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Degradation of HEPA Filters Exposed to DMSO*
by

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Abstract

Dimethyl sulfoxide (DMSO) sprays are being used to remove the high explosive (HE) from nuclear weapons in the process of their dismantlement. A boxed 50 cfm HEPA filter with an integral prefilter was exposed to DMSO vapor and aerosols that were generated by a spray nozzle to simulate conditions expected in the HE dissolution operation. After 198 hours of operation, the pressure drop of the filter had increased from 1.15 inches to 2.85 inches, and the efficiency for 0.3 μ m dioctyl sebacate (DOS) aerosols decreased from 99.992% to 98.6%. Most of the DMSO aerosols had collected as a liquid pool inside the boxed HEPA. The liquid was blown out of the filter exit with 100 cfm air flow at the end of the test. Since the filter still met the minimum allowed efficiency of 99.97% after 166 hours of exposure, we recommend replacing the filter every 160 hours of operation or sooner if the pressure drop increases by 50%. Examination of the filter showed that visible cracks appeared at the joints of the wooden frame and a portion of the sealant had pulled away from the frame.

Since all of the DMSO will be trapped in the first HEPA filter, the second HEPA filter should not suffer from DMSO degradation. Thus the combined efficiency for the first filter (98.6%) and the second filter (99.97%) is 99.99996% for 0.3 μ m particles. If the first filter is replaced prior to its degradation, each of the filters will have 99.97% efficiency, and the combined efficiency will be 99.999991%. The collection efficiency for DMSO/HE aerosols will be much higher because the particle size is much greater.

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I. Introduction

This study was initiated in support of the nuclear weapons dismantlement program in which the HE, HMX, is being removed from the weapon by dissolution with DMSO. Heated DMSO is sprayed against the exposed HE to dissolve it and aid in breaking up the HE layer. The DMSO spray generates a high concentration of fine aerosols that is contained in a workstation. This aerosol may contain up to 25% by weight dissolved HE. The exhaust from the workstation is filtered through two, 135 cfm HEPA filters to prevent potential radioactive contamination or HE from being released to the environment.

A schematic of the ventilation system used for the HE dissolution workstation is shown in Figure 1. The ventilation system consists of a 35 cfm inlet HEPA filter with a butterfly valve to seal off the inlet during the DMSO spraying. The exhaust consists of two, 135 cfm HEPA filters in series followed by a Fischer valve (Associated Process Controls, Pleasanton, CA, 94566), and a flow meter. Although a standard 50 cfm HEPA filter would be sufficient to meet the required exhaust flow capacity of 55 cfm for safety considerations, we selected the 135 cfm HEPA filter to reduce the exhaust flow restrictions. The Fischer valve opens when the vacuum in the 16 cubic feet workstation drops below -1 inch of water and closes when the vacuum increases greater than -1 inch of water. During the dissolution process, there is no ventilation through the workstation except for short intervals when the Fischer valve opens to maintain a -1 inch of vacuum inside the workstation. After the dissolution operation is completed, the inlet butterfly valve is opened, and filtered room air sweeps the workstation clean and exhausts through the exhaust HEPA filter.

Since DMSO is an excellent solvent for many polymers, we were concerned that the solvent would dissolve the components of the HEPA filter and degrade the filter performance. The primary components of the HEPA filter that we suspected as being susceptible to attack from DMSO are the acrylic binder that holds the glass fibers together in the media and the polyurethane foam sealant that seals the pleated filter pack into the frame. The filter type that we tested was a combined, prefilter-HEPA filter unit boxed in a single plywood housing: Flanders, Dual Pack, 50 cfm, model 007-C-04-00-NL. The prefilter medium was a glass fiber medium with an atmospheric dust spot efficiency of 60% according to ASHRAE Standard 52-76. The HEPA medium met the requirements in MIL-F-51079.

Figure 1. Ventilation system for the HE dissolution workstation.

II. Characterizing DMSO challenge to HEPA filters

In order to evaluate the effect of the DMSO exposure on HEPA filters, we first had to characterize the challenge to the filters. Although the challenge consisted of both DMSO vapor and aerosols, we only measured the aerosol component. Since the spray operation generates a high concentration of aerosols, we could assume that the vapor concentration would be the saturated concentration, which is easily computed for each temperature. Table 1 shows the saturated vapor pressure and concentration of DMSO at various temperatures. Two of the data sets are experimental measurements, while the remainder were computed using the Clapeyron-Clausius equation

Table 1 Saturated DMSO vapor pressure and concentration

Temperature		Vapor Pressure	Concentration	
°F	°K	Torr	%	g/m ³
72*	293	0.40*	0.05	1.7
100	311	1.39	0.18	5.3
122*	323	3.00*	0.39	11.7
150	339	7.43	0.98	27.6
189	360	22.8	3.00	79.5

*experimental data

We measured the concentration and size distribution of the DMSO aerosols produced under simulated operating conditions using the apparatus shown in Figure 2.

Figure 2. Experimental apparatus used for measuring the mass concentration and size distribution of DMSO aerosols generated from a single nozzle.

We simulated the work station and spray operation with a sealed Plexiglass chamber (0.87 cu. ft.) in which a spray nozzle was positioned 1.5 inches from a flat plate. In practice, multiple nozzles would be directed against the exposed HE. A piston pump (ARO) fed liquid DMSO at 100 psi to the spray nozzle and pulled liquid from a can that served both as a collector for the liquid run-off and as a reservoir. The temperature in the test chamber was at room temperature, about 70°F. The Plexiglass chamber also had a HEPA filtered inlet and a vacuum exhaust to simulate the ventilation system. We used a MSA respirator cartridge filter to filter the DMSO aerosols from the exhaust. The mass concentration of DMSO aerosols was determined by weighing the filter before and after the test and dividing by the air flow volume. The average concentration for four measurements is 3.3 g/m³ with a standard deviation of ± 1.1 g/m³. We also measured the aerosol size distribution with a Climet 208 particle counter. Figure 3 shows the size distribution of DMSO aerosols plotted as a function of particle diameter. The peak number concentration occurs at 1.6 μ m diameter.

- Background (counts/cc.-Log Width)
- Upstream (counts/cc.-Log Width)

Figure 3. Size distribution of DMSO aerosols.

To verify that the DMSO concentration used in our filter experiments was realistic, we measured the mass concentration of DMSO/HE in a full-scale dissolution test. The tests were conducted on a simulated warhead that was sprayed with a solution of DMSO/HE. The temperature within the workstation was 120°F. Thirty-two nozzles (12 jets and 20 fans) were used in a manifold spray fixture. The aerosol mass was determined at twelve positions within a workstation that was 46 inches long, 34 inches wide, and 32 inches high.

Figure 4 shows a schematic of the workstation and sampling train used in the measurements along with the location of the twelve sampling locations. Each of the twelve sampling locations was six inches from the nearest wall. For example the top corner samples were taken six inches from the top wall and six inches from each side wall. The side samples were taken in the middle of the side wall, six inches from the side wall, and six inches from either the top or bottom walls. The aerosols were sampled at 1 cfm ($0.0283 \text{ m}^3/\text{min}$) for three minutes through eight feet of 0.625 inch ID nylon tubing prior to collection on a 2 inch filter disk that was cut from a standard HEPA media. The aerosol mass was determined by weighing the filter disks before and after the sample. No tests were conducted to establish the particle line loss since potential losses would be negligible compared to the variation in concentration found in the box. The concentration measurements were computed from the DMSO/HE mass collected divided by 0.0849 m^3 ($0.0283 \text{ m}^3/\text{min} \times 3 \text{ min.} = 0.0849 \text{ m}^3$) and are tabulated in Table 2.

The average DMSO/HE concentration from Table 2 is 1.87 g/m^3 with a standard deviation of $\pm 0.57 \text{ g/m}^3$. This concentration is less than what was measured with a single nozzle in the apparatus shown in Figure 2. We suspect that the larger particles were quickly settling out in the workstation yielding a smaller average particle size and hence a lower mass concentration. The larger aerosols in the single nozzle apparatus could not settle out because all of the air was being swept out and filtered for mass determinations. In contrast there was no air flow in the workstation during the spraying operation to prevent the larger particles from settling out. We did not measure the aerosol size distribution in the workstation to confirm our hypothesis because our instruments would be contaminated with HE and could not be cleaned. However, during the purge cycle the large particles will also be swept out into the filtration system. Thus, the single nozzle measurements provide a more conservative measurement of aerosol mass concentration.

Figure 4. Schematic of the sampling train and the location of the sample probes in the DMSO/HE dissolution workstation

In addition to the DMSO aerosol challenge, the HEPA filters would also be exposed to a vapor challenge. As seen in Table 1, the vapor concentration is comparable to the aerosol challenge. At higher temperatures, the vapor concentration is much higher than the aerosol concentration. However, most of the vapor DMSO will pass through the HEPA filter whereas more than 99.97% of the DMSO aerosols will be trapped on the first HEPA filter. In practice, since the DMSO/HE particles are greater than 1 μm diameter, more than 99.9999% of the DMSO/HE particles will be trapped on the first filter. Although we have not measured the size distribution of DMSO/HE aerosols, the dissolved HE should not significantly affect the size distribution. Thus based on the single nozzle and full-scale tests, we estimate that about 3 g/m^3 of aerosol and 1.7 to 35 g/m^3 of vapor will be generated in the DMSO workstation depending on the temperature between 72 F and 160 F. This aerosol and vapor will challenge the exhaust HEPA filter. At the higher temperature, a significant fraction of the DMSO vapor will penetrate the first filter and condense on the second filter.

Table 2 Concentration of DMSO aerosols at various locations in a HE dissolution workstation.

Location	Concentration g/m^3
Top Corner	
A	1.79
C	2.89
H	1.24
J	2.04
Bottom Corner	
B	1.62
D	2.76
I	1.31
K	1.58
Top Side	
E	1.30
G	2.48
Bottom Side	
F	2.16
L	1.41

III. Filter Media Tests

We exposed samples of HEPA media cut from a new HEPA filter (MSA 50 cfm, part 464891) to saturated DMSO vapor and then conducted tensile strength tests on the exposed media. The precut media samples were suspended over a pool of DMSO contained in a sealed container. Since DMSO readily absorbs water, the samples were preconditioned at 50 C in a vacuum oven for 65 hours to remove any water absorbed on the media. We also conducted baseline tests on samples with and without preconditioning. The tensile strengths were measured using an Instron tester in both the machine direction (MD) and in the cross direction (CD). The results of our tests are shown in Table 3. The number of samples tested at each condition are shown in the table and provide a measure of the standard deviation.

Table 3 Media tensile strength after DMSO vapor exposure

Exposure	Pretest Conditioning	Maximum tensile load at failure (lbs)	
		Machine direction	Cross direction
Baseline (ambient air)	As-is	1.03±0.08	0.74±0.06
"	Dried under vac @ 50°C for 65 hrs	1.48±0.01	0.99±0.09
"	Dried under vac @ 50°C for 65 hrs	1.30±0.11	0.92±0.20
Sat'd DMSO vapor @ RT for 483 hours	Dried under vac @ 50°C for 43 hrs	1.32±0.04	0.99
Sat'd DMSO vapor @ 50°C for 343 hrs + 149 hrs @ RT	Dried under vac @ 50°C for 43 hrs	1.38±0.05	1.04

Note: The "±" values represent a single standard deviation.

The test results show that exposure to saturated DMSO vapor has no effect on the HEPA media strength. Table 3 also shows that the preconditioning increases the media strength by about 30%. We suspect that the pretreatment provided additional curing of the acrylic binder used to hold the fibers together in the media.

IV Filter Tests

We conducted a series of DMSO exposure tests on a boxed 50 cfm HEPA filter with an integral prefilter. This is the typical first stage filter used in the exhaust from glove boxes at LLNL. A photograph of the HEPA filter with flanges removed after the exposure test is shown in Figure 5.

Figure 5. Boxed HEPA filter that was used in our simulation exposure test

The exposure test was designed to simulate conditions in the HE dissolution operation which consists of spraying heated DMSO for six hours to dissolve the HE. The inlet valve to the workstation is closed during the spraying operation to contain the DMSO/HE solution. The Fischer valve maintains a -1 inch pressure within the workstation during the dissolution by intermittently opening for short periods when the box vacuum drops below -1 inch due to thermal expansion of the air, leaks in the workstation, and evaporation of the solvent. We estimate that an exhaust flow of about 1 cfm is pulled through the HEPA filter during the six hour dissolution process. After the dissolution is complete, the DMSO spray is turned off and the inlet valve to the workstation is opened and the workstation is swept clean with room air for about 30 minutes.

We set up two different flow systems to simulate the HE dissolution operation. Figure 6 shows the experimental apparatus used to simulate conditions during the dissolution spraying operation. An air stream containing DMSO aerosols is heated and then passed through the HEPA

filter. Heating tape wrapped around the inlet tube can raise the temperature from room temperature up to 150 F at the inlet to the HEPA filter. Two different size Laskin nozzle generators were used to generate the DMSO aerosols: a single nozzle generator and a six nozzle generator. The air flow through the small and large generators was 1.5 and 6.5 cfm respectively. All of the air passing through the filter came from the aerosol generator. The concentration of DMSO aerosols for the small and large generators was computed from filter mass measurements to be 0.083 g/cu. ft. and 0.022 g/cu. ft. respectively.

Figure 6. Schematic of apparatus used for simulating HEPA exposure to DMSO during the HE dissolution mode.

Following the 6 hour exposure to DMSO in the test apparatus shown in Figure 6, the HEPA was connected to a blower and had 30 cfm of air pass through the filter for 30 minutes. This operation represents the purge mode of the filter exposure.

The filter efficiency was also determined at the beginning of the HEPA exposure and at the end of each week of exposure for the six week test. We used a laser particle counter (Particle Measuring Systems HS-LPS) to measure the penetration of DOS aerosols throughout the HEPA filter at 50 cfm as a function of particle size from 0.065 to 1.0 μm diameter. The DOS aerosols were generated with a Laskin nozzle generator. The upstream concentration measurement was diluted to prevent coincidence counting. A schematic of the filter efficiency test apparatus is shown in Figure 7

Figure 7. Schematic of filter efficiency test apparatus

For the first 81 hours of the 198 hour test, the HEPA filter was exposed daily to 2.9 g/m^3 of DMSO at 1.5 cfm for 6 hours followed by an air purge at 30 cfm for 0.5 hours. For the next 85 hours the HEPA filter was exposed to 0.78 g/m^3 of DMSO at 6.5 cfm for 6 hours, but with no air purges. The HEPA filter had no DMSO challenge or air flow during evenings and on weekends. This allowed liquid DMSO trapped on the filter to drain from the media and/or evaporate. During the final 32 hours, the HEPA filter was exposed to a 0.78 g/m^3 of aerosol generated from a solution of plastic EPON dissolved in DMSO to simulate the HE dissolved in DMSO. At the end of the test program, the filter was subjected to 100 cfm air flow (twice its rated flow) to see if the filter would develop structural damage.

V. Simulation Test Results

A summary of all of the filter exposure tests are given in Table 4., where the exposure time, initial and final pressure drop, flow rate, and computed mass of DMSO deposit is tabulated. The filter was exposed to DMSO aerosols for 198 hours over a six week period. Note that although the pressure drop of the HEPA filter increased during loading, it generally

Table 4. Summary of HEPA filter exposure tests

Date	Exposure time (hrs.)	ΔP Initial (w.g.)	ΔP final (w.g.)	Test	Flowrate (CFM)	Mass of DMSO (gms)
8/20/93	5.50	0.020	0.041	Loading (1)	1.52	41.349
8/25/93	8.00	0.035	0.046	Loading	1.50	60.144
	0.50	0.580	0.680	Purge	30.00	0.000
8/26/93	8.00	0.250	0.055	Loading	1.50	60.144
	0.50	0.700	0.650	Purge	30.00	0.000
8/30/93	8.00	0.025	0.050	Loading	1.50	60.144
	0.50	0.061	0.061	Purge	30.00	0.000
8/31/93	9.50	0.025	0.046	Loading	1.50	71.421
	0.50	0.640	0.680	Purge	30.00	0.000
9/1/93	9.00	0.020	0.052	Loading	1.50	67.662
	0.50	0.660	0.710	Purge	30.00	0.000
9/2/93	8.00	0.031	0.057	Loading	1.50	60.144
	0.50	0.660	0.680	Purge	30.00	0.000
9/3/93	8.00	0.025	0.047	Loading	1.50	60.144
	0.50	0.640	0.670	Purge	30.00	0.000
9/7/93	8.50	0.024	0.054	Loading	1.50	63.903
	0.50	0.670	0.690	Purge	30.00	0.000
9/8/93	8.00	0.030	0.061	Loading	1.50	60.144
9/9/93	4.50	0.031	0.038	Loading	1.50	33.831
	4.00	0.165	0.165	Loading (2)	6.50	0.000
9/13/93	10.00	0.110	0.192	Loading	6.50	85.700
9/14/93	10.00	0.120	0.179	Loading	6.50	85.700
9/15/93	10.00	0.125	0.195	Loading	6.50	85.700
9/16/93	6.00	0.170	0.190	Loading	6.50	51.420
9/17/93	8.00	0.134	0.180	Loading	6.50	68.560
9/20/93	10.00	0.130	0.195	Loading	6.50	85.700
9/21/93	9.50	0.123	0.190	Loading	6.50	81.415
9/22/93	8.00	0.135	0.190	Loading	6.50	68.560
9/23/93	4.00	0.320	0.350	Loading	6.50	34.280
	1.50	2.300	2.600	Loading (3)	42.00	12.855
9/24/93	7.00	0.250	0.390	Loading (4)	6.50	59.990
	2.00	0.390	0.430	Loading (5)	6.50	17.140
9/27/93	8.00	0.320	0.480	Loading	6.50	68.560
9/28/93	9.00	0.400	0.670	Loading	6.50	77.130
9/29/93	5.50	0.600	0.980	Loading	6.50	47.135
		5.000		Purge (6)	100.00	0.000
Notes:	(1) DMSO is generated at 7.518 gms/hr.					
	(2) DMSO is generated at 8.570 gms/hr.					
	(3) DMSO is generated at 8.570 gms/hr. and is put into a 42 CFM airstream					
	(4) DMSO is generated at 8.570 gms/hr.					
	(5) 8.570 gms/hr. of DMSO is collected on filter. 72.0 gms of EPON 1002F and 92.0 gms of EPON 1004F was added to 2.20 liters of DMSO					
	(6) Purge test with 100 CFM. Approximately 2.0 pints of DMSO spewed out of the downstream side of the filter and blower.					
	Total DMSO Collected on filter (gms)=					
	1568.88					

returned to its original value at the beginning of the next test on the following day. Figure 8 shows the typical increase in filter pressure drop at 1.5 cfm during the 6 hour DMSO exposure. The elevated pressure drop had decreased to its initial value by the start of the next day's test. This increase in filter pressure drop and the subsequent decrease on sitting overnight was typical throughout the test program, even for the DMSO loadings that were not followed by an air purge.

Figure 8 Typical increase in filter pressure drop during DMSO loading during the simulated HE dissolution process.

Filter penetration measurements with DOS aerosols were also conducted prior to DMSO exposure and after each week of DMSO exposures. All of the tests were conducted at the rated flow of 50 cfm. Figure 9 shows the filter penetration prior to DMSO exposure.

The filter penetration measurement after approximately every forty hours of DMSO exposure up to 166 hours was similar to the data for the fresh, unexposed HEPA filter. Although the filter pressure drop had increased from 1.15 inches to 1.55 inches after 166 hours, this increase is due to the atmospheric dust that deposited on the filter. Figure 10 shows that the filter penetration after 166 hours of DMSO exposure is comparable to the penetration for the new filter in Figure 9. It is clear from the data that exposure to DMSO will not cause a rapid degradation in HEPA filter performance.

Figure 9. Penetration of DOS aerosols through HEPA filter prior to DMSO exposure.

Figure 10. Penetration of DOS aerosols through HEPA filter after 166 hours of DMSO exposure.

Since the DMSO will have up to 25% dissolved HE, we conducted exposure tests on the HEPA filter with 6.3% dissolved plastic to see the effect of dissolved solids. After 32 hours of loading with the DMSO/plastic solution, the HEPA filter pressure drop increased from 0.32 inches to 0.98 inches (See Table 4) at a flow rate of 6.5 cfm. We then tried to pass 100 cfm through the loaded filter to see if the filter would be structurally damaged.

However, we quickly found that liquid DMSO was spraying out from the downstream side of the HEPA filter. By a combination of high air flow (100 cfm) and pouring out standing DMSO, we were able to remove about 1 liter of DMSO that was trapped inside the filter. According to Table 4, the computed mass of DMSO injected into the filter is 1.59 kg or 1.4 liters of liquid. Since we recovered 1 liter out of 1.4 liters, most of the DMSO aerosol injected into the filter will remain in the filter as a liquid. The HEPA filter apparently acts as a sponge soaking up liquid DMSO until the filter becomes fully saturated

After we removed the liquid DMSO from the filter, we conducted a DOS penetration test at 50 cfm and found the pressure drop had increased to 2.85 inches, and the aerosol penetration increased to 1.4%. The penetration measurements are shown in Figure 11. The significantly increased width of the penetration curve as well as the higher penetration values in Figure 11 compared to that in Figures 9 and 10 is characteristic of a filter leak. It is unlikely that a filter leak was caused by the high air flow since the total pressure drop across the HEPA was only 5 inches, and that pressure was divided between the prefilter and the HEPA filter.

We then tried to remove any residual DMSO remaining in the filter by passing heated air at 150 F through the filter. After four hours, the filter pressure drop decreased from 2.85 to 2.1 inches, and the filter penetration decreased from 1.4% to 1.1%. Three additional days of passing 50 cfm of 150 F heated air through the filter reduced the pressure drop to 1.68 inches and the penetration to 0.4%. The DOS penetration curve for the HEPA filter after the three day purge is shown in Figure 12.

Figure 12. Penetration of DOS aerosols through HEPA filter after three days of purging with 50 cfm of heated air

Figure 11. Penetration of DOS aerosols through HEPA filter exposed to 198 hours of DMSO aerosols followed by 32 hours of DMSO/dissolved plastic aerosols.

A summary of all the penetration measurements made in this evaluation is given in Table 5.

Table 5. Summary of penetration and pressure drop tests.

<u>Exposure</u> <u>(Hours)</u>	<u>Pressure Drop</u> <u>(Inches Water)</u>	<u>Penetration at 0.3 μm</u>
0	1.15	8×10^{-5}
6	1.25	8×10^{-5}
56	1.32	6×10^{-5}
81	1.25	9×10^{-5}
120	---	---
166	1.55	1.1×10^{-4}
198	2.85	1.4×10^{-2}
+	2.10	1.1×10^{-2}
++	1.68	4.0×10^{-3}
+++	1.30	3.0×10^{-4}
+ After purging with 50 cfm air at 150°F for 4 hours		
++ After purging with 50 cfm air at 150°F for 3 days		
+++ HEPA requirements		

We can attribute the changes in filter performance to the residual DMSO in the filter that was driven off by heated air. The filter pressure drop and the penetration decreased from 2.85 inches to 1.68 inches and from 1.4% to 0.4% respectively by passing heated air through the filter. The remaining effects are due to the atmospheric dust deposits and the permanent structural damage from the DMSO attack on the HEPA filter. Table 5 shows that the pressure drop increased by about 0.1 inch of water for each 40 hour week of operation except for the final week when liquid DMSO had saturated the filter. However, once the DMSO was driven off by heat, the increase in pressure drop for the final week was also about 0.1 inch. This pressure drop increase is most likely due to the atmospheric dust that has accumulated on the filter. The accumulation of atmospheric dust is seen as the darkened center of the filter pack in Figure 13. The front end of the wooden box was cut open to expose the filter.

Figure 13. Inlet side of the prefilter-HEPA filter with end cut open to expose the media. Note the dust accumulation in the center of the media pack.

Figure 14. Close-up of upper right corner of Figure 13 showing a crack in the urathane sealant between the wooden frame and the media pack. This crack is a leak path.

We cut the HEPA filter open to expose the inlet and exit filter faces to determine if we could see signs of physical degradation that could explain the increased filter penetration. Figure 14 shows that there is a small crack in the sealant between the wooden frame and the filter pack. This crack was found to be one of two leaks that produced the higher aerosol penetration

We also found that the DMSO exposure created cracks and warped the plywood frame of the HEPA. Figure 15 shows the exterior corner of the plywood frame with the paint blistering and the edges separating due to warpage. Figure 16 is a cut-away portion of the same corner and shows a direct leak path from the interior to the exterior of the HEPA box. Since the leak path is on the inlet side of the HEPA, it can not be the cause of the increased aerosol penetration because any particles leaking into the box would be filtered.

Figure 15. Photograph of a corner of the HEPA filter showing box warpage and joint separation.

Figure 16. Photograph of cut-away portion of the corner in Figure 15. Note the direct leak path at the corner.

We conducted a series of scan tests to verify that the cause of the filter failure was due to the crack in the sealant between the filter pack and the plywood frame shown in the upper right corner of Figure 14. The scan test consisted of scanning across the open filter face (inlet side with prefilter) with a 1/4 inch probe and measuring the DOS concentration with a light scattering photometer (Phonex Precision Instruments, model JM-7000). DOS aerosols were injected in the opposite filter face with a 5 cfm air stream. Measurements confirmed that aerosols were leaking through the visible crack in the upper right corner. A similar leak was also detected on the bottom right corner, although no visible crack was seen. The filter was then reversed and another scan made across the filter face (exit side with HEPA filter). The scan measurements showed leaks on the upper and lower left corners between the sealant and the plywood frame, and directly opposite from the leaks on the other side. There were no visible cracks. It appears that the leak path between the sealant and frame runs along the entire filter depth.

VI. Preliminary Field Test Results

We evaluated the HEPA filter that was used in trial tests for removing HE from mock warheads to see if there was any deterioration in performance. The filter was a dual-stage prefilter-HEPA filter unit manufactured by Donaldson and similar to the boxed unit in Figure 5, but with a 135 cfm capacity. The larger capacity HEPA filter was used to reduce the restriction in the exhaust flow compared to the standard 50 cfm filter used in our laboratory tests. The filter had been exposed to a total of 50 hours of DMSO/HE exposure: 5 hours of the venting phase when the exhaust valve was open and 45 hours of the dissolution phase in which hot DMSO is sprayed against the HE. We estimate the exhaust flow was about 5 cfm during this dissolution process. Unfortunately, the work station was not instrumented to provide a measure of the exhaust flow or the pressure drop across the HEPA filter.

The test apparatus for measuring the filter penetration and the pressure drop is shown in Figure 8. Prior to conducting the penetration tests, we monitored the downstream flow for potential HE release, but found none. The results of the penetration measurements at 135 cfm and 27 cfm are shown in Figures 17 and 18 respectively. The filter penetration values at $0.3\text{ }\mu\text{m}$ are .006% and .0004% at 135 cfm and 27 cfm respectively. The corresponding pressure drop measurements are 1.80 inches and 0.30 inches at 135 cfm and 27 cfm respectively. For comparison the filter certification tests on the new filter at the Rocky Flats Filter Test Station showed the penetration was less than .01% for both 135 cfm and 27 cfm. The only pressure drop recorded was 2.2 inches at 135 cfm. We suspect that restriction in the adapters used to connect to the boxed HEPA filter was responsible for the higher initial pressure drop.

The preliminary data suggests that there was no degradation in filter efficiency or pressure drop within the 50 hours of DMSO/HE exposure. If the HEPA degradation for the 135 cfm HEPA follows the same trend as seen for the 50 cfm HEPA filter, then no degradation would be seen until about 200 hours of DMSO exposure. The field evaluation was clearly too short to see any loss in HEPA performance.

Figure 17. Penetration of DOS aerosols through 135 cfm HEPA filter at 135 cfm after 50 hours exposure to DMSO/HE

Figure 18. Penetration of DOS aerosols through 135 cfm HEPA filter at 27 cfm after 50 hours exposure to DMSO/HE

V. Conclusions

Preliminary tests show that DMSO aerosols degrade the performance of HEPA filters over time by chemical attack to create leak paths and by saturating the filter media to increase both the pressure drop and the aerosol penetration. A 50 cfm HEPA filter was exposed to DMSO aerosols for 198 hours under conditions that simulate the HE dissolution operations in weapons dismantlement. The efficiency for 0.3 μm particles decreased from 99.992% to 98.6%, and the pressure drop increased from 1.15 inches to 2.85 inches during the exposure. We found that most of the DMSO aerosol that was captured by the HEPA filter had condensed in the filter as a pool of liquid. Since the efficiency of the HEPA filter drops below the minimum allowed efficiency of 99.97%, it has to be replaced with a new filter.

The larger portion of the decreased efficiency and increased pressure drop is due to the DMSO saturation of the HEPA filter media. Of the 1.39% decrease in efficiency, 1.00% is due to the saturation, while 0.39% is due to the leak paths. Of the 1.70 inches increase in pressure drop, 1.17 inches is due to the saturation, while 0.53 inches is due to the atmospheric dust that was not prefiltered in our experiments. We were able to isolate the effect of the DMSO saturation by driving off the liquid with heated air. The difference in efficiency and pressure drop before and after the DMSO is driven off can be attributed to the DMSO saturation. Loss in filter performance due to liquid saturation or partial saturation is not unique to DMSO, but applies to all liquids.

The smaller portion of the decreased efficiency in these preliminary tests is due to the leak paths generated by DMSO attack. The DMSO had produced two leak paths between the polyurethane sealant and the plywood frame. One of the leak paths was visible in the photograph in Figure 14 where the sealant was separated from the plywood frame. Although the penetration due to the leak path is about one third of the total penetration, the 0.39% penetration due to the leaks is still more than ten times the allowed 0.03% penetration. The filter would have to be replaced.

The DMSO exposure also produced visible cracks and warpage on the inlet portion of the plywood frame as shown in Figures 15 and 16. Although the cracks formed a leak path to the exterior of the filter, the leak was not measured as an increase in aerosol penetration because the filter was under vacuum, and the ambient aerosols would be filtered. We

believe that the accumulated DMSO liquid in the boxed HEPA filter is responsible for both the plywood warpage and the creation of leak paths due to separation of the sealant from the plywood frame.

The efficiency of the two exhaust HEPA filters in Figure 1 to remove potential radioactive or DMSO/HE aerosols depends on the exhaust flow rate, the particle size distributions of the aerosols, and any degradation resulting from DMSO exposure. Although most of the DMSO aerosols will be trapped in the first HEPA filter, a large fraction of DMSO vapor may pass through the first filter and condense on the second HEPA filter and cause degradation. Since the HE is not volatile, it will remain on the first filter except for the small fraction that passes through as an aerosol. Thus the combined efficiency for a degraded first filter (98.6%) and a standard second filter (99.97%) is 99.99996% for 0.3 μ m particles. If both filters are degraded (98.6%) by DMSO attack, then the combined efficiency will be 99.98%. If the first filter is replaced prior to its degradation, each of the filters will have 99.97% efficiency, and the combined efficiency will be 99.999991%. The collection efficiency for DMSO/HE aerosols will be much higher because the particle size is much greater. However, if liquid DMSO/HE is allowed to accumulate in the filter, it can flow unobstructed through the filter, thereby leaving only the second HEPA filter for stopping the DMSO/HE aerosols. In this case the overall efficiency for the two filters is 99.97% for 0.3 μ m particles.

VI Recommendations

We recommend that the first stage HEPA filter from the DMSO dissolution workstation be replaced after 160 hours of exposure. If the pressure drop across the HEPA filter increases by more than 50% of its initial value, then the filter should also be replaced even if the exposure is less than 160 hours. This will assure that the HEPA filter will not be degraded if different operating conditions cause accelerated filter saturation. The first stage HEPA filter should also be mounted in a vertical configuration to promote liquid drainage into the workstation. The second stage HEPA filter also should be monitored (pressure drop increase) for DMSO accumulation due to condensation from the vapor. If the pressure drop increases by 50% of its initial value, the second stage HEPA should be replaced.

We also recommend that the filters removed from the dissolution workstations be evaluated for filter efficiency and examined for any

structural damage. This will provide a data base for defining the HEPA degradation under actual field conditions.

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