

Efficiency of Degraded Electret Filters: Part I – Laboratory Testing Against NaCl and DOP before and after Exposure to Workplace Aerosols

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ABSTRACT

Laboratory studies have demonstrated degradation of electrostatically-enhanced (electret) respirator filter performance after exposure to excessive levels of ionizing radiation, immersion in solvents, and when exposed intermittently to specific aerosols. This study was conducted to determine if such degradation has practical significance in the workplace. N95, R or P95 and P100 filters from two manufacturers were tested. All filters were electrets except the P100 filters from one manufacturer. Each filter type was divided into three groups: 1) untreated; 2) irradiated with ionizing radiation; and 3) dipped in isopropanol for 15 seconds. The purpose of the irradiation and isopropanol treatments was to produce laboratory penetration values above those allowed for approval using NIOSH test conditions. Initial penetration and pressure drop measurements were made with an automated filter tester (AFT) using sodium chloride for N filters and DOP for R and P filters. Filters from each group were then exposed to a grinding aerosol or an oil mist in a steel foundry. Following the workplace exposure, the filters and controls for each group were retested for initial penetration and pressure drop. Results of the AFT testing did not indicate changes in penetration or pressure drop attributable to the workplace aerosols.

Keywords: Filters, respirator, electret, filter efficiency, filter penetration

INTRODUCTION

Filters are used in respiratory protective devices to remove particulate respiratory hazards from the air workers inhale. They are broadly classified as either mechanical or electret type filters. Mechanical filters remove aerosols using the processes of inertial impaction, interception, and diffusion. These processes are detailed in the literature (Hinds, 1982). Modern electret filters consist of electrically charged polymer fibers. The electrical charges augment the mechanical removal processes and improve collection efficiency for submicrometer particles. Charged airborne particles are attracted to opposite charges on the media by coulombic attraction. Uncharged particles can also be attracted to charged media via polarization forces (Hinds, 1982).

A number of laboratory investigations have reported reduction or elimination of the electrical charges on electrets following exposure to high levels of ionizing radiation, immersion in solvents or intermittent exposure to specific aerosols (Chen *et al.*, 1993; Chen and Huang, 1998; Moyer and Bergman, 2000; Martin and Moyer, 2000; Rousseau *et al.*, 2001). The filters are then tested against laboratory aerosols and typically show increased penetration in the submicrometer range. If penetration

above 1-2 μm is reported, little or no increase is seen. This is significant because the mass median aerodynamic diameter (mmad) of workplace aerosols is nearly always well above 1 μm (Hinds and Bellin, 1988).

This study was undertaken to determine if penetration of submicrometer laboratory aerosols predicts the penetration of typical workplace aerosols. Because laboratory testing is intentionally conducted under "worst case" conditions (Federal Register, 1995), it was hypothesized that workplace aerosol penetration would be much lower than laboratory penetration. Thus, in the event that some charge loss occurs in the workplace, workers using electret filters would still receive effective protection.

This paper describes the laboratory portion of the study. Filters were tested for penetration and pressure drop before and after exposure to workplace aerosols. Field testing procedures and performance measurements are addressed in a companion paper (Janssen *et al.*, 2003).

MATERIALS AND METHODS

All filters used in the study were among the classes approved by the U.S. National Institute for Occupational Safety and Health (NIOSH). Class N95 filters are tested for approval with sodium chloride and must permit no more than 5% penetration until a loading of 200 mg is reached. R95 filters must meet the same penetration and loading criteria when tested with dioctyl phthalate (DOP) instead of sodium chloride. P95 filters must permit no more than 5% DOP penetration during approval testing. If penetration is increasing at 200 mg of loading, testing continues until minimum efficiency is reached. The loading criterion for P100 filters is the same as P95, but maximum penetration must not exceed 0.03%. Initial inhalation resistance (pressure drop) is limited to 35 mm water column at 85 L/min (per respirator assembly) for all classes of filters (Federal Register, 1995).

Filters from two respirator manufacturers were used in the study. Filters from Manufacturer A included NIOSH approval classes N95, P95 and P100. All Manufacturer A filters were electrets. Manufacturer B filters included NIOSH classes N95, R95 and P100. N95 and R95 filters from Manufacturer B were electrets. The P100 filter was a fiberglass mechanical filter. No attempt was made in this study to identify specific electret media used by either manufacturer in any of the electret filters.

Each type of filter from both manufacturers was divided into three groups prior to initial penetration and pressure drop testing:

1. Untreated;
2. Irradiated with X-radiation;
3. Isopropanol-dipped.

Irradiation was done to reduce electrical charges on the electret filters so that initial penetration values would exceed those permitted for NIOSH approval. A target range of 6-14% initial penetration was sought for the class 95 filters, and approximately 1% for the P100 filters. These penetration values are representative of those reported in recent laboratory studies of filter degradation (Moyer and Bergman, 2000; Martin and Moyer, 2000). The irradiation was done with an industrial X-ray unit (Balteau Electric Corporation, Stamford, Conn.). Each filter type was exposed separately in a lead-lined chamber. The X-ray dose rate was approximately 720 R/min. Total exposure time to reach the target penetration range for each type of filter was determined empirically with test filters of each type. Penetration with DOP or sodium chloride was measured after each of a series of incremental X-ray exposures. Increased penetration was not apparent in the mechanical P100 after 20 minutes of trial incremental exposure. Therefore, it was decided that those filters would receive the same X-ray dose required to increase the penetration of the electrostatic P100 filters to approximately 1%. When the exposure times for each of the filter types were determined, the filters were irradiated in groups of four to six. Exposure times and total X-ray doses for all filters are shown in Table I. It should be noted that all exposures needed to reach the target penetration ranges exceeded the human LD_{50/30} (the dose of radiation expected to cause death to 50 percent of an exposed population within 30 days) of 400-450 rem (4-5 Sv) (U.S. Nuclear Regulatory Commission, 2002).

The third group of filters of each type was dipped in 99.5% isopropanol (IPA) to remove or reduce electrical charges. The filters were completely submersed for 15 seconds and promptly removed. Liquid IPA was allowed to drain from the filters, which were then air-dried for approximately 24 hours. A 15-second dip was chosen because Martin and Moyer (2000) reported no significant difference in filter efficiency degradation when they compared 15-second, one-hour and two-hour dip times.

Table I. X-ray Exposure Time and Dose by Filter Type

Filter	Exposure Time (min)	Approximate X-ray Dose (R)
Manufacturer A N95	3.25	2340
Manufacturer B N95	2.50	1800
Manufacturer A P95	1.67	1202
Manufacturer B R95	3.25	2340
Manufacturer A P100	15.0	10800
Manufacturer B P100	15.0	10800

Next, all filters from the untreated, irradiated and IPA-dipped groups were tested for initial penetration and pressure drop with a TSI Certitest® Model 8130 Automated Filter Tester (TSI, St. Paul, MN). Test conditions were essentially those specified for NIOSH approval, except the N-series filters were not preconditioned with high humidity (Federal Register, 1995). Sodium chloride aerosol was used for the N-series filters and DOP was used for the R and P-series filters. The count median diameters/geometric standard deviations (CMD)/(GSD) for the Model 8130 are $0.075 \mu\text{m}/<1.83$ and $0.20 \mu\text{m}/<1.6$ for the NaCl and DOP aerosols, respectively (TSI, 2000). Since these filters are normally used in pairs, airflow rate through each filter was approximately 42.5 L/min, equivalent to the NIOSH rate of 85 L/min per respirator assembly.

Following the penetration and pressure drop tests, the filters were placed in self-sealing plastic bags and taken to a steel foundry. Subsets of each series and each treatment were randomly chosen and exposed to either a grinding aerosol or an oil mist generated by a quenching operation. Exposure times in the foundry were approximately 30 to 60 minutes for each filter. The airflow rate through each filter was approximately 25 L/min. Other randomly chosen filters were used as unexposed controls. Control filters were exposed to the work environment for several seconds and immediately placed in self-sealing plastic bags. This was done to determine if laboratory penetration and/or pressure drop were affected by handling procedures in the workplace. No air was drawn through the control filters. Specific workplace procedures and results are detailed in a companion paper (Janssen *et al.*, 2003). After the workplace portion of the study, the exposed and control filters were returned to the laboratory for post-exposure initial penetration and pressure drop testing.

RESULTS

Mean initial penetration and pressure drop measurements for all filters tested prior to the study are shown in Table II. Tables III through VII present mean laboratory penetration and pressure drop measurements taken after the workplace portion of the study. These measurements are reported only for filters actually used as exposed or control filters in the foundry.

N95 and P100 filters were used in both the grinding aerosol and oil mist exposure areas of the plant. Only one set of control filters was used for each treatment of these filter types. For reader convenience, the same N95 control values are listed on Tables III and VII. Similarly, the same P100 control values are included in Tables IV and VI.

It was intended to test six N95 filters of each treatment from each manufacturer in the grinding area. Investigator error resulted in testing one additional untreated filter from Manufacturer A and one additional irradiated filter from Manufacturer B. This is reflected in Table III.

Table II. Initial Penetration and Pressure Drop Values-All Filters

Filter	N	Mean Penetration (%) ^a	Range (%)	Mean Pressure Drop (mm water)	Range (mm water)
Manufacturer A N95 – Untreated	16	0.561	0.406 - 0.769	11.5	10.8-12.7
Manufacturer A N95 – Irradiated	24	6.79	4.64 - 11.1	11.6	10.4-12.9
Manufacturer A N95 – IPA-dipped	16	26.9	18.7 - 37.1	12.8 ^b	10.0-16.4
Manufacturer A P95 – Untreated	14	0.780	0.684 - 0.974	14.9	13.2-18.3
Manufacturer A P95 – Irradiated	14	7.94	5.8 - 14.2	15.2	13.8-17.2
Manufacturer A P95 – IPA-dipped	16	0.975	0.619 - 1.32	15.0	12.5-20.3
Manufacturer A P100 – Untreated	25	<0.001	<0.001-0.001	23.9	20.1-29.7
Manufacturer A P100 – Irradiated	24	0.712	0.191 - 1.39	23.2	18.4-29.2
Manufacturer A P100 - IPA-dipped	20	0.064	0.045 - 0.082	22.0 ^b	19.0-27.4
Manufacturer B N95 – Untreated	20	0.494	0.216 - 1.69	9.7	8.6-11.2
Manufacturer B N95 – Irradiated	24	12.9	8.35 - 21.0	9.8	8.4-11.4
Manufacturer B N95 – IPA-dipped	16	59.6	51.1 - 64.8	10.0	8.7-11.6
Manufacturer B R95 – Untreated	14	0.068	0.043 - 0.098	13.6	11.8-14.5
Manufacturer B R95 – Irradiated	14	15.2	11.3 - 19.5	13.3	11.9-14.7
Manufacturer B R95 – IPA-dipped	16	45.6	37.0 - 51.3	13.7	12.3-14.7
Manufacturer B P100 – Untreated	25	0.0055	0.004 - 0.007	17.8	17.0-18.8
Manufacturer B P100 – Irradiated	23	0.0070	0.005 - 0.009	17.8	17.0-18.4
Manufacturer B P100 -IPA-dipped	22	0.0099	0.009 - 0.011	17.3 ^b	16.7-19.1

^a Mean penetration values for all irradiated and IPA-dipped filters are significantly higher than the mean value for untreated filters of the same type (P<0.05).

^b Mean pressure drop value is significantly different than the mean of the untreated filters of the same type (P<0.05).

Table III. Laboratory Penetration and Pressure Drop for N95 Filters Before and After Exposure to Grinding Aerosol (Mean and Standard Deviation)

Treatment	N	Initial Penetration (%)		Initial Pressure Drop (mm water)		Final Penetration (%)		Final Pressure Drop (mm water)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Manufacturer A									
Untreated	7	0.598	0.064	11.4	0.392	0.671	0.129	11.5	0.341
Untreated Control	4	0.519 ^a	0.061	11.8	0.082	0.448 ^a	0.045	11.8	0.216
Irradiated	6	7.60	1.77	11.4 ^b	0.601	7.21	1.34	11.8 ^b	0.599
Irradiated Control	4	6.83 ^c	1.67	11.2 ^d	0.408	6.38 ^c	1.53	11.5 ^d	0.419
IPA-Dipped	6	24.9 ^e	6.45	12.5	1.43	21.4 ^e	5.78	12.1	0.875
IPA-Dipped Control	4	28.8 ^f	8.08	12.7	2.21	24.8 ^f	8.62	12.3	1.61
Manufacturer B									
Untreated	6	0.581	0.565	9.5	0.542	0.797	0.450	10.0	0.950
Untreated Control	4	0.376 ^g	0.106	9.6	0.802	0.628 ^g	0.116	9.8	0.755
Irradiated	7	13.7	3.89	9.5	0.926	13.2	3.70	10.0	1.18
Irradiated Control	4	14.3	2.03	9.6	0.330	11.6	1.85	10.0	0.483
IPA-Dipped	6	61.2 ^h	2.80	10.0	0.729	60.2 ^h	2.50	9.7	0.46
IPA-Dipped Control	4	56.2 ⁱ	4.64	10.4	0.551	57.3 ⁱ	4.48	9.9	0.47

Note: Values marked with the same letter are significantly different from one another (P<0.05).

Six P95 filters from Manufacturer A and six R95 filters from Manufacturer B were exposed in the oil quenching area. Likewise, six P100 filters from each manufacturer were exposed in this area. However, because the mist generation of the quenching operation was highly variable, not every filter was exposed to a measurable concentration of oil mist. Thus, Tables V and VI include penetration and pressure drop measurements only for those test filters that had measurable oil mist exposure.

Table VI also includes data for P100 filters intermittently exposed to the oil mist. Only one filter from each manufacturer was tested in this manner.

Table VII contains data for N95 filters tested in the oil quenching area. Three untreated and three irradiated N95 filters from each manufacturer were exposed. One irradiated filter from Manufacturer B was exposed when there was no measurable oil mist and is not included in Table VII. Only one untreated N95 filter from each manufacturer was intermittently exposed to oil mist.

DISCUSSION

Table II shows that mean initial penetration values for all irradiated class 95 filters were in the desired range of 6-15%. Mean initial penetration for the irradiated electret P100 filters from Manufacturer A was slightly below the 1% target. However, the mean penetration value of 0.712% was nearly 24 times the 0.03% permitted for NIOSH P100 approval, and more than 700 times the value of the untreated P100 electret filters.

Table IV. Laboratory Penetration and Pressure Drop for P100 Filters Before and After Exposure to Grinding Aerosol (Mean and Standard Deviation)

Treatment	N	Initial Penetration (%)		Initial Pressure Drop (mm water)		Final Penetration (%)		Final Pressure Drop (mm water)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Manufacturer A									
Untreated	6	<0.001	---	24.9	2.67	<0.001	---	28.7	5.10
Untreated Control	6	<0.001	---	23.4	2.722	<0.001	---	23.3	3.20
Irradiated	6	0.579	0.210	24.1	4.12	0.637	0.210	25.4	5.04
Irradiated Control	6	0.887 ^a	0.474	23.7	2.18	1.00 ^a	0.535	26.3	3.10
IPA-Dipped	6	0.062 ^b	0.011	21.4 ^c	2.48	0.076 ^b	0.017	24.9 ^c	3.81
IPA-Dipped Control	6	0.068 ^d	0.006	21.9	1.58	0.087 ^d	0.019	25.2	2.95
Manufacturer B									
Untreated	6	0.0058 ^e	0.001	17.8 ^f	0.251	0.0072 ^e	0.001	18.5 ^f	0.283
Untreated Control	6	0.0055 ^g	0.001	18.2 ^h	0.572	0.0070 ^g	0.001	18.8 ^h	0.613
Irradiated	6	0.0072 ⁱ	0.001	17.9	0.455	0.0058 ⁱ	0.000	18.5	0.543
Irradiated Control	6	0.0077	0.001	17.8 ^j	0.423	0.0063	0.001	18.4 ^j	0.343
IPA-Dipped	6	0.0100 ^j	0.001	17.1 ^k	0.179	0.0115 ^j	0.001	17.8 ^k	0.214
IPA-Dipped Control	6	0.0102 ^l	0.001	17.4 ^m	0.838	0.0117 ^l	0.001	18.0 ^m	0.838

Note: Values marked with the same letter are significantly different from one another (P<0.05).

The mechanical P100 filters from Manufacturer B were exposed to the same radiation dose (over 10 000 R) as the P100 electrets. While mean initial penetration remained below the limit allowed for P100 approval, it was significantly higher (P<0.05) than that of the untreated mechanical P100 filters. To the authors' knowledge, this has not been reported previously in the literature. The reasons for this apparent increase in penetration are not known, nor were they investigated as a part of this study. It is possible that weak electrostatic charges are naturally present on the surface of the mechanical filter media, and the high radiation dose eliminated these charges.

Thus, ionizing radiation is an effective method of reducing charges and controlling the efficiency of electret filter media for experimental work. However, based on these data, it is not a significant consideration for electret filter use in the workplace: The radiation doses needed to cause the filters to exceed the NIOSH test criteria for penetration far exceed the median lethal dose for humans.

Also shown in Table II are the effects of dipping filters in IPA. Mean penetration values increased over the untreated filters in all cases. Again, this phenomenon is well known for electret filters (Chen *et al.*, 1993; Chen and Huang, 1998; Martin and Moyer, 2000) but has not been reported for mechanical filters. The reason for this effect may be similar to that suggested above for the effect of ionizing radiation.

While the N series filters from both manufacturers and the R series from Manufacturer B showed large increases in mean penetration following the IPA dip, P series filters from Manufacturer A were much more resistant to this treatment. Indeed, penetration of the P95 filters from Manufacturer A remained well below the NIOSH 5% penetration criterion following the IPA dip.

Table V. Laboratory Penetration and Pressure Drop for P95 and R95 Filters Before and After Exposure to Oil Mist (Mean and Standard Deviation)

Treatment	N	Initial Penetration (%)		Initial Pressure Drop (mm water)		Final Penetration (%)		Final Pressure Drop (mm water)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
<u>Manufacturer A P95</u>									
Untreated	3	0.797	0.039	16.2	0.945	0.832	0.062	16.2	1.60
Untreated Control	5	0.808	0.129	15.4	2.07	0.882	0.125	16.2	1.46
Irradiated	3	8.20	3.49	15.1	1.31	10.3	4.12	19.0	4.04
Irradiated Control	5	8.71 ^a	3.20	14.9 ^b	1.22	10.3 ^a	3.27	16.1 ^b	1.85
IPA-Dipped	1	1.06	---	13.0	---	1.26	---	13.2	---
IPA-Dipped Control	5	0.923	0.242	14.1	0.760	1.36	0.575	17.5	3.63
<u>Manufacturer B R95</u>									
Untreated	2	0.072	0.023	14.4	0.000	0.136	0.004	14.2	0.071
Untreated Control	5	0.076	0.019	13.2	0.728	1.28	0.455	13.1	0.936
Irradiated	2	13.9	3.68	13.6	0.071	16.4	1.49	12.8	0.495
Irradiated Control	5	15.5	3.50	13.5	0.879	17.4	3.84	13.2	1.09
IPA-Dipped	-	---	---	---	---	---	---	---	---
IPA-Dipped Control	5	45.3 ^c	6.01	13.7	0.973	48.0 ^c	5.47	13.5	1.35

Note: Values marked with the same letter are significantly different from one another ($P < 0.05$).

Therefore, it is logical to conclude that different electret media are affected differently by IPA saturation. As is the case with irradiation, the effects of IPA saturation have no practical significance outside the laboratory because filters are not saturated with solvents in the workplace. Additionally, it has been documented that concentrations of solvent vapors encountered in work environments do not adversely affect electret filter efficiency (Eitzman and Mullins, 2001; Martin *et al.*, 2002, Martin *et al.*, 2003).

Table II also shows that the pressure drop values for all the filters were well below the 35 mm value permitted for NIOSH approval. T-tests revealed that mean pressure drop values for the IPA-dipped N95 and P100 filters from Manufacturer A were significantly different ($P < 0.05$) from their respective untreated filters. The mean pressure drop for the IPA-dipped mechanical P100 filters from Manufacturer B was significantly lower than the mean value for their untreated filters. Chen and Huang (1998) reported a slight increase (not statistically significant) in average pressure drop in electret filter media following a 5-minute IPA dip. They speculated that impurities in the IPA may have slightly increased the packing density of the media. It was also suggested that the IPA dip may have caused some compression of the media. In the present study, the mean pressure drops for both electret and mechanical P100 filters were lower than the untreated mean pressure drops. Thus, it appears that a change in structure is the more plausible of the two arguments offered by Chen and Huang. Structural change in the filter media could also partially account for the increased penetration values discussed earlier.

Table VI. Laboratory Penetration and Pressure Drop for P100 Filters Before and After Exposure to Oil Mist (Mean and Standard Deviation)

Treatment	N	Initial Penetration (%)		Initial Pressure Drop (mm water)		Final Penetration (%)		Final Pressure Drop (mm water)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Manufacturer A									
Untreated	4	<0.001	0.000	22.5 ^a	2.877	<0.001	0.000	26.4 ^a	2.794
Untreated Control	6	<0.001	0.001	23.4	2.722	<0.001	0.001	23.3	3.20
Untreated- Intermittently Exposed	1	0.001	---	24.3	---	<0.001	---	21.8	---
Irradiated	2	0.842	0.002	23.3	2.546	0.900	0.116	25.2	0.990
Irradiated Control	6	0.887 ^b	0.474	23.7	2.18	1.00 ^b	0.535	26.3	3.10
IPA-Dipped	2	0.0675	0.018	23.6	5.303	0.0655	0.015	23.8	5.940
IPA-Dipped Control	6	0.0678 ^c	0.006	21.9	1.58	0.0870 ^c	0.019	25.2	2.95
Manufacturer B									
Untreated	3	0.0057	0.001	17.9	0.404	0.0063	0.001	18.4	0.208
Untreated Control	6	0.0055 ^d	0.001	18.2 ^e	0.572	0.0070 ^d	0.001	18.8 ^e	0.613
Untreated- Intermittently Exposed	1	0.007	---	17.7	---	0.010	---	18.7	---
Irradiated	4	0.0058	0.001	18.0 ^f	0.100	0.0065	0.001	18.5 ^f	0.141
Irradiated Control	6	0.0077	0.001	17.8 ^g	0.423	0.0063	0.001	18.4 ^g	0.343
IPA-Dipped	3	0.0097	0.001	17.0 ^h	0.300	0.0110	0.001	17.6 ^h	0.351
IPA-Dipped Control	6	0.0102 ⁱ	0.001	17.4 ^j	0.838	0.0117 ⁱ	0.001	18.0 ^j	0.838

Note: Values marked with the same letter are significantly different from one another ($P < 0.05$).

Tables III through VII list the results of the pre-and post-study penetration and pressure drop measurements taken on the filters used in the foundry. T-tests revealed statistically significant differences ($P < 0.05$) in some of the pre- versus post-study values for one or both measurements for essentially all groups of filters. Control values changed slightly more often than did the values for the test filters. Post-study penetration values for the test filters decreased in three instances and increased in three others. Penetration values for the control filters after the study were significantly lower than the pre-study values three times and higher than the initial values eleven times. All the changes were numerically small and within the range of normal measurement variability for both test and control filters. Thus, no effect on laboratory filter penetration measurements can be attributed to the workplace exposures for any of the filters.

Post-study pressure drop measurements for the test filters were significantly higher ($P < 0.05$) than the initial measurements in eight instances. Control filter pressure drop readings significantly increased in five instances and decreased once. While the increase in the pressure drop values for the test filters may

have been due to the effects of loading with the workplace aerosol, the small sample sizes and relatively low exposures make it impossible to say this with certainty.

Table VII. Laboratory Penetration and Pressure Drop for N95 Filters Before and After Exposure to Oil Mist (Mean and Standard Deviation)

Treatment	N	Initial Penetration (%)		Initial Pressure Drop (mm water)		Final Penetration (%)		Final Pressure Drop (mm water)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Manufacturer A									
Untreated	3	0.495	0.086	11.7 ^a	0.907	0.737	0.465	11.8 ^a	0.945
Untreated Control	4	0.519 ^b	0.061	11.8	0.082	0.448 ^b	0.045	11.8	0.216
Untreated- Intermittently Exposed	1	0.459	---	12.2	---	0.785	---	12.3	---
Irradiated	3	6.29	1.038	11.1	0.624	6.53	1.35	11.3	0.709
Irradiated Control	4	6.83 ^c	1.67	11.2 ^d	0.408	6.38 ^c	1.53	11.5 ^d	0.419
Manufacturer B									
Untreated	3	0.723	0.391	10.4	0.917	0.590	0.289	10.3	0.964
Untreated Control	4	0.376 ^e	0.106	9.6	0.802	0.628 ^e	0.116	9.8	0.755
Untreated- Intermittently Exposed	1	0.419	---	8.9	---	1.09	---	8.5	---
Irradiated	2	13.8	1.943	9.5	0.252	14.8	1.450	9.3	0.252
Irradiated Control	4	14.3	2.03	9.6	0.330	11.6	1.85	10.0	0.483

Note: Values marked with the same letter are significantly different from one another (P<0.05).

CONCLUSIONS

In this study, extremely high levels of radiation and saturation with isopropanol were shown to reduce the efficiency of both electret and mechanical filters when tested under worst-case laboratory conditions. Some types of electret filters were much less sensitive to the IPA saturation than others. For these filters, radiation dose was more effective in increasing penetration to the desired level.

Workplace exposure to grinding aerosol or industrial oil mist did not adversely affect the laboratory penetration or pressure drop of either electret or mechanical filters. This holds true for both untreated and intentionally degraded filters.

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