IN-DEPTH SURVEY REPORT:

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

AT

San Joaquin Helicopter Company
Delano, California

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ABSTRACT

Tractors equipped with environmental enclosures can be used to protect workers from pesticide spray mist and other particulate air contaminants In these cabs, a fan pulls air through filters and then blows this cleaned air into a cab, pressurizing the cab These enclosures may be used instead of respirators to protect the workers from pesticide spray mist Because such enclosures may be in use for many years, enclosure performance may degrade due to aging and inadequate maintenance To evaluate the extent to which this occurs, 3- to 4-year-old enclosures retrofitted to tractors were evaluated at San Joaquin Helicopter Company A single 3 to 4-year-old enclosure was evaluated Optical particle counters were used to measure the aerosol concentration inside and outside of the cab The ratio of these concentrations is termed penetration, the fraction of the aerosol which penetrates into the enclosure For particles in the 0 3 to 0 4 μm range, penetration into the cab was reduced from 0 11 to 0 004 by eliminating leakage around the filter Some of this reduction in penetration occurred because manufacturing mistakes were corrected This leakage occurred due to a bowed flange and inappropriate sealing of the sheet metal used to separate the incoming air from the air which has passed through the filter Also, the filter gasket material appeared to be a source of leakage When the gasket material on a used filter was replaced with new gasket material, the observed penetration was reduced from 0 048 to 0 0065 This suggests that the filter gaskets are deforming and allowing leakage The results collected during this survey indicate that the manufacturer needs to implement a quality control program to ensure that all cabs provide adequate exposure reduction Furthermore, the degradation of filter gasket material over time needs to be minimized to ensure that the environmental cabs continue to provide acceptable exposure reduction

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, 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

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 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 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 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 (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 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 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

San Joaquin Helicopter is a custom pesticide applicator which uses helicopters and tractors to apply pesticide to their customers' fields in the neighboring 3 or 4 counties This company has 30 to 40 Nelson Spray Cabs mounted on Massey-Ferguson tractors (Model 398) The tractors evaluated during this study were no more than 4 years old

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 Massey Ferguson Model 398 tractor is shown in Figure 1 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 The cab contains a magnehelic static pressure gauge The manual for this cab states that static pressures greater than 0 03 inches (0 85 mm) water gauge are necessary in order to protect the worker This cab was certified by California EPA before the ASAE developed the S525 standard

Figure 1 Photograph of cab setting on top of a tractor This photograph was taken during another survey, however, the same sampling location on the outside of tractor was used during this study

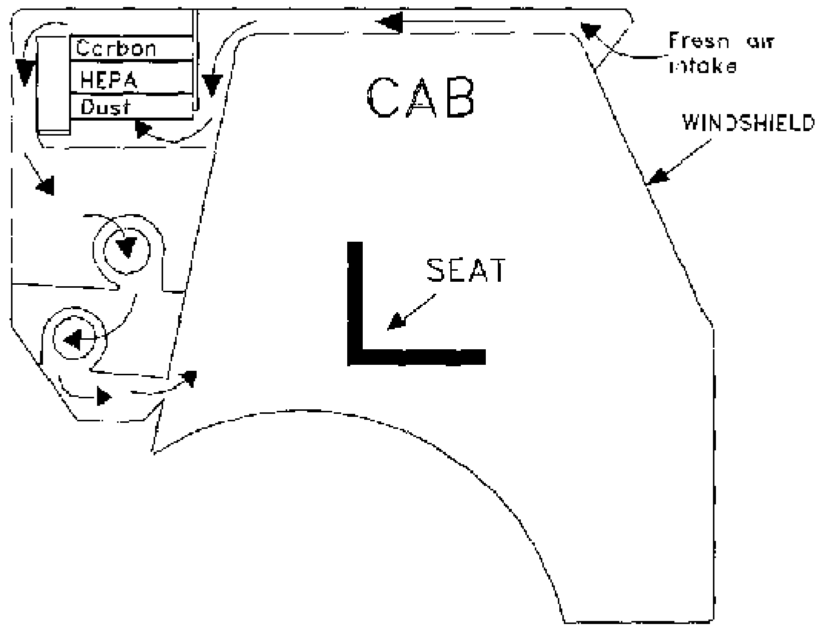

Figure 2 Schematic illustration of air flow into the ventilated cab

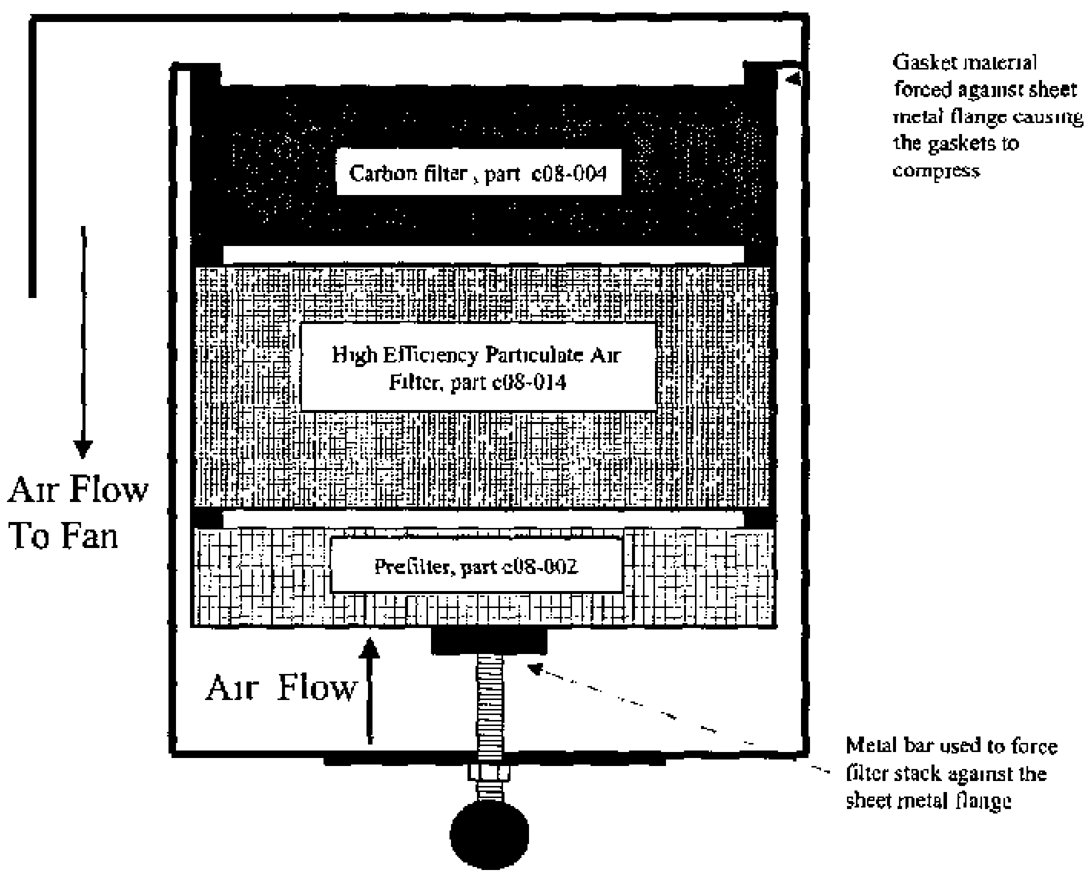

Figure 3 Schematic cross-sectional view of filters and mechanism for seating the filter

PROCEDURES

Before evaluating aerosol penetration into a tractor, the air flow into the cab was measured using a velometer (Velocicalc, TSI Inc , St Paul, Minnesota) 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 either the static pressure gauge in the enclosure or with an electronic manometer (Model MP20SR, Neutronics, Herts. United Kingdom)

The aerosol penetration into the cab was evaluated while an operator drove the tractor around the perimeter of a flat, unpaved field adjacent to the San Joaquin Helicopter facility in Delano The speed of the tractor was 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 1108, Ainring, Germany) were used to measure aerosol concentration inside and outside the simulated cab One was attached with elastic rubber cords to the engine cowling in the position shown in Figure 1 The second Grimm PDM was placed in the cab near the driver These instruments were used with their omnidirectional sampling inlets or impactors as sampling inlets The Grimm PDM counts individual particles and sizes each particle, based upon the amount of light scatted, into one of fifteen 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 sets of four measurements or replications The location of the optical particle counters was switched after each measurement During the course of the testing, significant leakage was found on the existing tractors As leakage and problems were identified, penetration into the enclosure was reduced The four test series are described in Table 1 During test series b, c, and d, the normal order of the filters was altered During these tests. the air flowed through the carbon filter, the prefilter, and then the HEPA filter

Table 1 Adjustments to Spray Cab

Test Series	Description
a	Untreated cab, as used during pesticide applications The filter used during this testing had 187 hours of use
b	After test series "a," a number of problems* were found by the supplier These included (1) the flange on the top of the filter holder was found to be bowed, allowing some air flow around the filters, (2) sheet metal seams separating the air which was upstream of filters from the air downstream of the filters were not caulked, allowing air to bypass the filter, and (3) the metal bar used to force the filters against the flange incorrectly mounted, causing an uneven pressure on the filter gaskets All of these problems would cause air to flow around the filter instead of through the filter These problems were corrected before these data were collected The filter had 115 hours of use
c	The holes in a new filter were fixed and the new HEPA filter was placed in the cab More caulking of the sheet metal separating the incoming air flow from the cleaned air which has passed through the filter
d	The used filters were repaired and the gaskets were replaced

* After the test series "a," Nelson Manufacturing promptly warned users of the correct way to use the filter-seating bar This notice is included in Appendix C

During the first two runs of a test series, the Grimms were operated with an impactor (PEM 200-2-2 5, MSP Corporation, Minneapolis, Minnesota) used as a preselector 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 [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 (cm)
Q = air flow through each impactor jet (cm^3/sec)
η = viscosity of air (poise)
d_p = particle diameter in cm

During the second two runs of a test series, the Grimms were operated with omnidirectional inlets By comparing the aerosol size distributions measured outside the cab with the impactor to the size distribution measured without the impactor, one can evaluate how closely the optical particle counter is measuring aerodynamic diameter The impactor should eliminate practically all of the particles larger than 4 08 µm, aerodynamic diameter

A second method was used for screening the environmental cab performance This screening method consisted of measuring ambient 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 procedure consisted of using one or two MetOne Model 227B 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 airflow inlet to the cab and the other inside the enclosed environmental cab The cab was closed and an operator started the tractor and cab, and maintained the tractor RPM at field operating conditions (1800 to 2000 RPM) A five-minute period was used for warmup and cab equilibration at operating conditions Subsequently, one-minute MetOne samples were obtained from inside and outside the cab at particle sizes of 0 3 and 3 micrometer (two replications)

The MetOne Model 227B simultaneously counts two particle size ranges simultaneously We selected 0 3-micrometer and 3-micrometer sample interval The inside/outside particle count ratio was calculated A ratio of less than or equal to 0 02 is needed to meet the cab criterion of less than 0 02 (2%) penetration (for particles larger than 3 micrometers)

RESULTS AND FINDINGS

Ventilation Measurements are summarized in the following table The static pressure measurement made on September 21, 1999, was made with the electronic manometer The measurements made in October were made with the magnehelic gauge mounted in the tractor

Summary of Ventilation Measurements

Date	Tractor Number	Air Flow (cfm)	Static Pressure (Inches of Water)
9/21/99	tr65	162	0 07-0 08
10/26/99	tr74	167	0 09-0 10
10/27/99	tr74	179	0 15

These tractors were 3 to 4 years old

Grimm PDM Measurements

The average aerosol particle concentration measured inside and outside of the tractor are presented in Appendix 1 In Figure 4, average aerosol penetration into the cab is plotted as a function of root mean channel particle size Because the observed penetrations were varying greatly, statistical analysis was conducted to evaluate whether the test series affected the aerosol penetration into the cab This analysis was based upon only the penetrations measured in the first channel of the Grimm PDM The range of particles counted in this channel is 0 3 to 0 4 μm The statistical analysis was performed on the logarithms of the penetration for each experimental run because experimental variability appeared to be proportional to the mean penetration for each test series An analysis of variance was conducted using the SAS General Linear Models Procedure with "test series" as the only independent variable [10] The variable "test series" significantly affected the logarithm of penetration (p<0 0001) Tukey's HSD test indicated that all of the geometric means presented in Table 2 were significantly different from each other at an overall level of confidence of 0 05 The residuals from this analysis of variance were tested for normality using a Shapiro Wilke statistic [11] The observed deviations from a normal distribution were not significant (p=0 33) The statistical analysis indicates that the improvements to the filtration system made after the completion of each test series significantly reduced the aerosol penetration into the enclosure

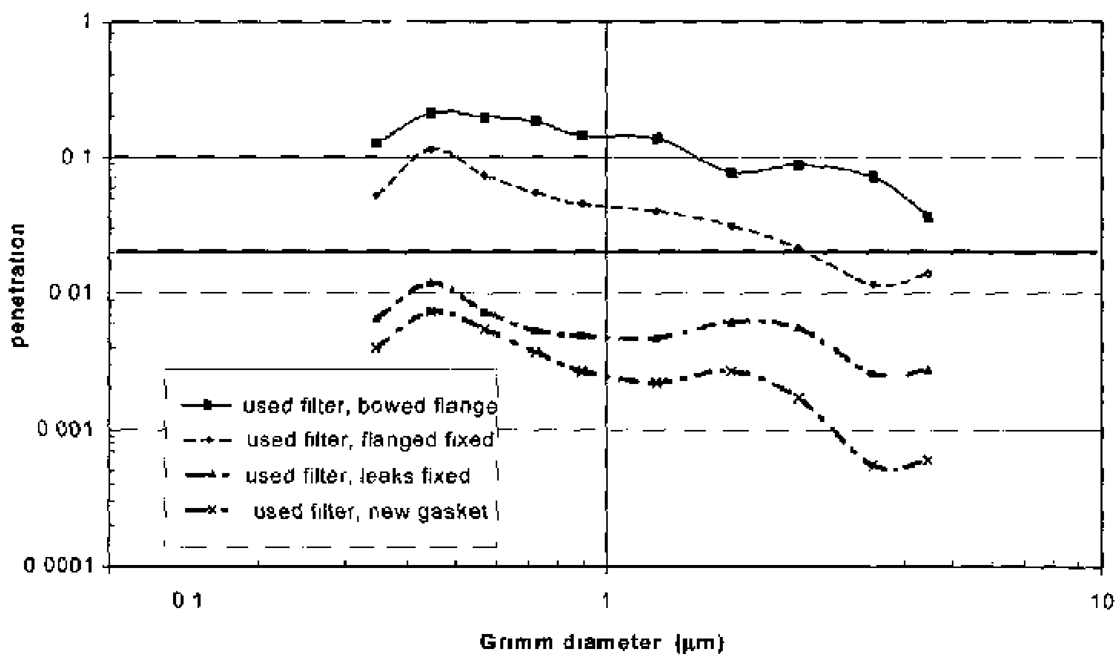

Figure 4 The condition of the flange and gasket affects the aerosol penetration into the cabin

Table 2 Geometric Mean and Standard Deviation at the Smallest Particle Size.

Test Series	Geometric Mean	Geometric Standard Deviation
a	0 1106	1 38
b	0 0481	1 14
c	0 0065	1 07
d	0 0039	1 07

After test series "a" was completed, the filters and filter holder assembly was visually examined for leakage As shown in Figures 5 and 6, the filter gaskets were not seating properly against the flange Further visual inspection led to the identification of these problems

1 The flange on the top of the filter holder was found to be bowed, allowing some air flow around the filters,

2 The sheet metal seams separating the air which was upstream of filters from the air downstream of the filters were not caulked, allowing air to bypass the filter, and

3 The metal bar used to force the filters against the flange was incorrectly mounted, causing an uneven pressure on the filter gaskets

All of these problems would cause air to flow around the filter instead of through the filter In addition, the order of the filters in the filter holder was altered so that the air flowed first through the carbon filter, then the prefilter, and finally through the high-efficiency particulate air filter These items were all fixed before run b was conducted Addressing these issues reduced aerosol penetration into the cab from 0 11 to 0 048, however, this is still greater than the recommended ratio of 0 02 in the ASAE S525

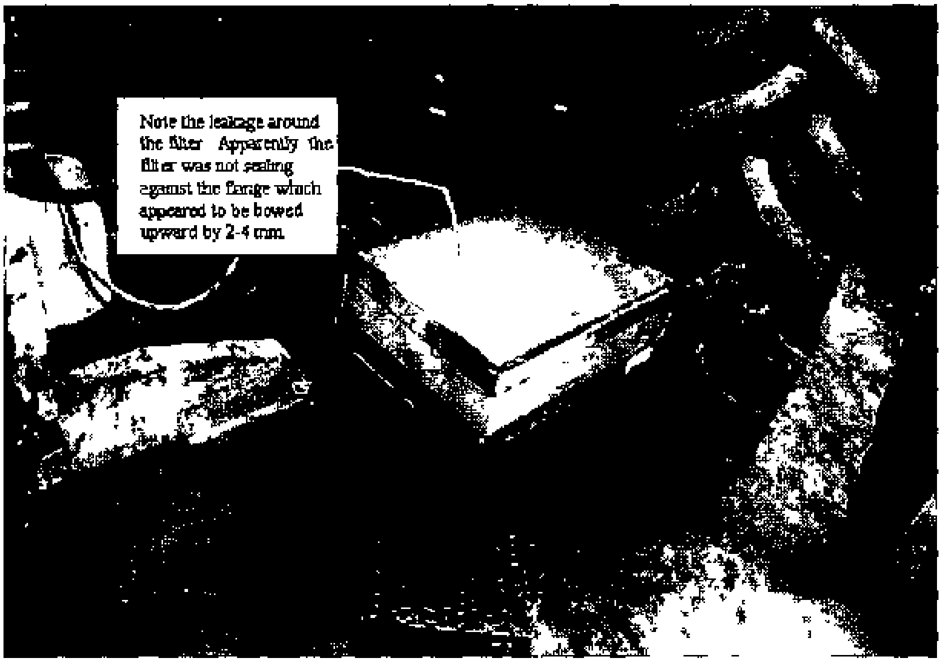

Figure 5 Photograph showing dust on outside filter walls and gasket suggesting leakage

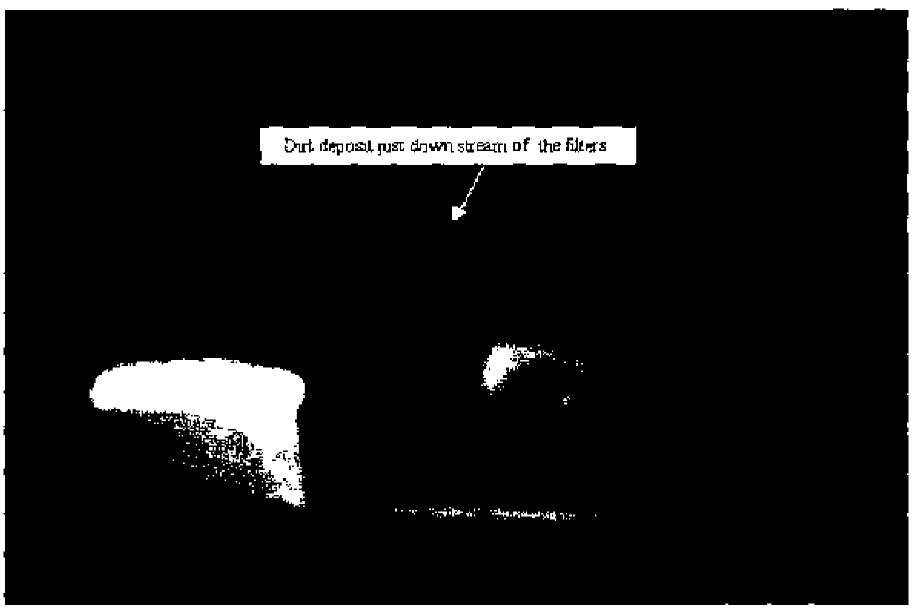

Figure 6 Dust on ceiling of filter holder just downstream of filter Apparently, large particles are impacting on ceiling of the filter holder

After test series "b", holes in the filter were identified in a new filter and fixed Before test series "c," the used filter was replaced with a new filter This reduced the aerosol penetration into the cab from 0 048 to 0 0065 The reason for this improvement was believed to be the filter gasket material To test this hypothesis, the gasket material on the used filter was replaced with new gasket material After placing the used filters with the new gasket material back into the enclosure, test series "d" was run This reduced aerosol penetration from 0 0065 to 0 0039 This suggests that gasket material degradation can cause increased aerosol leakage into the enclosure

During half the experimental runs, the outside Grimm was operated with an omnidirectional inlet and during the other runs, the outside Grimm was operated with an impactor which had a 50% cut diameter of 4 08 micrometers Figure 7 presents the ratio of the average concentration with the impactor to the average concentration with the omnidirectional inlet This ratio was 0 52 for the particles in the 4- to 5-µm range The root mean diameter for this channel was 4 5 µm The apparent 50% cut diameter based upon the Grimm PM measurements was 4 5 µm Apparently, the Grimm PDM is overstating by no more than 1 µm This suggests that the Grimm PDM is doing a reasonable job of sizing particles

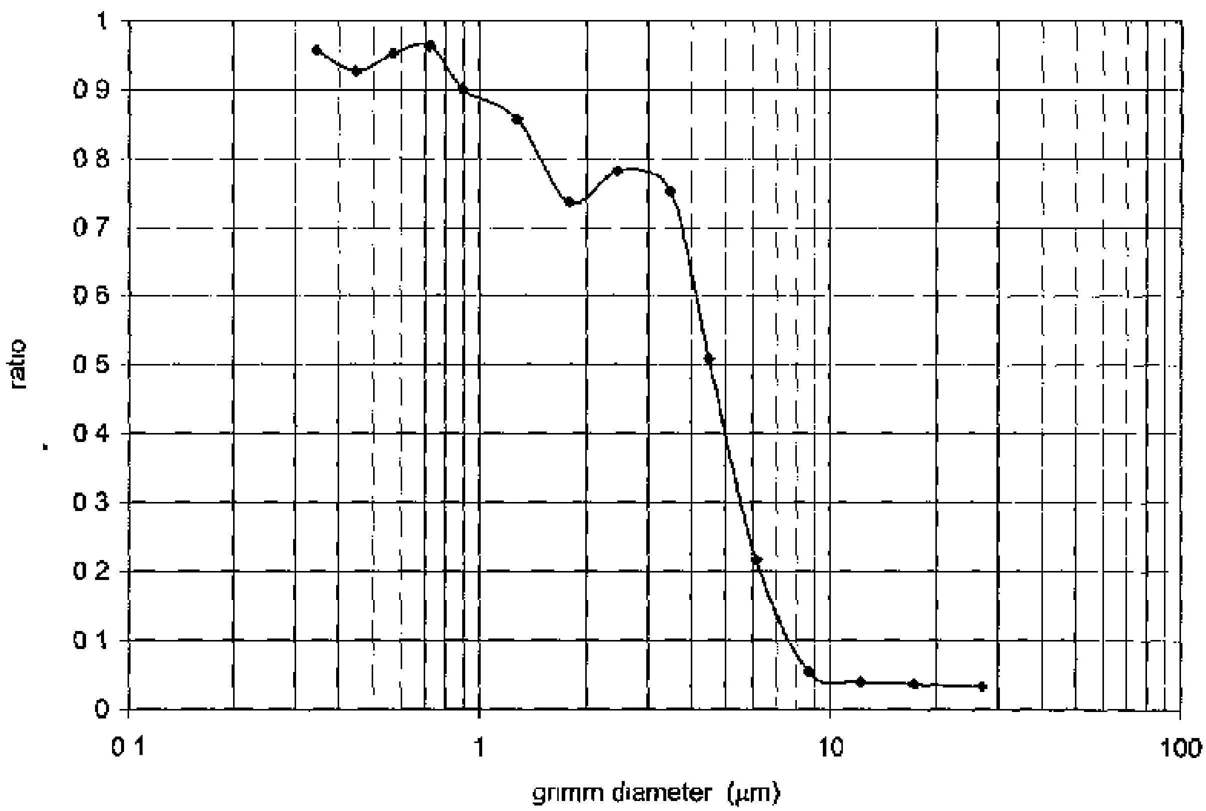

Figure 7 Ratio of average particle concentration with the impactor to average particle concentration with the omnidirectional inlet These particle concentration measurements were made outside the tractor

MetOne optical particle counters were used as a screening tool for measuring cab integrity The Met One data were limited in that only two aerosol particle sizes were monitored at a single time Nonetheless, it proved to be a means of monitoring cab-sealing fluctuations The two particle sizes were selected such that critical data was provided The 0 3 µm particles are in the range (0 3 to 3 µm) Inspection of the ambient aerosol size distributions measured with the Grimm PDM and reported in Appendix I reveal that most of these particles are in the 0 3- to 0 65-µm range as measured by the Grimm Particles in this size range are close to the most penetrating particle size and are capable of entering the regions of the deep lung The 3-µm particles are of the size range employed in the ASAE standard [6]

Table 3 presents MetOne screening data on numerous cabs that were available for inspection The ratio of inside aerosol concentration to outside aerosol concentration is the value of interest The smaller this value the better the cab is functioning A high value signals a problem For example, tractor TR 66 gave a value of greater than 0 10 at 0 3 micrometers An investigation of the filter housing assembly on tractor TR 66 showed that the clamp holding the filter in position was in upside down The clamp could not seal the filters properly to the housing flanges when placed upside down The MetOne data clearly showed with this rapid screening test that a major problem existed When the clamp was installed properly and aerosol concentration measurements repeated, a high ratio was still obtained This was attributed to the fact that the filter housing had not been cleaned prior to this determination Ultimately, the entire internal filter housing must be cleaned before optimal exposure reduction is obtained

The data obtained with the MetOne optical particle counters must be viewed with great care In these studies, the outside aerosol concentrations, 500 to 700,000 particle counts per liter, exceeded the MetOne's counting capability The MetOne optical particle counters have a coincidence problem at count levels above 70,000 particle counts per liter In optical particle counters, coincidence occurs when two or more particles are in the sensing volume at the same time This causes the instrument to mistakenly classify these particles as a single, larger particle Thus, the MetOne data can only be used as a trend and screening indicator method and absolute values must be disregarded However, the MetOne optical particle counters have a concentration mode capability which could be used to circumvent this counting problem in the future Use of the concentration mode feature needs to be investigated to validate its utilization for future cab integrity testing

Table 3 Various Nelson Cabs - MetOne Results

Tractor	Cab	Filter-Use Hours	Pressure (in w g)	Size (μm)	Inside	Outside	Ratio In/Out
TR 76	97-0975	120	0 045	0 3	21,800	654,000	0 033
				3 0	69	2,890	0 024
TR 70	97-0918	150	0 085	0 3	13,240	700,000	0 0189
				3 0	41	1,828	0 022
TR 69	97-0917	152	0 080	0 3	8,784	640,600	0 0137
				3 0	46	1,713	0 027
TR 72	97-0919	1	0 120	0 3	22,600	585,000	0 039
				3 0	184	1,453	0 127
TR 4	99-0159	28	0 230	0 3	14,380	687,500	0 021
				3 0	29	2,508	0 0116
TR 66*	95-0879	403	0 075	0 3	91,930	585,100	0 157
				3 0	106	1,642	0 065
TR 66**	95-0879	403	0 070	0 3	96,480	585,800	0 165
				3 0	17	1,777	0 0096
TR 74	97-0977	115	0 155	0 3	17,570	538,400	0 033
				3 0	65	1,304	0 050

* Clamp upside down
** Clamp right, housing not cleaned

Table 4 presents data obtained on a new 1999 cab with the MetOne optical particle counter The data trend which progressed toward a higher ratio led to the identification and resolution of the major problem found with the Nelson cabs The most significant problem identified with the Nelson cabs was with the filters seating and sealing to the cab Problems with the metal flanges, filter clamp assembly, and cracks in the metal tractor housing and filter housings were ultimately responsible for the majority of aerosol particle leakage into the cab by way of the air inlet and filtration system As the data in Table 4 show, upon proper filter seating, tractor housing caulking, and filter corner seam caulking, the ratio was decreased significantly by a factor of more than two This leakage around the filters, not the filter's filtration efficiency, appears to be the most significant cause of reduced cab performance

Table 4   Nelson Cab on TR 4 - MetOne Results

Condition	Filter-Use Hours	Pressure (in w g)	Size (μm)	Inside	Outside	Ratio In/Out
Used Filters	28	0 230	0 3	14,380	687,500	0 021
			3 0	29	2,508	0 0116
New HEPA	0*	0 205	0 3	8,207	587,600	0 0140
			3 0	31	1,264	0 025
New Gaskets on Used Filters	28	0 205	0 3	13,260	623,100	0 022
			3 0	71	1,469	0 048
New HEPA with Hole	0	0 210	0 3	22,180	659,400	0 034
			3 0	86	1,622	0 053
Reinstalled Used Filters with New Gaskets	28	0 202	0 3	23,320	661,400	0 035
			3 0	85	1,635	0 052
Same as Above plus Chalked Housing Seams	28	0 202	0 3	5,531	683,800	0 0081
			3 0	83	1,501	0 055
Same as Above plus Chalked Corners	28	0 202	0 3	4,487	711,200	0 0063
			3 0	44	1,472	0 025

* New HEPA may have been damaged
Engine exhaust may have been directed into the cab

Finally, Table 5 gives data with a similar trend to that presented in Table 4 However, Table 5 presents MetOne observations that were taken in conjunction with field runs Again the significance of caulking the tractor filter housing and filter corner seams was demonstrated With proper maintenance of these identified problem areas. the filter's integrity and functionality was maintained, even when operating in the rough field environment where vibrations are an important consideration for ensuring filter seating integrity

Table 5. Nelson Cab on TR 74 - MetOne Results

Condition	Filter-Use Hours	Pressure (in w g)	Size (μm)	Inside	Outside	Ratio In/Out
Used Filter	115	0 155	0 3	17,570	538,400	0 033
			3 0	65	1,304	0 050
New Filter	0	0 155	0 3	13,310	601,200	0 022
			3 0	38	1,572	0 024
Filter Housing Re-chalked	0	0 155	0 3	10,020	596,200	0 0168
			3 0	64	1,444	0 044
Next Day Rerun*	0	0 153	0 3	10,700	788,100	0 0136
			3 0	34	1,297	0 026
After 30-min Field Test	0 5	**	0 3	11,160	620,200	0 018
			3 0	46	1,447	0 032
Used Filters, New Gaskets & New Chalk	115	0 130	0 3	7,860	643,500	0 0122
			3 0	25	2,282	0 0110
After 2-hour Field Test	117	**	0 3	7,271	554,100	0 0131
			3 0	44	1,564	0 028

* HEPA filter last element
** Pressure not recorded
Engine exhaust may have been directed into the cab

DISCUSSION

Optical particle counters can be quickly used to evaluate leakage sources using the smaller particles Aerosol leakage around filters was attributed to manufacturing defects involving bowed flanges, failure to seal seams, and perhaps degradation of gasket materials Perhaps, these problems could be eliminated by using an optical particle counter to perform quality control checks for the assembled cabs If an optical particle counter had been used to check the assembled tractor cab and tractor before it had been sent to the user, perhaps these errors could have been identified and avoided Manufacturers could use optical particle counters to conduct further studies of possible gasket material aging degradation and also in their quality control plan for monitoring performance of the ventilated cabs

Spray cab maintenance at San Joaquin Helicopter involves changing filters at the specified time and making sure that the cabin static pressure is in excess of 0 03 inches of water (0 76 mm of water) This static pressure is much less than the static pressure of 6 mm of water as specified by ASAE Standard S525 When the wind's velocity pressure exceeds the static pressure in the spray cab, aerosol infiltration into the cab increases [12] In an experimental study of air infiltration in a simulated cab, a cabin static pressure of 3 mm of water (0 12 inches of water static pressure) would prevent the aerosol penetration into the cab from increasing when wind speeds were below 20 km/hour [12] When the sum of the tractor speed and the wind speed are less than 20 km/hr, cabin pressures of at least 3 mm of water are adequate to prevent air infiltration into the cab

CONCLUSION

A quality control program is needed to ensure that each cab provides acceptable exposure reduction This quality control program needs to include quantitative measures of control performance including cabin pressure and aerosol penetration into the cabs In addition, a cabin maintenance program employing an optical particle counter would help ensure that cab performance is optimized Ultimately, an effective cabin filtration quality control and maintenance programs are essential to ensure continuously reliable cab performance and work protection.

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Appendix A

Raw Data from the Grimm Portable Dust Monitor.

		Penetrations for different particle channels, the stated diameter (µm) is the lower limit for the channel										
date	time	0 3	0 4	0 5	0 65	0 8	1	1 6	2	3	4	5
test series b												
10/26/99	9 04-9 24	0 0465	0 0951	0 0693	0 0499	0 0527	0 0530	0 0579	0 0391	0 0193	0 0212	0 0481
10/26/99	9 56 - 10 14	0 0422	0 1013	0 0693	0 0589	0 0548	0 0456	0 0525	0 0326	0 0177	0 0313	0 1025
10/26/99	10 30-11 00	0 0627	0 1238	0 0803	0 0591	0 0482	0 0496	0 0303	0 0215	0 0111	0 0075	0 0052
10/26/99	11 33-11 53	0 0514	0 1200	0 0713	0 0478	0 0347	0 0265	0 0138	0 0108	0 0062	0 0035	0 0033
test series c												
10/26/99	15 01-15 21	0 0067	0 0143	0 0080	0 0066	0 0069	0 0073	0 0141	0 0142	0 0075	0 0079	0 0200
10/26/99	15 36-15 55	0 0070	0 0126	0 0078	0 0045	0 0042	0 0043	0 0051	0 0031	0 0008	0 0011	0 0020
10/26/99	16 10-16 29	0 0064	0 0123	0 0071	0 0055	0 0043	0 0033	0 0024	0 0023	0 0008	0 0007	0 0004
10/27/99	8 15-8 40	0 0059	0 0082	0 0065	0 0046	0 0040	0 0039	0 0031	0 0026	0 0011	0 0012	0 0015
test series d												
10/27/99	9 57-10 20	0 0037	0 0066	0 0052	0 0036	0 0027	0 0027	0 0050	0 0027	0 0006	0 0010	0 0021
10/27/99	10 29-10 50	0 0037	0 0075	0 0055	0 0039	0 0028	0 0016	0 0022	0 0015	0 0005	0 0006	0 0010
10/27/99	11 00-11 21	0 0043	0 0072	0 0057	0 0036	0 0024	0 0024	0 0019	0 0014	0 0006	0 0005	0 0005
10/27/99	11 29-11 54	0 0041	0 0081	0 0053	0 0037	0 0027	0 0021	0 0017	0 0012	0 0004	0 0003	0 0003
test series a												
9/21/99	8 59-9 14	0 1775	0 3354	0 3158	0 2903	0 1990	0 1588	0 1208	0 1171	0 0753	0 0384	0 0202
9/21/99	9 55-10 15	0 0868	0 1198	0 1193	0 1218	0 1077	0 1357	0 0738	0 0813	0 0625	0 0352	0 0141
9/21/99	11 28-11 29	0 0940	0 1713	0 1727	0 1808	0 1518	0 1305	0 0478	0 0849	0 1018	0 0528	0 0168
9/21/99	11 56-12 28	0 1035	0 1694	0 1455	0 1156	0 1055	0 1100	0 0596	0 0631	0 0447	0 0192	0 0065

Average particle number concentrations (particles/liter) in different particle size diameters (µm)
The stated diameters is the lower limit for the particle size channel

date	loca	Gnmm #	time	0 3	0 4	0 5	0 65	0 8	1	1 6	2	3	4	5
10/26/99	in	564	9 04-	10453 6	8104 7	3455 3	798 1	422 1	170 7	83 3	78 7	21 9	9 4	8 3
10/26/99	out	565	9 24	224836 5	85202 8	49862 9	16000 8	8004 5	3218 3	1438 6	2011 0	1135 4	445 0	172 3
10/26/99	out	564	9 29 -	249760 4	91520 7	57391 1	15739 3	9133 7	4713 8	2728 7	3875 5	1985 1	825 1	320 0
10/26/99	in	565	10 14	10535 1	9273 7	3974 5	926 5	500 9	214 8	143 3	126 2	35 2	25 9	32 8
10/26/99	in	564	10 30-	15432 7	11425 3	4743 0	1152 1	576 5	220 8	79 1	79 8	26 0	12 9	10 8
10/26/99	out	565	11 00	246261 2	92290 9	59097 9	19509 7	11949 5	4453 3	2610 4	3716 8	2336 3	1708 4	2066 7
10/26/99	out	564	11 04-	292344 4	98902 8	73056 0	25347 6	17812 9	8864 8	5868 9	7362 3	4239 4	3201 0	3272 7
10/26/99	in	565	11 55	15028 0	11863 6	5206 1	1212 3	618 8	234 8	81 3	79 8	26 4	11 4	11 0
10/26/99	out	564	15 03-	303507 5	91303 3	84798 7	30260 7	16171 9	5611 8	2086 4	2329 6	1095 7	480 4	212 5
10/26/99	in	565	15 22	2042 2	1303 8	676 3	198 5	111 5	40 8	29 5	33 1	8 3	3 8	4 3
10/26/99	in	564	15 36-	2332 6	1278 2	688 3	174 0	94 0	38 0	20 2	17 6	2 6	1 4	0 9
10/26/99	out	565	15 55	335136 1	101318 4	88763 5	38616 7	22204 4	8746 8	3967 2	5694 7	3124 4	1224 8	455 2
10/26/99	out	564	16 10-	329828 7	98836 3	90363 2	32908 6	20064 8	8358 0	5299 8	6036 6	2864 0	2335 2	2890 3
10/26/99	in	565	16 29	2109 4	1215 7	637 5	182 5	87 0	27 5	12 6	13 8	2 4	1 6	1 2

Average particle number concentrations (particles/liter) in different particle size diameters (µm)
The stated diameters is the lower limit for the particle size channel

date	loca	Grimm #	time	0 3	0 4	0 5	0 65	0 8	1	1 6	2	3	4	5
10/27/99	in	564	8 25-8 40	1979 7	1066 2	535 4	136 3	66 0	32 1	14 8	17 1	4 5	3 6	5 3
10/27/99	out	565		334362 3	130286 1	82749 4	29324 1	16485 0	8261 0	4841 2	6658 2	4140 5	3110 6	3634 2
10/27/99	in	564	9 57-10 20	1276 4	807 1	427 7	115 2	57 5	31 6	31 9	27 8	3 7	2 1	1 8
10/27/99	out	565		344290 7	122641 0	82609 3	32417 9	20915 5	11602 1	6427 0	10457 2	5823 6	2216 7	862 4
10/27/99	out	564	10 29-10 52	326249 5	109361 7	81834 6	31983 0	23023 6	13865 2	7804 5	12436 2	8437 6	2601 3	976 3
10/27/99	in	565		1220 3	824 3	453 2	124 5	63 9	22 7	17 5	18 9	3 5	1 5	1 0
10/27/99	in	564	11 00-11 21	1369 3	850 7	491 1	136 4	72 7	34 5	19 0	20 4	5 5	3 3	3 2
10/27/99	out	565		320694 1	118173 6	86230 8	37426 4	29771 5	14240 2	9991 2	14997 1	9525 8	6276 0	7005 6
10/27/99	out	564	11 29-11 54	319725 8	108741 9	87003 5	35046 6	27951 4	16686 3	10838 1	15294 3	9723 8	7404 7	8090 8
10/27/99	in	565		1301 2	677 6	462 4	130 6	76 3	34 3	17 9	19 0	4 0	2 3	2 1
9/21/99	out	564	8 45-9 35	311818 8	107447 1	48991 7	14669 4	14143 0	10846 0	7225 2	10762 7	6945 5	5463 5	6467 7
9/21/99	in	565		55348 6	36040 0	15472 6	4258 0	2813 8	1721 9	872 6	1260 2	522 8	209 8	130 8
9/21/99	in	564	9 40-10 37	24379 2	13249 7	5430 0	1231 8	748 4	436 0	223 1	303 8	118 8	51 3	29 6
9/21/99	out	565		280869 7	110572 0	45499 0	10116 2	6949 5	3212 4	3022 9	3737 3	1899 1	1458 4	2108 0
9/21/99	out	564	11 28-11 29	261022 0	90187 5	38353 0	9075 0	7037 5	3697 5	4495 5	4500 0	1600 5	1156 0	2084 5
9/21/99	in	565		24548 5	15447 5	6622 5	1640 5	1068 0	482 5	215 0	382 0	163 0	61 0	35 0
9/21/99	in	564	11 56-12 28	24548 5	15447 5	6622 5	1640 5	1068 0	482 5	215 0	382 0	163 0	61 0	35 0
9/21/99	out	565		227018.5	77278 4	37715.7	11955.6	8597 8	4747.7	4518.9	5728 1	3097.5	2521.9	3427 2

Appendix B

Printout from the Statistical Analysis.

```
Dependent Variable lnp   (This is the natural logarithm of penetration)
                              Sum of
   Source              DF      Squares    Mean Square   F Value   Pr > F
   Model                3   30 38737100   10 12912367    307 89   <.0001
   Error               12    0 39478800    0 03289900

 Corrected Total       15   30 78215900

            R-Square   Coeff Var    Root MSE    lnp Mean
            0 987175   -4 589305    0 181381    -3 952250

   Source               DF    Type I SS    Mean Square   F Value   Pr > F
   run                   3   30 38737100   10 12912367    307 89   < 0001

              Tukey's Studentized Range (HSD) Test for lnp

NOTE  This test controls the type I experimentwise error rate but generally has a higher type II
                 error rate than REGWQ

              Alpha                                    0 05
              Error Degrees of Freedom                  12
              Error Mean Square                     0 032899
              Critical Value of Studentized Range   4 19852
              Minimum Significant Difference         0 3808

         Means with the same letter are not significantly different
      Tukey Grouping   Mean      N   run

                 A     -2 2015   4   a   (initial run with bowed flange and filter holder
                                                 inappropriately sealed)
                 B     -3 0335   4   b   (Bowed flanged fixed and filter holder sealed)

                 C     -5 0375   4   c   (New Filter with new gasket material and
                                         filter leakage plugged)
                 D     -5 5365   4   d   (USED FILTER WITH NEW GASKET MATERIAL AND
                                                 FILTER Leaks fixed)
```

This is an annotated printout of an analysis of variance and a multiple comparison test obtained from the SAS General Linear Models Procedure (SAS Institute, Cary, North Carolina) The annotations are in parenthesis and italics The penetration data is for the smallest particle size channel and this data was log-transformed before analysis The gist of the analysis is that the treatments had a significant affect upon penetration into the cab All of the Geometric Mean Penetrations differed significantly from each other at an overall level of confidence of 95%

Appendix C

Maintenance Notice Sent by Nelson Manufacturing to Customers.

(Note- this copy was scanned into the document)

NELSON MFG CO , INC
2860 Colusa Hwy Yuba City CA 95993 TEL (530) 673-0919 TOLL FREE (877) 673-0919
FAX (530) 673-2072

November 9, 1999

Safety and Maintenance Notice

To all Nelson Spray Cab@ owners

Researchers from the National Institute of Occupational Safety and Health (NIOSH) are conducting a study of particulate filters used in agricultural cabs for pesticide applications The study objective is to evaluate filter replacement schedules

Test results of the Nelson Spray Cab@ and filtration system, when properly maintained, are within the required performance specifications During the tests, however, these concerns with the Nelson Spray Cabs have been identified

-Filters not changed according to schedule
-One or more filter housing flange bowed or damaged
-Missing filter housing seam caulking
-improper installation of the filter clamping bar
-inadequate cab pressure

BE SURE TO PERFORM THESE INSPECTIONS AND REPAIRS BEFORE YOUR NEXT SPRAY APPLICATION

1 FILTER CHANGING SCHEDULE
As described in the Spray Cabs Operator's Manual and the IMPORTANT decal inside the cab

"**ALWAYS** service or replace filters before each use Clean or replace **PRE-FILTER** daily Replace **HEPA** (High Efficiency Particulate Air) Filter every 400 hours or every 3 months, whichever comes first Replace **CARBON FILTER** every 100 hours or every 2 weeks, whichever comes first "

Follow the operating, servicing and cleaning instructions described in the Operator's Manual when using dangerous chemicals to maintain air quality, minimize interior contamination and to comply with State and federal regulations

2 FILTER HOUSING FLANGES AND SEAM CAULKING
As described in the Spray Cabs Operator's Manual on page titled FILTER REMOVAL and on page titled TO INSTALL FILTERS in section OPERATING & SERVICING CAB FILTER SYSTEM

"Clean inside of filter housing, make sure filter housing flange is straight and undamaged, replace missing seam caulking and repaint as described in section- CLEANING THE NELSON SPRAY CAB (CLEANING EXTERIOR)"

Be sure to inspect the filter housing, straighten sealing flanges and replace seam caulking as necessary Follow the detailed instructions in Operator's Manual, particularly procedure #4 on page titled CLEANING EXTERIOR in section CLEANING THE NELSON SPRAY CAB (see below)

44 Clean interior of cab filter housing and air intake duct (located above cab ceiling from air intake to filter area) using a long handled brush and wet soapy rag, then wipe with clean rinse rag **When dry, replace and repaint ALL seam caulking using automotive body sealer and good quality synthetic enamel paint. Use mirror to check and reseal seams in the air duct just in front of filters and where direct visual inspection is not possible Make sure filter housing flange is not bent or damaged, preventing a proper seal with carbon filter "**

3 FILTER CLAMPING BAR INSTALLATION

As described in the Spray Cab@ Operator's Manual on page titled FILTER INSTALLATION in section OPERATING & SERVICING CAB FILTER SYSTEM

"Filters MUST be aligned and seated tightly with filter housing flange and with each other "

All cabs manufactured since 1989 (with either an "L" or an "H" in the serial number) included a filter clamping bar with a bend near the guide pin When installing the filter clamping bar, **the angled portion with the guide pin MUST be positioned downward** If it is positioned upward, the guide pin will hit the top of the guide slot before the front portion of the carbon filter gasket has sealed against the filter housing flange

Be sure filter clamp bar is installed properly with "THIS SIDE DOWN" decal on bottom If this decal is missing, we will send one at your request

DOWN

Filter Clamping Bar
(Angled portion with pin positioned downward)

Enclosed with this notice is **an adhesive addendum that is to be inserted in the Spray Cab@ Operator's Manual.** This addendum describes the filter clamping bar installation **Peel off the protective backing and apply the addendum to the bottom of the page titled· TO INSTALL FILTERS in section OPERATING & SERVICING CAB FILTER SYSTEM**

4 AIR SEAL MAINTENANCE

To maintain a positive cab pressure of filtered air, be sure to inspect and repair cab seals and blowers as necessary Maintenance directions can be

found in the Operator's Manual on Page titled CAB PRESSURE DROP in section TROUBLESHOOTING CAB AND FILTRATION
Replace damaged or deteriorated air seals, door and window trim, seam caulking, windows, wipers, washers, blower motors, blower cover seals, safety decals, filters and filter gaskets

Enclosed with this notice is the Spray Cabs Parts List All cab replacement parts, including the latest version of the Nelson Spray Cabs Operator's Manual (#OM-SC1 194), are available from

NELSON MFG CO , INC
2860 Colusa Hwy , Yuba City, CA 95993
Toll Free 1-877-673-0919
Tel (530) 673-0919
Fax (530) 673-2072

NOTE If **any of your Nelson Spray Cabs have been sold, or ownership has changed, please lets us know to whom we should send this notice**

Please call with any questions

Thank you,

Jim Bennett Nelson
Mfg Co , Inc

INSTALLING FILTERS

HIGH PROFILE

CABS WITH ELECTRIC BLOWERS **(ONLY)**