110 6	118 6
New Filters, Tractor Moving											
3	63	12 12-12 34	in	1917 5	793 4	291 2	288.0	175 5	125 8	47 3	53 0
	64		out	100659 6	88362 2	32878 7	164999 7	369812 2	66223 0	34623 3	109759 8
4	63	12 52-13 14	out	98979 4	87953 0	5877 8	147404 9	373849 8	67073 6	33297 1	122890 6
	64		in	1950 4	769 1	247 8	248 0	155 6	103 6	40 1	88 1
Stationary Tractor, New Filters											
5	63	13 20-13 24	out	151431 4	72955 6	20998 4	6048 8	1347 8	799	341 8	0 4
	64		in	3570 8	1287 4	422 8	360 4	212 6	164 4	76 6	158

Table 4 Dust Concentrations Inside		
Run Number	Inside Cab	Outside Cab
0	0 019	0 10
1	0 018	45 07
2	0 027	40 62
3	0 030	52 45
4	0 061	60 80
5	0 074	0 28