Final Report

APR Cartridge Performance Evaluation for Firefighting (254-2007-M-19684)

Prepared For:

National Institute of Occupational Safety and Health
National Personal Protective Technology Laboratory

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Abstract

This work evaluated the performance of four 40-mm threaded respirator canisters. These canisters were tested in laboratory experiments simulating environments similar to those encountered during structural overhaul firefighting operations.

The same smoke generation and delivery system used in previous work (254-20C5-M-12750) was used in this study. This time, only 40-mm threaded canisters were tested, as these canisters are purported to be most easily interchangeable with SCBA facepieces currently used by North American firefighters. Three CBRN canisters, from MSA, 3M, and Scott, were tested along with a multi-gas canister similar in appearance to the above but without CBRN certification (3M FR-64040). These tests were not intended to define contaminant breakthrough time. Rather, the testing protocol was designed to evaluate the effectiveness of these canisters over the 30-minute period reported by firefighters as a typical period in which overhaul activities would be performed.

This report includes data and analysis of contaminant concentrations for 12 tests, in which a large matrix of contaminants were simultaneously examined in both the challenge smoke ("chamber air") and in air filtered by the respirator canister ("filtered air"). Originally, we proposed conducting 6 tests, completed in August; in November, we performed additional testing where hydrogen chloride was added to the analytical matrix while removing naphthalene, benzene and total hydrocarbon. All tests included examining CO; NO_2; SO_2; respirable dust; aldehydes including formaldehyde, acrolein and glutyraldehyde; and cyanide. The challenged and filtered-air concentrations for contaminants considered to be respiratory irritants were aggregated into an irritant index to determine how efficient the air purifying respirator (APR) canisters would protect a firefighter against the multiple contaminants in smoke. This index was computed using 15- and 30-minute occupational exposure limits. When the index exceeded unity, a firefighter would be at risk of respiratory irritation if the smoke was inhaled.

In all cases, the challenge concentration irritant index exceeded unity, ranging from 2.9 to 26. For all 12 test cases, the APR canister reduced the overall irritant index to levels below unity, indicating that these canisters would provide protection for firefighters working in overhaul environments. Note: in some tests, levels of carbon monoxide were higher than recommended for persons wearing APRs; these canisters do not protect against carbon monoxide. Firefighters must rely on direct reading warning to indicate high CO levels, indicating the need to leave the area if wearing an APR, as these air purifying respirator canisters would be inappropriate.

These APR canisters performed better than previous multi-gas cartridges in our initial studies. Additional work needed to interpret the importance of the free radical penetration; but a much larger firefighter study focused on field measurements would be better suited for this additional investigation.

Table of Contents

List of Tables

List of Figures

Final Report: NPPTL Contract Update
APR Cartridge Performance Evaluation for Firefighting (254-2007-M-19684)
January 31, 2008
PI: T. Renée Anthony, University of Arizona

Purpose of Contract

This work was to evaluate chemical, biological, radiological, and nuclear (CBRN) respirator canister to determine their performance in structural overhaul firefighting operations. The data generated in this contract will be used to support the establishment of performance criteria to be used to develop respirator standards.

Background

Representatives from the University of Arizona, Phoenix Fire Department, National Fire Protection Association (NFPA) and NPPTL have been involved in discussions regarding use of Air Purifying Respirators (APRs) for use in fire operations. APRs would provide an additional respiratory protection option for structural firefighters involved in overhaul operations and wildland firefighters. There is an urgent need to establish performance criteria and a validated testing method to evaluate "smoke cartridges" that would provide protection against low to moderate concentrations of products of combustion. Data from the chamber testing method development indicated that breakthrough of aldehydes, PAHs, and other contaminants occurs with existing multigas cartridges when smoke contaminant concentrations are less than levels identified in the literature. There is an urgent need to establish performance criteria and a standard for respiratory protective equipment to enhance firefighter health and safety when the use of a self-contained breathing apparatus (SCBA) is not practical.

Methods

The same apparatus that was used under contract number 254-20C5-M-12750 were used in this study (Anthony *et al.*, 2007, Appendix E). The test system included a combustion grill for smoke generation, ductwork and fan to transport the smoke to and exhaust smoke from the test chamber (6650 Lpm), a smoke chamber (2.44 x 0.91 x 1.22 m), and a manifold to draw air through a respirator cartridge (65.3 Lpm plus sample pump flows) and allow sampling of this filtered air.

Sample Matrix

Contaminants were monitored using direct reading and integrated sampling methods. Respirable particulate concentrations were measured with two personal DataRAMs (*p*DR, Thermo Electron, Waltham, MA). For the November tests, 4 pDRs were used: three inside the chamber along with the one outside the chamber. This allowed for the examination of the chamber quality, to determine whether there was any positioning bias attributable to the placement of the particle sampler. Two multi-gas monitors (V-RAE, Rae Systems, Inc.) were used to measure carbon monoxide, oxygen, LEL, nitrogen dioxide, and sulfur dioxide in the chamber and filtered air, simultaneously. The direct-reading monitors were calibrated and zeroed prior to each burn test. Integrative sampling techniques were used to measure 30-minute averages for aldehdyes (EPA T011 and NIOSH 2532, 0.9 Lpm, 7 compounds), benzene and total hydrocarbons as hexane (OSHA 7, 0.2 Lpm), naphthalene (NIOSH 5506, 2.0 Lpm), and hydrogen cyanide (NIOSH 6010, 0.2 Lpm).

After we identified relatively low contaminant concentrations in the chamber for the August tests, we conducted another evaluation of these cartridges in November. This allowed us to include the Scott CBRN canisters in this test matrix, as they did not arrive before the August testing. For this second set of tests, hydrogen chloride (NIOSH 7903, 0.5 Lpm) was added to the sampling matrix to allow an investigation of an additional possible irritant gas component. Integrated samples were analyzed by ESIS/EHL in Cromwell, CT, IHLAP accredited (#100127). Table 1 indicates the sampling matrix for all test dates in this study.

Table 1: Sampling matrix. On each sample date, three tests were performed. Concentrations were measured simultaneously in the chamber and in air filtered by the respirator cartridge

Analyte	August 11-12	November 11-12	Method Reference	Sample Rate, Lpm
CO, NO_2, SO_2	X	X	Direct read (V-Rae)	0.4
Respirable dust	X	X	Direct Read (pDR)	Chamber used internal pump; filtered at 2.6 with BGI cyclone
Dust – CFC	X		NIOSH 0500	2.5
Free Radicals	X	X	Literature: NIOSH	2.5
Aldehyde scan	X	X	EPA T011	0.9
Glutyraldehyde	X	X	NIOSH 2532	0.9
Naphthalene	X		NIOSH 5506	2.0
Benzene	X		OSHA 7	0.2
Total HC	X		OSHA 7	0.2
Cyanide	X	X	NIOSH 6010	0.2
Hydrogen Chloride		X	NIOSH 7903	0.5

APR Canisters Studied

Four respirator canisters were evaluated during this study. All models had 40 mm threads on the canisters and, hence, would fit currently existing respirator cartridge adapters for firefighters. However, not all 4 were approved CBRN cartridges. Table 2 identifies the respirator models used in this work. (Additional literature on these canisters are provided for reference in Appendix D.)

Table 2: Respirator canisters tested

Manuf.	Model	Designation	Approval #	Expiration	Aug IDs	Nov IDs
MSA	CBRN Cap1 (PN 10046570)	CBRN	TC-14G-0270	2012/03	811_1 812_2	1111-4
3M	FR-15 Cap1 (PN 70-0710-9297-0)	CBRN	TC-14G-0271	2009/04	811_2 812_3	-
3M	FR-64040 (PN 70-0710-4013-6)	Not CBRN	--	2012/04	811_3 812_1	1110_2 1110_3* 1111_6
Scott	M120 / Cap1 (PN 045135)	CBRN	TC-14G-0283	2014/06	-	1110_1 1111_5

* 1110_3 used the same CBRN canister used in the previous 1110_2 run, for a total filtration time of 60 minutes at the end of the second test.

Combustion materials

The wood combusted in the study was once again furring strips (pine). These strips were purchased in July 2007 and cut to 8 inch lengths. The wood combusted in August was much greener than the wood in November. The weights of the woods dropped significantly as wood was allowed to dry out in the low-humidity environment over three months. The "sofa foam" used in these tests was from the same stock as the 2006 tests. The carpet used in the 2006 studies were used up in the August tests and a new olefin berber carpet was used in the November 2007 tests.

The November tests were conducted to determine whether additional household materials could be used to generate higher cyanide and aldehyde concentrations. As such, laminate quarter-round trim and sheets of plastic cut from shower curtains were added to the combustion cycle. The laminate trim burned much hotter than the furring strips, but no additional smoldering effects were detectable during the set-up and test runs. The plastic sheets essentially melted in the combustion chamber.

The S.O.P. detailing the burn procedures are provided in Appendix A of this report.

Table 3: Combustion Data

	Mass of Item Combusted (g)					
Sample ID	**Wood**	**Foam**	**Carpet**	**Trim**	**Plastic**	**Flooring**
811_1	225.5	8.8	23.0	-	-	-
811_2	225.5	8.8	23.8	-	-	-
811_3	225.6	8.8	23.3	-	-	-
812_1	224.1	8.8	23.3	-	-	-
812_2	225.5	8.8	21.5	-	-	-
812_3	225.5	8.8	24.5	-	-	-
1110_1	217.8	8.7	24.0	-	-	-
1110_2	229.4	8.7	24.8	7.7	2.1	-
1110_3	224.0	8.7	25.4	7.7	2.1	65.3
1111_4	223.6	8.7	23.3	7.7	2.0	62.2
1111_5	226.0	8.7	24.8	7.6	2.1	61.3
1111_6	216.8	8.7	22.4	7.6	1.9	59.2
Mean	224.0	8.75	23.7	7.66	2.04	62.0
StDev	3.64	0.05	1.11	0.05	0.09	2.53

Analysis
For integrated samples collected over each 30-minute test period, a single time-weighted average data point was provided from the contaminant mass reported by the lab and the total volume of sampled air passed through the sample. These computed concentrations are provided in full in Appendix B.

Data from direct reading instrumentation were downloaded and data from the test-period were extracted. The time-series data are provided in Appendix C, and the mean concentration was used to evaluate penetration and exposure indices.

Aggregate challenge and filtered concentrations were evaluated to determine a hazard index as an aggregate exposure metric. The use of a hazard index requires that only contaminants with similar health end points be aggregated. For wildland firefighting studies, Reinhardt and Ottmar (2004) determined an Irritant Exposure Index, generated for full-shift exposures to formaldehyde, acrolein and respirable dust:

$$\text{Irritant Hazard Index} = \sum_i \frac{concentration_i}{OEL_i} \qquad (1)$$

where
i indicates the i^{th} compound in the challenge concentration, and
OEL indicates the occupational exposure limit.

Owing to the short-term (30-minute) exposures of these tasks, the OEL in the denominator should reflect short-term exposure limits (STELs) or Ceiling limits. Where STELs and Ceiling limits were available, they were used in these calculations. When contaminants had no STEL, the ACGIH excursion limit of 3 times the full-shift TLV was used to assign a short-term OEL (ACGIH, 2006). Table 4 indicates the OELs used in these calculations. In previous tests, the index included the following compounds: formaldehyde, acetaldehyde, acrolein, naphthalene, total hydrocarbon (as hexane), and respirable dust, all respiratory irritants.

Table 4: Exposure limits used in hazard index calculations

Contaminant	Exposure Limit		Exposure Limit Source
Formaldehyde	0.3	ppm	ACGIH ceiling
Acetaldehyde	25	ppm	ACGIH ceiling
Acrolein	0.1	ppm	ACGIH ceiling
Glutyraldehyde	0.05	ppm	ACGIH Ceiling
Respirable Dust	9	mg/m^3	3 mg/m3 ACGIH TLV, converted to a 30-minute STEL
SO_2	5	ppm	ACGIH STEL
NO_2	5	ppm	ACGIH STEL

In this set of tests, additional compounds were tested. Naphthalene and total hydrocarbons were assessed in the first 6 tests, and hydrogen cyanide and hydrogen chloride were assessed in the last 6 tests. However, they were present in the chamber at concentrations near or below the detection limit and at levels which contributed 0.05 or less to the overall irritant index (see Table 5). These compounds are excluded from the irritant index computations.

Table 5: Additional compounds analyzed and peak contribution to hazard index

Compound (tests analyzing)	Highest Chamber value (mg/m^3)	30-min exposure limit (mg/m^3)	Maximum Hazard Index Contribution
Naphthalene (first 6)	0.19	75	0.0025
Total Hydrocarbon (first 6)	9.5	186	0.0511
Hydrogen Cyanide (all 12)	0.044	5	0.0088
Hydrogen Chloride (last 6)	0.33	7	0.0471

Results

Raw data are provided in Appendix B of this report. The chamber concentrations exceeded the exposure limits in Table 4 for respirable dust and formaldehyde for each of the 12 tests conducted. As occurred in previous studies, the acrolein chamber concentrations exceeded short-term exposure limits in only some (9 of 12) tests, while acetaldehyde levels did not exceed the 25 ppm short-term limit. In this study, glutyraldehyde was added to the analyte panel, and 7 of the 12 tests were identified with chamber concentrations exceeding the 0.05 ppm ACGIH ceiling. While only 25% of the field exposure tests have reported glutyraldehyde in concentrations exceeding levels of detection (Bolstad-Johnson *et al.*, 2000), the range of values identified in our respirator challenge gas was similar to the range reported in the literature, where our maximum concentration was 0.18 ppm and field data maximum has been reported at 0.15 ppm.

Figure 1 presents the relative chamber concentrations of the irritant components of the smoke quantified in these 12 tests. Data are presented in order of the test run, from left to right, with the APR canister indicated below the test id reference. As indicated by the figure, the irritant index of the respirator challenge air, within the chamber and immediately upstream of the respirator cartridge, exceeded unity for each test, indicating respiratory protection would have been needed if firefighters were working in overhaul conditions of similar smoke levels. However, only four tests had challenge concentrations exceeding 10 times the exposure limit for the aggregate of chemicals; two tests had concentrations less than 5 times this limit.

Figure 1: Chamber concentration of irritant components of smoke, by test and contaminant. Data reported in concentration normalized by short-term exposure limits, defined as the hazard index.

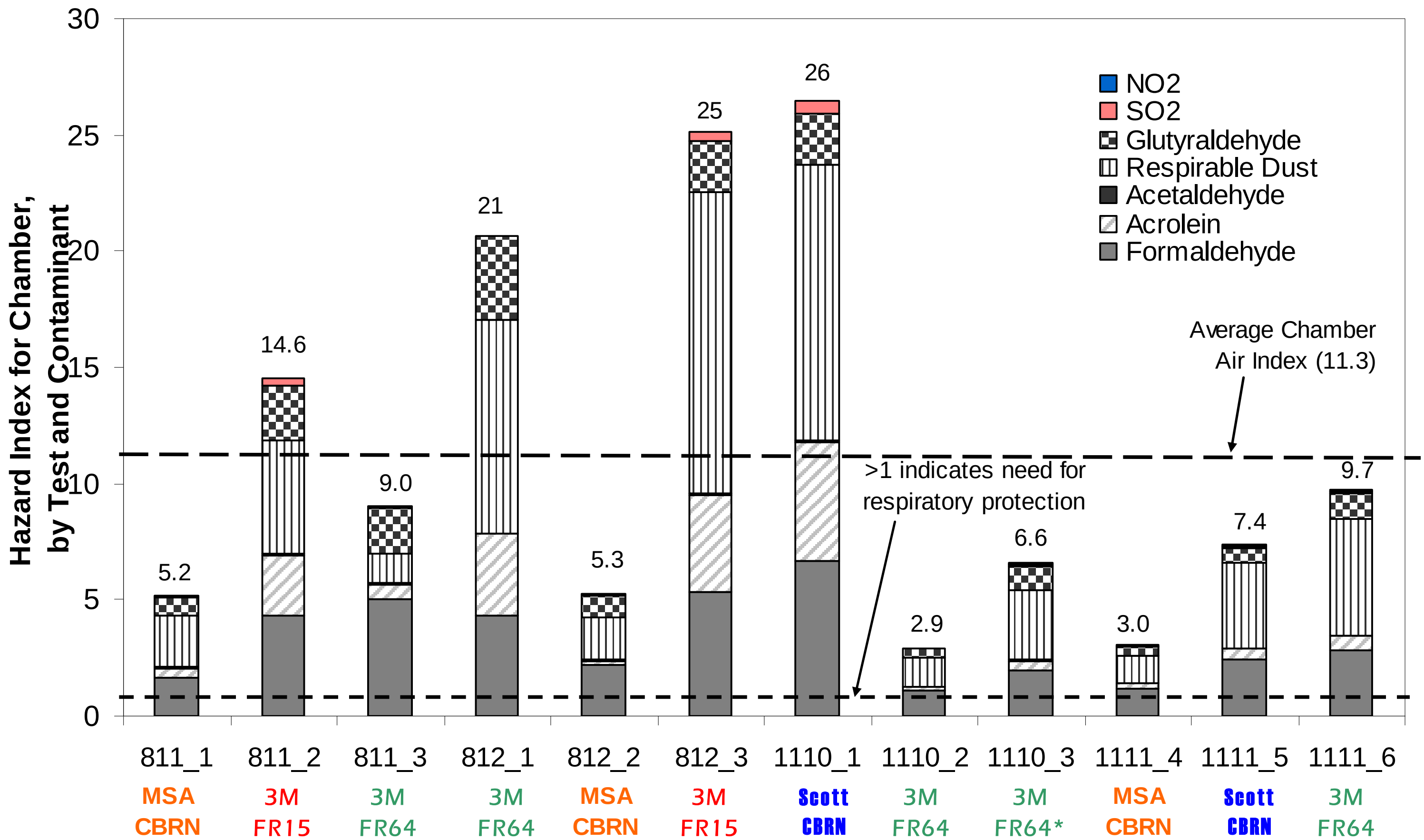
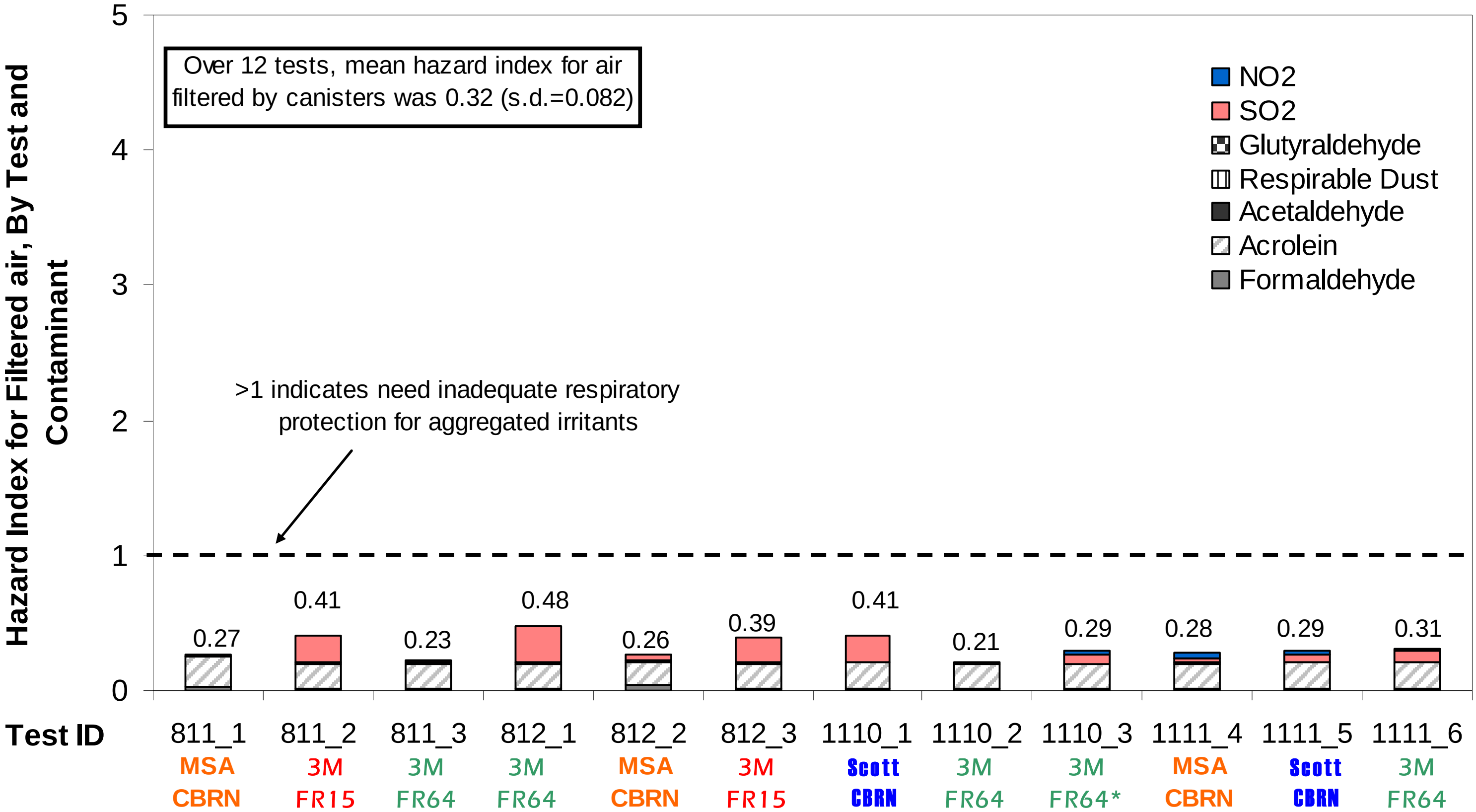


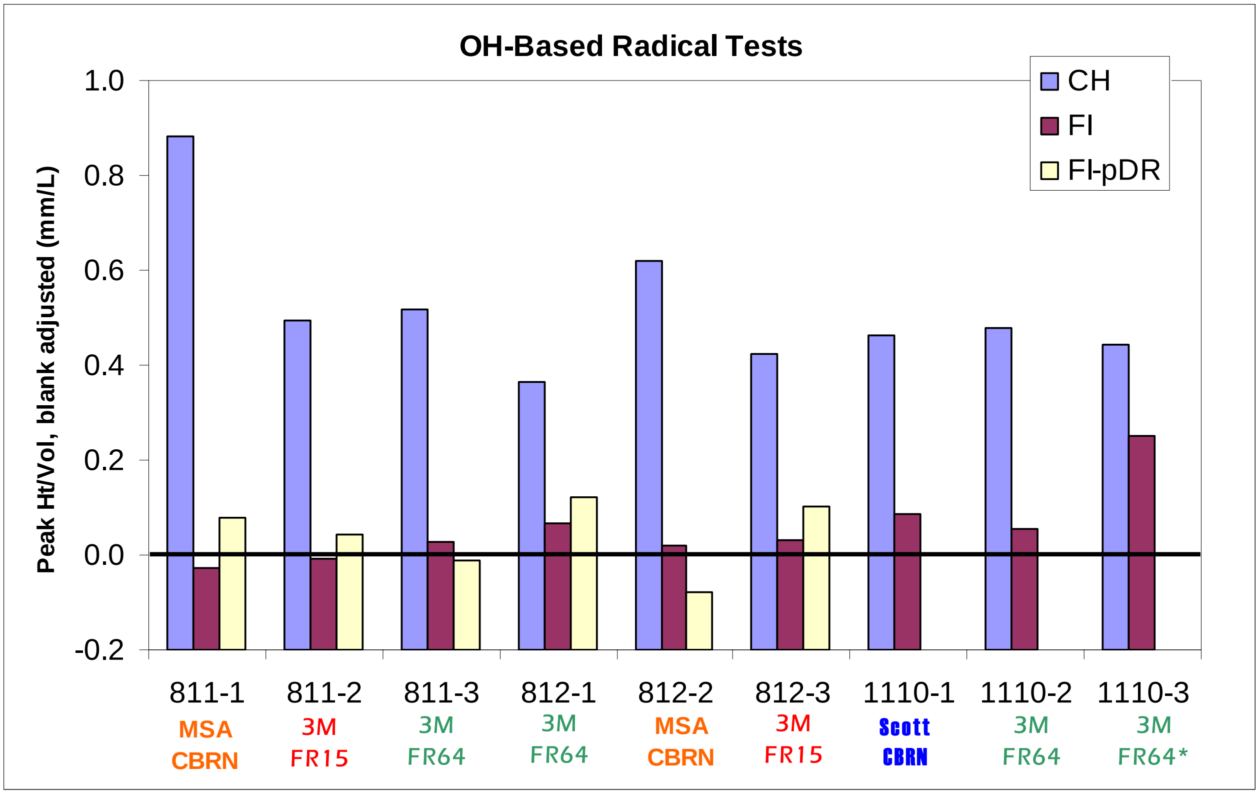
Figure 2 presents the relative concentration of the irritant components in air filtered by the APR canister, again for each of the 12 tests. In no test did the concentration of smoke exceed the aggregated exposure limit for the irritating compounds tested. The mean irritant index, over all tests, was 0.32 (s.d.=0.082). The maximum irritant index of the filtered air was 0.48, indicating that someone breathing overhaul smoke filtered by these respirator canisters would be protected to concentrations below 48% of levels that may cause short-term irritation that would put the firefighter at risk.

Figure 2: Concentration of irritant components of smoke, by test and contaminant, after filtration by the APR canister. Data reported in concentration normalized by short-term exposure limits, defined as the hazard index.



Free-radical samples were submitted to NIOSH Morgantown for analyses. Figure 3 summarizes hydroxyl-radicals in the chamber (CH) and filtered air using two sampling methods, NIOSH 0500 (FI) and using the cyclone and pump attachment on the direct-reading pDR (FI-pDR). These data are reported as the peak height reported for each sample, adjusted by the sample's associated blank and normalized by the sample volume required to obtain the sample. Negative values indicate the amount of OH-radicals exceeded the amount of OH-radical on the associated blank. Once again, no carbon-based radicals were identified in air filtered by the APR canisters (FI and FI-pDR columns), confirming no particulate penetration. However, hydroxyl-based radicals were identified as penetrating the APR canister. In some cases, the values were in the range of the blank (mean= 26.9 mm height in ESR spectra, CV=11%). Additional raw data are provided in Appendix B.

Figure 3: Hydroxyl radical test results comparing chamber (CH) concentrations with air filtered by APR canister



In comparing the chamber hydroxyl-radical data in Figure 3 to all measured components integrated into Figure 1, we can see that the greatest OH-radicals were identified in tests 811-1 and 812-2, with all other days having nearly similar hydroxyl-radical capabilities. What is interesting is to compare Figure 3 with Figure 1: we note that the highest OH-radical tests are not associated with the highest overall challenge concentration tests (812-3 and Nov-1). Further, no single component of the overhaul smoke had similar patterns to that of the OH-radical. Additional research is needed to explain a relationship between the concentration and composition of the smoke and an increased indication of short-lived hydroxyl-radicals. Even more research would be needed to determine whether the presence of these short-lived hydroxyl radicals in air filtered by the respirator canister is significantly associated with acute or chronic toxicity in firefighters to determine the significance of these measures.

Discussion

Over all tests, neither any single nor any aggregate of the irritant hazards penetrated these canisters at levels that would pose a short-term exposure risk to firefighters. Even for the four tests with the highest challenge hazard indices, the hazard index for the air filtered by these APR canisters was below 50%. Previous tests that examined multi-gas cartridges indicated that formaldehyde penetrated the APR cartridge. However, the evidence from these tests indicate that the three CBRN canisters and the 3M FR64 canister performed well in smoke simulating overhaul exposures. The MSA CBRN canister had the lowest challenge concentrations over all tests, with the maximum hazard index of only 5.3 in three tests. A higher challenge concentration would lead us to more confidence that this canister would be efficient if firefighters were exposed to extreme smoke exposures during overhaul. Due to the random selection of canister order and the unfortunate variability in contaminant generation in this study chamber, this was unavoidable.

The test indicated as "1110_3" used a 3M FR64 canister (no CBRN approval) was interesting in that we inadvertently used the same canister that was used in the previous test. As such, this canister was used for a total of 60-minutes of simulated overhaul exposure. The canister appeared to maintain its effectiveness over two tests, as the hazard index for the second run was 0.28, below the value of 1.0 which indicates ineffective protection. This provides an indication that these CBRN canisters may be used for more than one 30-minute overhaul event, although this was not specifically addressed in the study design. Additional testing focusing on breakthrough time would be required to adequately assess the lifetime of these canisters for use in the field for firefighters for any duration greater than 30-minutes.

The initial contract had allowed for conducting 6 experiments on 3 CBRN canisters. However, because students working on this project could not receive additional salary due to employment constraints, we were able to use these proposed salary funds to add additional tests to the study matrix and include an additional respirator canister, which was not available from the distributor until November of this year.

This also allowed us to examine additional compounds of current concern to firefighters, namely hydrogen chloride, by eliminating the hydrocarbon and naphthalene tests which yielded little to the overall hazard evaluation. For these last 6 tests, we added additional plasticized materials during the combustion process, including plastic shower curtains and laminated wood. Unfortunately, the burn materials did not contribute significant cyanide or hydrogen chloride to the challenge concentration: we cannot assess whether these canisters are effective for these compounds when present in firefighting overhaul smoke. Additional tests would need to be conducted using cyanide-generating materials, such as wool upholstery or carpet products, to test this hypothesis.

Conclusion

The canisters used in this test appear to provide adequate protection for the irritant components of smoke during overhaul activities associated with firefighting. Caution is recommended to ensure that firefighters using APR canisters monitor carbon monoxide levels and leave areas when CO levels increase, as APRs do not provide protection from high carbon monoxide. Challenge concentrations of hydrogen cyanide were not sufficiently high to determine the effectiveness for this contaminant of concern to firefighters. The smoldering of household materials of wood (pine), sofa foam, nylon / olefin carpet, laminated woods, and plastic did not generate adequate cyanide concentrations for this study. Wool-based household materials known to generate cyanide gases could be evaluated in further tests.

References

American Conference of Governmental Industrial Hygienists (ACGIH): *2006 TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices.* Cincinnati, OH, ACGIH, 2006.

Anthony TR, Joggerst P, James L, Stephen L, Shogren E, Burgess J. (2007) Method Development study for APR cartridge evaluation in fire overhaul exposures. *Ann. occup. Hyg.* 51(8):703-716

Bolstad-Johnson, DM, JL Burgess, CD Crutchfield, S Storment, R Gerkin, and JR Wilson (2000) Characterization of firefighter exposures during fire overhaul. *Am. Ind. Hyg. Assoc. J.* 61:636-641.

Reinhardt, TE and RD Ottmar (2004) Baseline measurements of smoke exposure among wildland firefighters. *Journal of Occupational and Environmental Hygiene* 1:593-606

Appendix A: Standard Operating Procedures

Standard Operating Procedure	
University of Arizona	Prepared by: Jennifer Currie
Reference: APR-001	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Preparation of Combustion Products	Total number of pages: 1

Materials Needed:

For use in APR-002, use items 1 through 5 only. For use in APR-003, use items 1 through 8.

1. Piece of aluminum foil – one piece for each burn, approximately 12" X 12"
2. Paper – plain white 8 ½ X 11 inch office paper, unprinted (5 to 10 sheets per test)
3. Wood – furring strips of pine (3 pieces per test); 8-inch strips; target average weight of 3 wood pieces: 224.0 grams
4. Foam – sofa cushion foam (1 piece per burn test); target weight of 8.8 grams
5. Carpet – nylon berber carpet or 26-ounce berber olefin/nylon blend carpet (1 piece per test); target weight of 23.7 grams
6. Trim – polymer styrene with laminate face trim (1 piece per test); target weight of 7.7 grams
7. Plastic – PVC shower curtain liner (1 piece per test); target weight of 2.0 grams
8. Flooring – laminated medium density fiberboard flooring (1 piece per test); target weight of 62.0 grams

Sequence:

1. Cut wood, carpet, trim, plastic and flooring into equal sizes and weigh.
2. Record weight on the individual pieces with a permanent marker
3. Cut uniform pieces of foam from large block and weigh
4. Remove small pinches of foam until all pieces are approximately the same weight; record weight on the individual pieces with a permanent marker
5. If more than 5 days pass between weighing wood and performing burn test, re-weigh wood to accommodate for drying and re-record weight

Standard Operating Procedure	
University of Arizona	Prepared by: Jennifer Currie
Reference: APR-002	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Burn Sequence – paper, wood, foam, carpet	Total number of pages: 1

Materials Needed:

1. Obtain materials listed in SOP reference APR-001
2. Combustion chamber with removable connection to smoke chamber duct system
3. Igniter (lighter with extended tip)
4. Easy-squeeze wash bottle filled with tap water
5. A/B/C fire extinguisher
6. PPE: nitrile gloves and respirator (N95)
7. Stopwatch
8. Note pad and pen

Note: Combustion chamber must be located outside of any building structure.

Burn Sequence (Time-Sensitive):

1. Place piece of foil in the bottom of the burn chamber
2. Crumple 5 individual sheets of paper into balls
3. Place paper balls into a pyramid shape (4 for the base and one on top of the base) in the center of the piece of aluminum foil
4. Stack 3 pieces of wood into teepee shape over the top of paper balls
5. Light paper with gas lighter; start stopwatch
6. Allow paper and wood to burn for 6 minutes
7. Rip a small piece of foam from the larger block and add to the fire
8. Wait for 1 to 1.5 minutes
9. Add the carpet piece and the larger piece of foam to fire
10. Wait for fire to die down, approximately 2-3 minutes
11. Extinguish fire, close burn chamber lid leaving a 1-inch gap in opening
12. Immediately connect combustion chamber to smoke chamber, turn on fan, and restart start stopwatch simultaneously
13. Observe smoldering remnants of combustion: extinguish any flare-ups with water
14. After 10 minutes has elapsed from time of duct work attachment, decrease the gap in the burn chamber opening to 0.5 inches
15. After 30 minutes has elapsed from time of duct work attachment, remove duct work, turn off smoke chamber fan, and fully extinguish any smoldering remnants of combustion with water
16. When combustion products are doused, using nitrile gloves, remove foil and ash from combustion chamber and place in metal trash can.

Standard Operating Procedure	
University of Arizona	Prepared by: Jennifer Currie
Reference: APR-003	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: : Burn Sequence – multiple household items	Total number of pages: 1

Materials Needed:

1. Obtain materials listed in SOP reference APR-001
2. Combustion chamber with removable connection to smoke chamber duct system
3. Igniter (lighter with extended tip)
4. Easy-squeeze wash bottle filled with tap water
5. A/B/C fire extinguisher
6. PPE: nitrile gloves and respirator (N95)
7. Stopwatch
8. Note pad and pen

Note: Combustion chamber must be located outside of any building structure.

Burn Sequence (Time-Sensitive):

1. Place piece of foil in the bottom of the burn chamber
2. Crumple up 5 individual sheets of paper into balls
3. Place balls of paper into a pyramid shape (4 for the base and one on top of the base) in the center of the piece of aluminum foil
4. Stack 3 pieces of wood into teepee shape over the top of paper balls
5. Light paper with gas lighter; begin stopwatch
6. Allow paper and wood to burn for 4 minutes
7. Add piece of trim to fire
8. Wait for 1 minute
9. Add piece of carpet and piece of flooring to fire
10. Wait for 2 minutes
11. Add piece of foam to fire
12. Wait for 2 minutes
13. Add piece of plastic to fire
14. Wait for 1 minute
15. Extinguish fire, close burn chamber lid leaving a 1-inch gap in opening
16. Immediately connect combustion chamber to smoke chamber, turn on fan, and restart stopwatch simultaneously
17. Observe smoldering remnants of combustion: extinguish any flare-ups with water
18. After 10 minutes has elapsed from time of duct work attachment, decrease the gap in the burn chamber opening to 0.5 inches
19. After 30 minutes has elapsed from time of duct work attachment, remove duct work, turn off fan, and fully extinguish any smoldering remnants of combustion with water
20. When combustion products are doused, using nitrile gloves, remove foil and ash from combustion chamber and place in metal trash can, outside.

Standard Operating Procedure	
University of Arizona	Prepared by: Delayne Caseman
Reference: APR-004	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Sampling Pump Selection	Total number of pages: 1

Materials Needed:

1. Number of air-sampling pumps, high- and low-flow mode
2. Primary standard (Bios DryCal)
3. Tubing and sampling media (see APR-008)
4. Low flow adjusters for SKC adjustable pumps
5. Lab book, pen, calculator
6. Stickers / colored tape to mark pumps with analyte information and pump location.
7. Sample media for calibration

Sequence:

1. Fully-charge sampling pumps, per manufacturer's directions. Recommend 18-hour charge at minimum.
2. Using laboratory and NIOSH NMAM requirements, determine flow rate and sample volume ranges and determine optimum flow rate for 30-minute sample to minimize the detection limit. You will need two pumps for each contaminant of interest.
3. Connect tubing that will be used in the experiment to the sample pump.
4. If low-flow adjusters are needed, place in line.
5. Place appropriate media on the tubing.
6. Connect to primary flow standard and adjust pump / flow-adjusters to obtain working flow rate. Record initial flow rate.
7. Run pump for 30 minutes
8. Test flow rate again and record.
9. If flow faulted or battery failed, recharge the pump and test again (step 1).
10. If flow changed by more than 5%, recharge the pump and test again (step 1).
11. If either of these conditions are not remediated, remove the pump from service
12. Place color-coded sticker / electrical tape to indicate the pump position (chamber vs filtered) and write the analyte on the label.
13. Keep pump on charging station until used in experiments.

Standard Operating Procedure	
University of Arizona	Prepared by: Delayne Caseman
Reference: APR-005	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Sampling Pump Calibration	Total number of pages: 1

Materials Needed:

1. Pre-selected pumps, per SOP reference APR-004
2. Primary standard (Bios DryCal)
3. Tubing and sampling media
4. Low flow adjusters for SKC adjustable pumps
5. Lab book, pen, calculator
6. Stickers / colored tape to mark pumps with analyte information and pump location.

Sequence:

1. Select paired pumps from APR-004 that have the same analyte(s).
2. Attach tubing and calibration sample media to pumps (APR-008).
3. Turn pumps on and allow to run for 5 minutes at a minimum.
4. Connect to primary standard (Bios DryCal).
5. Obtain initial flow reading in the range of desired flow, per sampling method (APR-008)
6. If necessary, adjust flow until the desired rate is obtained. Once flow rate is set, do not adjust flow rate again.
7. Obtain three sets of 10-readings from Bios DryCal and record in lab book, along with pump ID number, sticker with sampler location and analyte name, and proposed sample id reference.
8. Place a label on the sampling tubing to indicate the analyte(s) type to make connecting sampling media easier during experiment setup.
9. Disconnect the sampling train and prepare to transfer the pumps and tubing to the smoke chamber room.

Standard Operating Procedure	
University of Arizona	Prepared by: Delayne Caseman
Reference: APR-006	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Positioning Pumps in Smoke Chamber	Total number of pages: 1

Materials Needed:

1. Number of pre-calibrated air-sampling pumps, see SOP reference APR-005
2. New APR cartridge / canister to test
3. Lab book, pen
4. Camera
5. Lapel clips
6. Sample media for experiments
7. Tube breaker, duct tape
8. Smoke chamber, mesh sampling screen

Sequence:

1. Ensure air in the chamber has been purged for at least 30 minutes.
2. Enter the chamber and replace the previous APR cartridge / canister. Check seals. Exit the chamber.
3. Using pre-calibrated and labeled pumps from APR-005, position pumps on top of chamber so the "chamber" pumps are grouped together and the "filtered air" pumps are grouped together near the sampling manifold.
4. For "chamber" samples, thread tubing into the chamber through one of the two ports in the chamber top. Ensure tubing labels match pump labels.
5. Prepare sampling media (e.g.. sorbent tubes, cassettes), per Lab and NIOSH NMAM sampling recommendations and APR-008.
6. Enter the chamber and connect the sample media to the proper tubing.
7. Place appropriate media on the tubing, paying attention to required airflow direction.
8. Clip the media tubing so the inlet to the sampling media is centrally located directly upstream from the APR canister / cartridge to be tested.
9. Double check the direction of flow through the sample media; reorient tube / cassette if needed
10. Once all chamber pumps are connected, take photos to document positions, exit the chamber, seal the entrance.
11. Connect sampling media to the manifold for "filtered" samples and connect to the "filtered air" pumps.
12. Double check the direction of flow and connection to the proper pump.
13. Ensure all timers on pumps are set to zero: turn pump on, place on hold.
14. Check battery indication light
15. Block off any unused manifold ports on the sampling manifold for "filtered air".
16. Pull air through the APR cartridge/canister and manifold with high-volume pumps for 30 seconds to ensure the manifold is purged.
17. You are now prepared to start the combustion sequence (see SOP references APR-001 through -003)

Standard Operating Procedure	
University of Arizona	Prepared by: Delayne Caseman
Reference: APR-007	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: 30-minute testing in chamber and in filtered air	Total number of pages: 2

Materials Needed:

1. Number of pre-calibrated air-sampling pumps, see SOP reference APR-005 and -006
2. Combustion chamber, ready for testing, see SOP reference APR-001 through -003
3. Temperature and humidity sensor
4. Lab book, pen
5. Camera
6. Test chamber
7. Pre-printed sample labels
8. Two persons to operate test chamber, one person to operate combustion chamber

Sequence:

1. Prepare test chamber and pumps as indicated in SOP APR-005 through -006
2. Prepare combustion chamber as indicated in SOP APR-001 through -003.
3. When at Step 12 in APR-002 or 16 in APR-003, simultaneously:
    a. Turn the fan to the smoke chamber onto the “High” position
    b. Turn the high-volume pumps pulling air through APR on
    c. Hit the “hold” button on the SKC pumps to activate the sampling pumps
    d. Start the stopwatch
4. Check to make sure everything is operating
5. Check operation of direct reading instrumentation that may be used during these tests
6. At least every 60 seconds, record output of direct reading equipment, including temperature and humidity.
7. Watch for pump failures and record, if any.
8. During the 30-minute period, match
    a. the stopwatch time to the wall / cell phone time to match direct reading time with experiment time
    b. the stopwatch time to the sample pump roll-over time to record any discrepancies (especially important if you have any pump failures)
9. At the end of 30-minutes, simultaneously:
    a. Stop flow through manifold
    b. Stop flow through chamber
    c. Place all sample pumps on hold
    d. Disconnect the duct from the combustion chamber (see step 15 on APR-002 and 19 in APR-003) and position duct away from combustion chamber
    e. If direct reading instrumentation indicates high CO or low oxygen, purge chamber until readings are acceptable.

Continued on next page

10. One at a time, disconnect sample media from manifold samples, double checking that the media is appropriate for the sample tubing and pump labels.
    a. Seal media with appropriate caps
    b. Place pre-printed sample labels onto media ("F" labels)
    c. Place in storage bag
11. When safe to enter the chamber, retrieve the sample media, again confirming the media type matches the name on the sample line tubing and sample pump labels.
    a. Seal media with appropriate caps
    b. Place pre-printed sample labels onto media ("CH" labels)
    c. Place with other samples.
12. Prepare blanks, at least one set per day's run.
    a. Break open tube
    b. Immediately reseal the tube
    c. Place pre-printed sample labels onto media ("B" labels)
    d. Place with other samples
13. Place grouped samples into -20 C freezer for accumulation.
14. At end of day, confirm the samples collected and generate a master file of sample identifiers, sample duration, sample flow rate, and total air volume for submitting samples to the lab for analysis.

Standard Operating Procedure	
University of Arizona	Prepared by: Delayne Caseman
Reference: APR-008	Reviewed by: TR Anthony
Project Ref: 300600 (NPPTL Smoke Study)	Date: 1/2/07
Title: Sampling Method Summary for APR Study	Total number of pages: 1

Materials Needed:

1. See list of media and shipping requirements in table, below
2. Tube capper; plastic bags
3. For chilled shipping: Plastic bags; bubble wrap; blue ice; cooler; box to ship cooler to lab; completed lab packing / chain of custody sheet
4. For shipping on dry ice: Dry ice shipping box with cooler; dry ice; double-packing (plastic bags) for samples; bubble wrap; completed lab packing / chain of custody sheet

Sequence:

Use the flowrates, media, and storage procedures in table below. Incorporate into APR-007

Sample ID	Analytes	Q (Lpm)	Sampling Method	Media	Storage	Shipping
pDR	Respirable Dust (pDR)	2.6	NIOSH 0600	37 µm PVC filter (BGI cyclone) and direct-read	Pre-weighed filter Sealed in 3 piece cassette Store @ room temp.	No plastic: minimize static
R	Respirable Dust	2.5	NIOSH 0600	37 µm PVC filter (SKC Al cyclone)	Pre-weighed filter Sealed in 3 piece cassette Store @ room temp.	No plastic: minimize static
R-FR	Respirable (free radicals)	2.5	NIOSH 0600	37 µm PVC filter (SKC Al cyclone)	Transfer filter to Petri dish Freeze (0º C) NIOSH-Morgantown to Analyze	Ship on dry ice
T	Total Dust	3.5	NIOSH 0500	37 µm PVC filter (3 piece cassette)	Pre-weighed filter Sealed in 3 piece cassette Store @ room temp.	No plastic: minimize static
T-FR	Total (free radicals)	3.5	NIOSH 0500	37 µm PVC filter (3 piece cassette)	Transfer filter to Petri dish Freeze (0º C) NIOSH-Morgantown to Analyze	Ship on dry ice
H	Aldehydes	0.7	EPA TO11	DPNH Sorbent Tube	Refrigerate pre- and post- sampling Cap tubes Store no more than 2 weeks	Ship chilled
N	Naphthalene	2.0	NIOSH 5506	37 µm PTFE filter + Orbo Tube	Filter - sealed in cassette Tube - capped Wrap in Al foil, freeze (0º C)	Ship @ 0º C
B	Benzene/ Total Hydrocarbons	0.2	OSHA 7	Small Charcoal Tube	Seal in storage tube Freeze (0º C) Analyze ASAP	Ship chilled
CN	Cyanide	0.2	OSHA 2	Soda Lime Tube-remove plug	Cap tube Freeze (0º C) Analyze ASAP	Ship chilled
HCl	Hydrogen Chloride	0.5	NIOSH 7303	SKC 226-10-03	Cap tube Freeze Analyze ASAP	Ship chilled
Multigas	$CO/H_2S/NO_2/SO_2$	-	Direct-Read	VRae Multi-Gas Monitors and Tubing	Pre- and post-calibrate Standard gases must be within expiration date	n/a

Appendix B: Data Tables

August Respirable Dust (pDR) Data

Run Number	APR Canister Tested	30-min run time averaged			
		Chamber (mg/m^3)	Filtered (mg/m^3)	Penetration	Efficiency
811_1	MSA CBRN Cap 1	20.3	0.001	0.004%	99.996%
811_2	3M FR-15CBRN Cap1	43.8	0.000	0.001%	99.999%
811_3	3M FR64	11.6	0.000	0.000%	100.000%
812_1	3M FR64	82.7	0.001	0.001%	99.999%
812_2	MSA CBRN Cap 1	16.3	0.000	0.000%	100.000%
812_3	3M FR15 Cap 1	116.1	0.001	0.001%	99.999%

November Respirable Dust (pDR) Data

Run Number	APR Canister Tested	Chamber Concentration (mg/m^3)				Filtered (mg/m^3)	Penetration	Efficiency
		Left	Center	Right	Mean			
1110_1	Scott CBRN Cap1	114	104	103	107	0.00	0.00%	100.00%
1110_2	3M FR64	11	10	11	11	0.00	0.00%	100.00%
1110_3	3M FR64*	29	24	27	27	na	-	-
1111_4	MSA CBRN Cap1	11	12	11	11	0.00	0.00%	100.00%
1111_5	Scott CBRN Cap1	32	35	31	33	0.00	0.00%	100.00%
1111_6	3M FR64	44	46	44	45	0.05	0.12%	99.88%

Gas (VRae) Data

Run ID	APR Canister Tested	CO, ppm		SO_2, ppm		NO_2, ppm	
		Chamber	Filtered	Chamber	Filtered	Chamber	Filtered
811_1	MSA CBRN Cap 1	14	11	0.4	0.1	0.0	0.0
811_2	3M FR-15CBRN Cap1	59	34	1.6	1.0	0.0	0.0
811_3	3M FR64	11	9	0.1	0.1	0.0	0.0
812_1	3M FR64	failure	48	failure	1.3	failure	0.0
812_2	MSA CBRN Cap 1	29	20	0.5	0.2	0.0	0.0
812_3	3M FR15 Cap 1	79	62	2.1	0.9	0.0	0.0
1110_1	Scott CBRN Cap1	106.2	85.7	2.68	1.04	0.02	0.00
1110_2	3M FR64	5.4	4.4	0.14	0.05	0.02	0.00
1110_3	3M FR64*	44.9	30.4	0.59	0.34	0.26	0.14
1111_4	MSA CBRN Cap1	16.3	14.6	0.26	0.14	0.04	0.22
1111_5	Scott CBRN Cap1	20.5	17.9	0.47	0.31	0.21	0.12
1111_6	3M FR64	60.2	42.1	0.62	0.37	0.10	0.10

2007 Aldehyde Data

Run ID	Acetaldehyde, mg/m³			Acrolein, mg/m³		
	Chamber	Filtered	Penetration	Chamber	Filtered	Penetration
811_1	0.48	0.036	7.5%	0.040	<0.022	< 55.0%
811_2	*1.2	0.34	< 28.3%	0.26	<0.018	< 6.9%
811_3	1.7	0.14	8.2%	0.063	<0.019	< 30.2%
812_1	*1.4	0.31	< 22.1%	0.35	<0.019	< 5.4%
812_2	0.90	0.082	9.1%	<0.019	<0.018	< 94.7%
812_3	*1.8	0.36	< 20.0%	0.42	<0.018	< 4.3%
1110_1	*1.9	0.0052	< 0.3%	0.51	<0.019	< 3.7%
1110_2	0.28	0.0070	2.5%	0.018	<0.019	-
1110_3	0.67	0.040	6.0%	0.039	<0.018	< 46.2%
1111_4	0.33	0.013	3.9%	0.018	<0.019	-
1111_5	0.83	0.012	1.4%	0.044	<0.019	< 43.2%
1111_6	1.0	0.0041	0.4%	0.063	<0.019	< 30.2%

Reporting Limit: 0.105 ug *Reporting Limit: 0.500 ug*

Run ID	Benzaldehyde, mg/m³			Butyraldehyde, mg/m³		
	Chamber	Filtered	Penetration	Chamber	Filtered	Penetration
811_1	0.064	<0.0086	< 13.4%	*0.043	0.0064	< 14.9%
811_2	0.054	<0.0074	< 13.7%	*0.11	0.0057	< 5.2%
811_3	0.024	<0.0074	< 30.8%	0.15	<0.0039	< 2.6%
812_1	0.077	<0.0074	< 9.6%	*0.15	0.0049	< 3.3%
812_2	0.021	<0.0070	< 33.3%	*0.012	0.0060	< 50.0%
812_3	0.032	<0.0070	< 21.9%	0.11	0.0072	6.6%
1110_1	*0.042	<0.0075	< 17.9%	0.018	0.0018	10.0%
1110_2	<0.0075	<0.0075	-	0.0081	0.0017	21.0%
1110_3	0.035	<0.0075	< 21.4%	<0.0013	<0.0013	-
1111_4	0.0093	<0.0075	< 80.6%	0.025	0.0036	14.4%
1111_5	0.033	<0.0075	< 22.7%	0.033	0.0024	7.27%
1111_6	0.044	<0.0075	< 17.0%	0.045	0.0021	4.67%

Reporting Limit: 0.200 ug *Reporting Limit: 0.105 ug*

Run ID	Crotonaldehyde, mg/m³			Glutyraldehyde, mg/m³		
	Chamber	Filtered	Penetration	Chamber	Filtered	Penetration
811_1	0.020	<0.0045	< 22.5%	0.038	<0.0086	< 22.6%
811_2	0.062	<0.0039	< 6.3%	0.12	<0.0074	< 6.2%
811_3	0.036	<0.0039	< 10.8%	0.100	<0.0074	< 7.4%
812_1	0.088	<0.0039	< 4.4%	*0.18	<0.0074	< 4.1%
812_2	<0.0039	<0.0037	< 94.9%	0.047	<0.0070	< 14.9%
812_3	0.098	<0.0037	< 3.8%	0.11	<0.0070	< 6.4%
1110_1	0.040	<0.0039	< 9.8%	*0.11	<0.0075	< 6.8%
1110_2	0.018	<0.004	< 22.2%	0.019	<0.0075	< 39.5%
1110_3	0.054	<0.0039	< 7.2%	0.051	<0.0074	< 14.5%
1111_4	0.021	<0.0039	< 18.6%	0.019	<0.0074	< 38.9%
1111_5	0.039	<0.0039	< 10.0%	0.033	<0.0075	< 22.7%
1111_6	0.070	<0.0039	< 5.6%	0.055	<0.0075	< 13.6%

Reporting Limit: 0.105 ug *Reporting Limit: 0.200 ug*

Run ID	Formaldehyde, mg/m^3		
	Chamber	Filtered	Penetration
811_1	0.50	0.0083	1.7%
811_2	1.3	<0.0037	< 0.28%
811_3	1.5	<0.0037	< 0.25%
812_1	1.3	<0.0037	< 0.28%
812_2	0.66	0.011	1.7%
812_3	1.6	<0.0035	< 0.22%
1110_1	2.0	0.0042	0.2%
1110_2	0.33	<0.0038	< 1.2%
1110_3	0.60	<0.0037	< 0.6%
1111_4	0.36	<0.0037	< 1.0%
1111_5	0.73	0.0042	0.6%
1111_6	0.84	0.0052	0.6%

Reporting Limit: 0.100 ug
Ceiling Limit = 0.1 ppm =
0.123 mg/m3

**Concentrations exceeded the capacity of the sampling media and may be larger than the value indicated.*

Additional Data: Benzene, Naphthalene, Total HC, Cyanide and Hydrochloric Acid

For the first 6 tests, the chamber concentrations of benzene were less than the detection limit (2 ug) and all challenge concentrations were less than 0.3 mg/m^3 (<0.1 ppm). Naphthalene and total hydrocarbon were also investigated. These data varied by test, but the chamber concentrations were near the detection limit, resulting in penetration calculations of limited use. No evaluation of these components was included in the November tests.

	Naphthalene, mg/m^3		
Run ID	Chamber	Filtered	Penetration
811_1	<0.017	<0.017	-
811_2	0.027	<0.016	< 59.00%
811_3	<0.017	<0.016	-
812_1	0.028	<0.016	< 57.00%
812_2	<0.016	<0.016	-
812_3	0.19	<0.016	< 8.00%

Reporting Limit: 1.01 ug

	Hydrocarbon, as n-Hexane, mg/m^3		
Run ID	Chamber	Filtered	Penetration
811_1	1.0	<0.70	< 69.0%
811_2	3.0	<0.70	< 23.5%
811_3	<0.79	<0.70	< 87.0%
812_1	7.4	0.75	< 10.0%
812_2	1.1	<0.71	< 66.7%
812_3	9.5	<0.71	< 7.4%

Reporting Limit: 5.00 ug

Cyanide concentrations were evaluated for all 12 chamber tests. Because these values were less than twice the limit of quantification, resulting in penetration estimates of limited use.

	Cyanide, mg/m^3		
Run ID	Chamber	Filtered	Penetration
811_1	<0.044	<0.041	
811_2	<0.044	<0.041	
811_3	<0.044	<0.041	
812_1	<0.045	<0.041	
812_2	<0.045	<0.041	
812_3	<0.045	<0.041	
1110_1	0.050	<0.037	< 74%
1110_2	<0.041	<0.037	
1110_3	<0.040	<0.037	
1111_4	<0.037	<0.041	
1111_5	<0.041	<0.037	
1111_6	0.044	<0.037	< 84%

Reporting Limit: 0.289 ug in August and 0.262 ug in November

Hydrochloric acid concentrations were assessed only on the November tests.

Run ID	Hydrochloric Acid, mg/m^3		
	Chamber	Filtered	Penetration
1110_1	0.042	0.045	100%
1110_2	0.040	<0.041	-
1110_3	0.33	<0.040	< 12.1%
1111_4	0.20	<0.039	< 19.5%
1111_5	0.12	<0.040	< 33.3%
1111_6	<0.039	n/a	-

Reporting Limit: 0.617 ug

Additional Data: Free Radicals

Information on Blanks

	Peak ht, mm	
Blank ID	**OH-based**	**C-based**
811-2FRBlank	26.5	0
811-3Blank	26.5	0
812-FRBlankA	29.5	0
812-FRBlankB	26.5	0
1110-1FRB	32.5	0
1110-2FRB	26.5	0
1110-3FRB1	22.5	0
1110-3FRB2	25	0

Basic statistics of free radical data

Data Groups	Mean Height (raw) OH	Mean Height (raw) C	S.D. Height (raw) OH	S.D. Height (raw) C	n
Blanks	26.9	0.0	3.0	0.0	8
Chamber	66.3	22.6	23.7	21.3	9
Filtered	31.6	0.0	11.4	0.0	9
FI thru pDR	30.4	0.0	6.0	0.0	6

Blank adjusted and volume normalized data, presented in Figure 3

	Peak Ht/Vol, blank adjusted (mm/L sampled)					
Test	**OH-based**			**Carbon-based**		
ID	CH	FI	FI-pDR	CH	FI	FI-pDR
811-1	0.884	*-0.026*	0.079	0.000	0	0
811-2	0.496	*-0.007*	0.044	0.326	0	0
811-3	0.518	0.027	*-0.013*	0.000	0	0
812-1	0.367	0.066	0.121	0.340	0	0
812-2	0.619	0.020	*-0.078*	0.143	0	0
812-3	0.424	0.033	0.101	0.444	0	0
1110-1	0.463	0.086	-	0.927	0	-
1110-2	0.480	0.053	-	0.197	0	-
1110-3	0.442	0.251	-	0.288	0	-

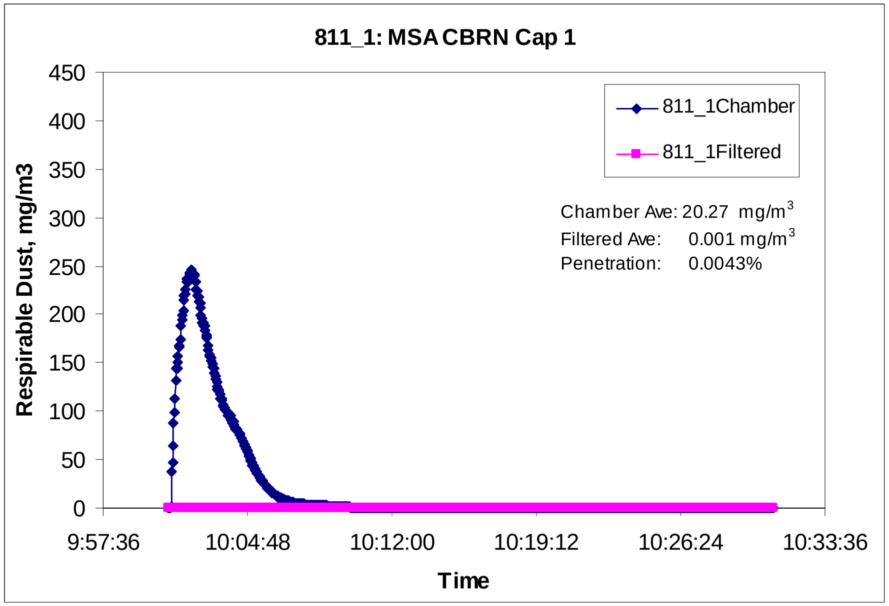
Penetration calculations for free radical samples

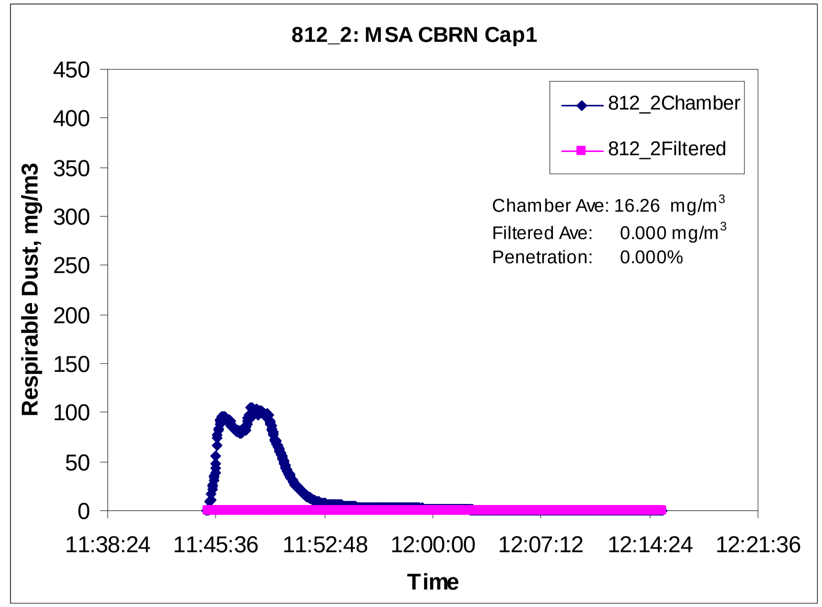
	% Penetration through Filter (FI/CH*100%)			
	OH-based		**Carbon-based**	
Test ID	**FI**	**FI-pDR**	**FI**	**FI-pDR**
811-1	*-3%*	9%	-	-
811-2	*-1%*	9%	0%	0%
811-3	5%	*-2%*	-	-
812-1	18%	33%	0%	0%
812-2	3%	*-13%*	0%	0%
812-3	8%	24%	0%	0%
1110-1	19%		0%	
1110-2	11%		0%	
1110-3	57%		0%	

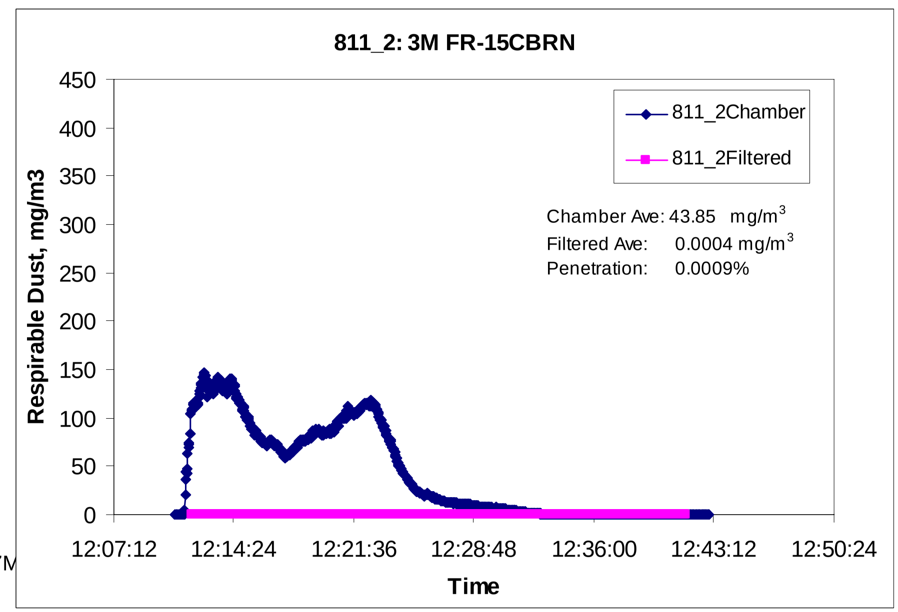
Notes:
- No samples were collected using the pDR with cyclone/pump in November.
- 811-2 and -3 had no carbon-based radical in the chamber nor in the filtered air, precluding penetration calculations.

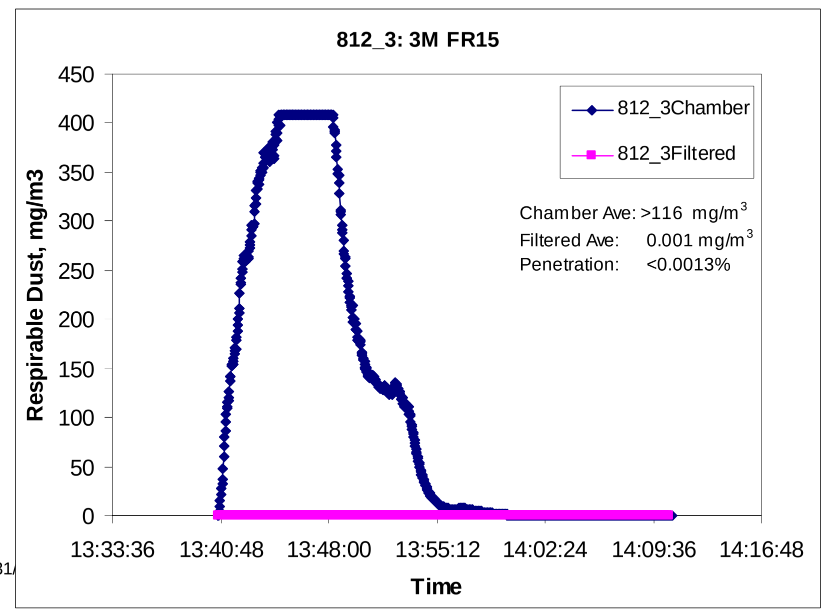
Appendix C: Time-Series Graphs for Direct-Reading Instrumentation

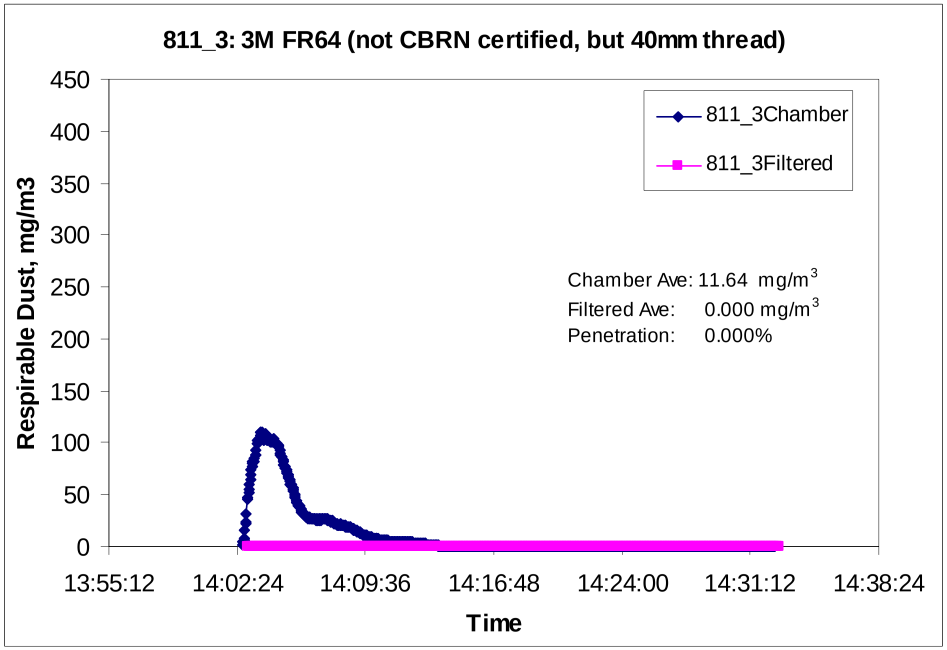
Respirable Dust Time-Series Data

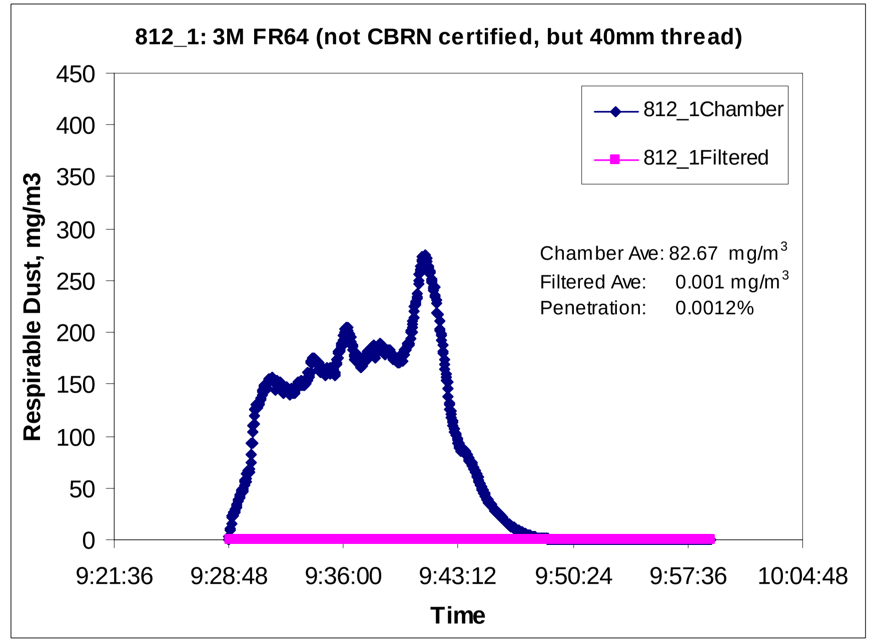


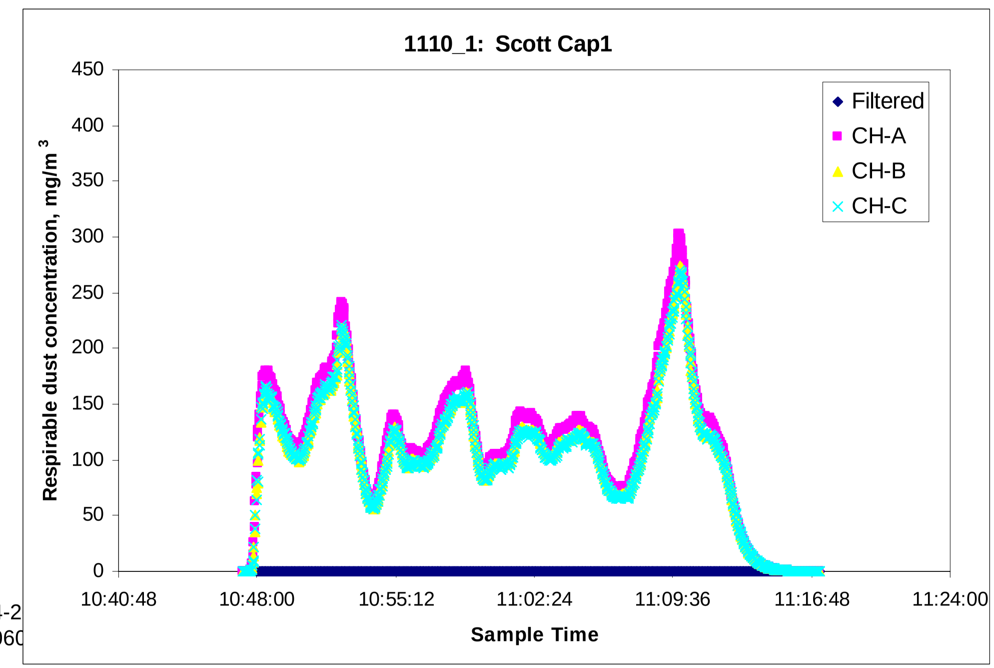


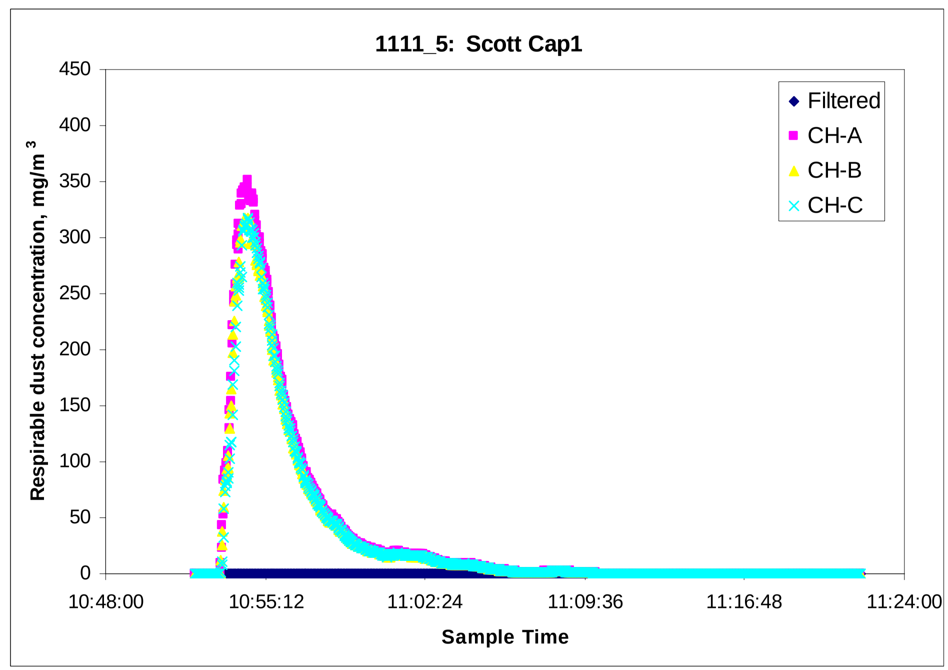


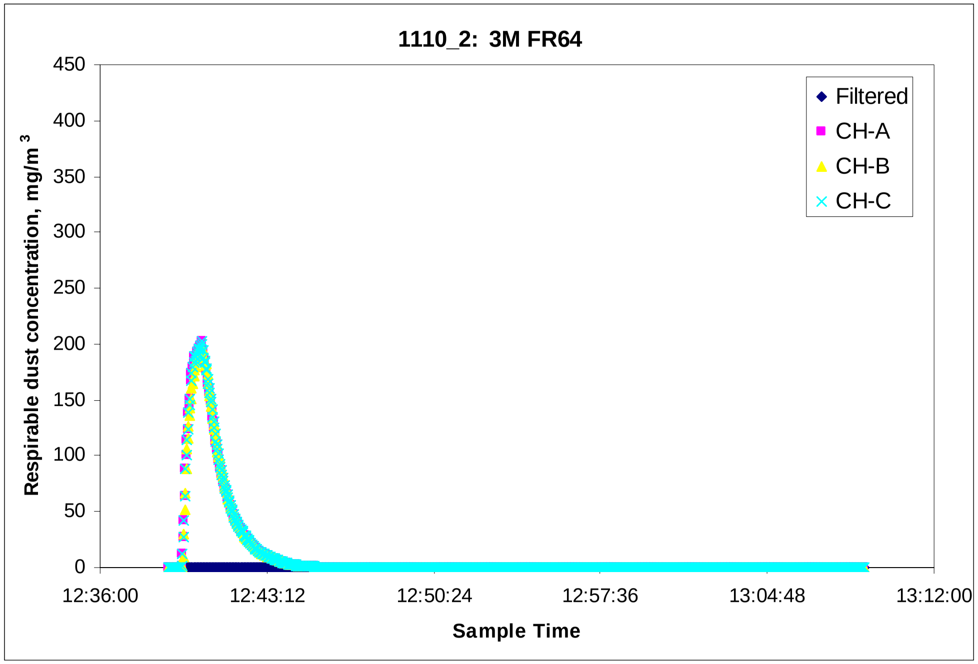


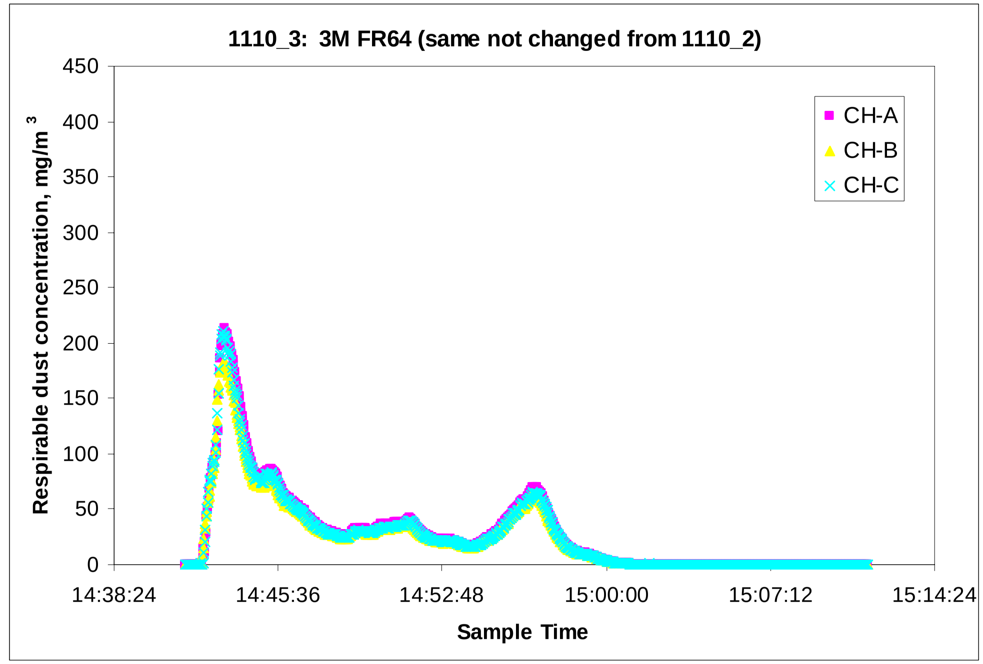

811_3: 3M FR64 (not CBRN certified, but 40mm thread)
Respirable Dust, mg/m3
Time
811_3Chamber
811_3Filtered
Chamber Ave: 11.64 mg/m3
Filtered Ave: 0.000 mg/m3
Penetration: 0.000%
0 50 100 150 200 250 300 350 400 450
13:55:12 14:02:24 14:09:36 14:16:48 14:24:00 14:31:12 14:38:24

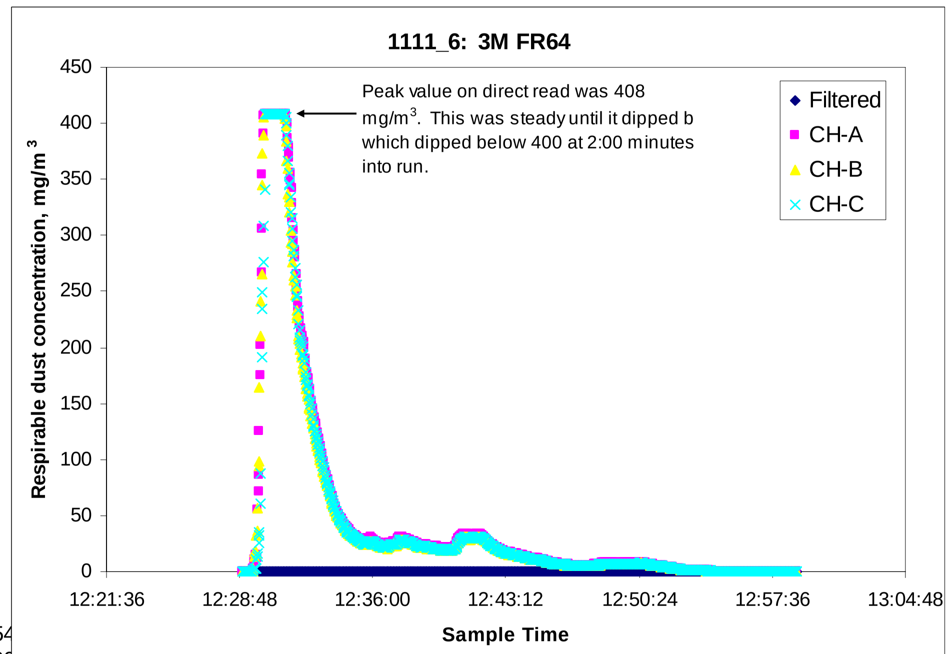

812_1: 3M FR64 (not CBRN certified, but 40mm thread)
Respirable Dust, mg/m3
Time
812_1Chamber
812_1Filtered
Chamber Ave: 82.67 mg/m3
Filtered Ave: 0.001 mg/m3
Penetration: 0.0012%
0 50 100 150 200 250 300 350 400 450
9:21:36 9:28:48 9:36:00 9:43:12 9:50:24 9:57:36 10:04:48

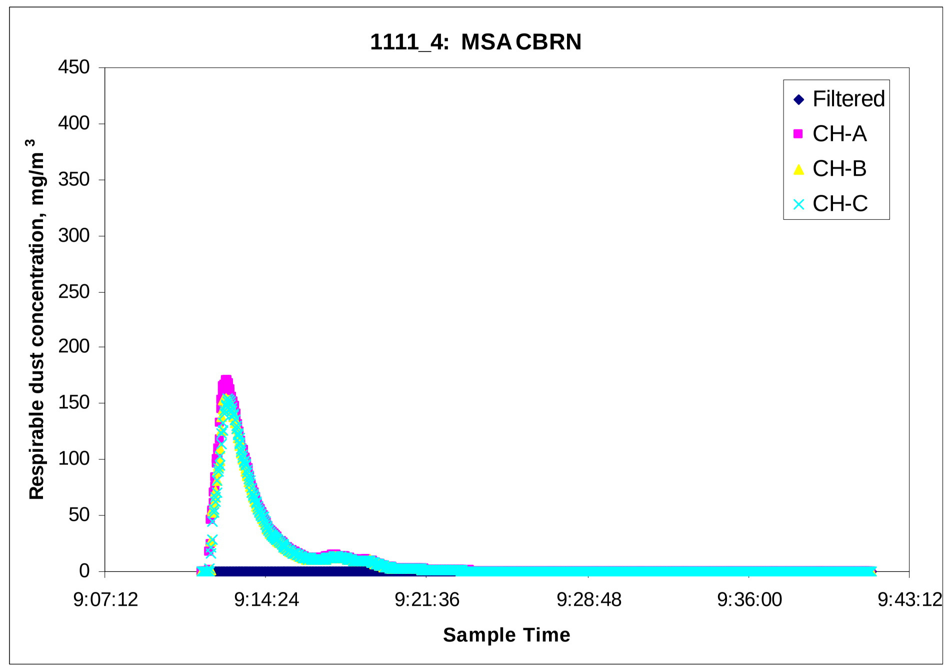

1110_1: Scott Cap1
Respirable dust concentration, mg/m 3
Sample Time
Filtered
CH-A
CH-B
CH-C
0 50 100 150 200 250 300 350 400 450
10:40:48 10:48:00 10:55:12 11:02:24 11:09:36 11:16:48 11:24:00


1111_5: Scott Cap1
Respirable dust concentration, mg/m 3
Sample Time
Filtered
CH-A
CH-B
CH-C
0 50 100 150 200 250 300 350 400 450
10:48:00 10:55:12 11:02:24 11:09:36 11:16:48 11:24:00


1110_2: 3M FR64
Respirable dust concentration, mg/m 3
Sample Time
Filtered
CH-A
CH-B
CH-C

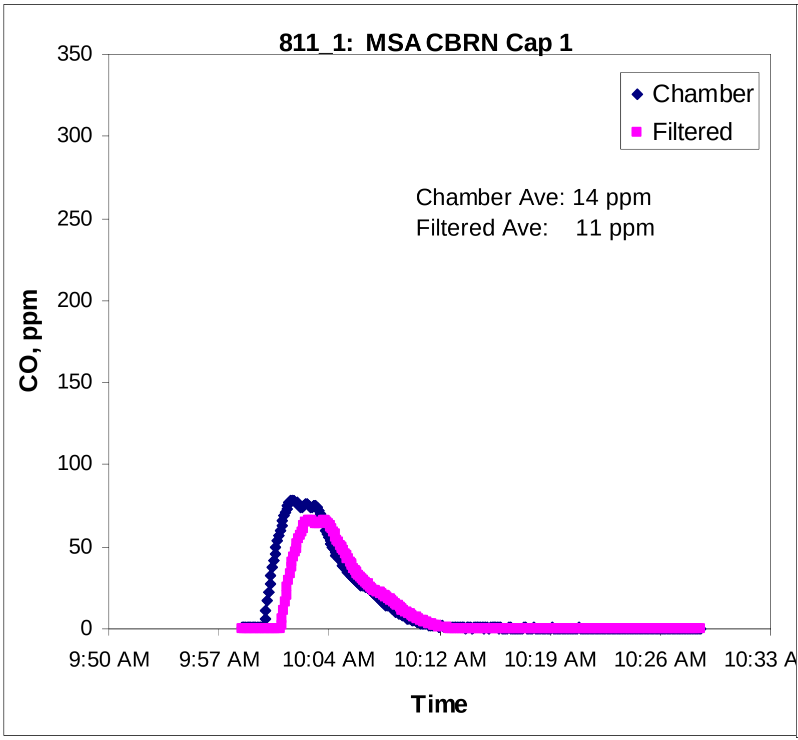

1110_3: 3M FR64 (same not changed from 1110_2)
Respirable dust concentration, mg/m 3
Sample Time
CH-A
CH-B
CH-C

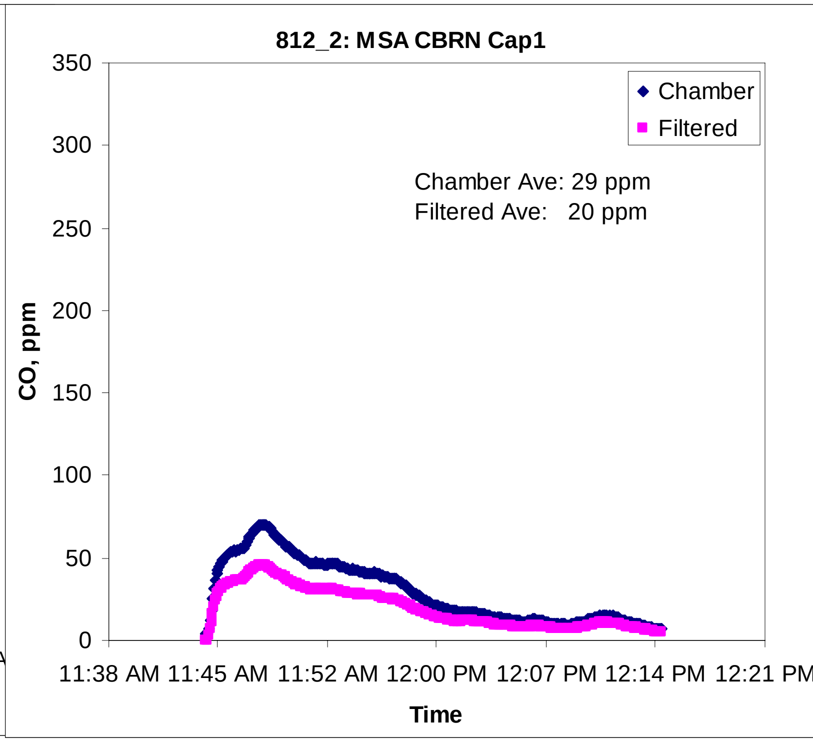

1111_6: 3M FR64
Peak value on direct read was 408 mg/m3. This was steady until it dipped b which dipped below 400 at 2:00 minutes into run.
Respirable dust concentration, mg/m 3
Sample Time
Filtered
CH-A
CH-B
CH-C

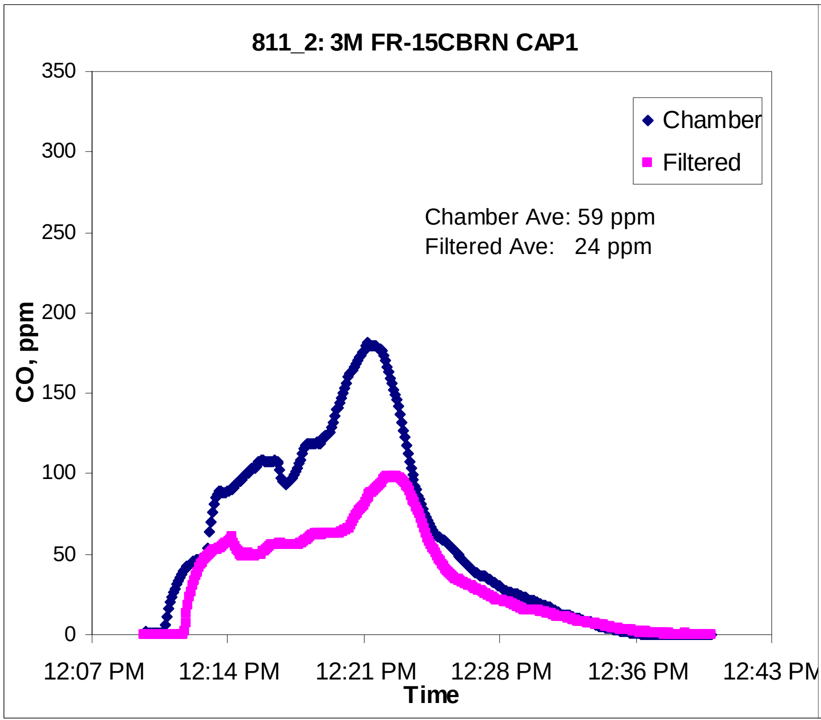

1111_4: MSA CBRN
Respirable dust concentration, mg/m 3
Sample Time
Filtered
CH-A
CH-B
CH-C

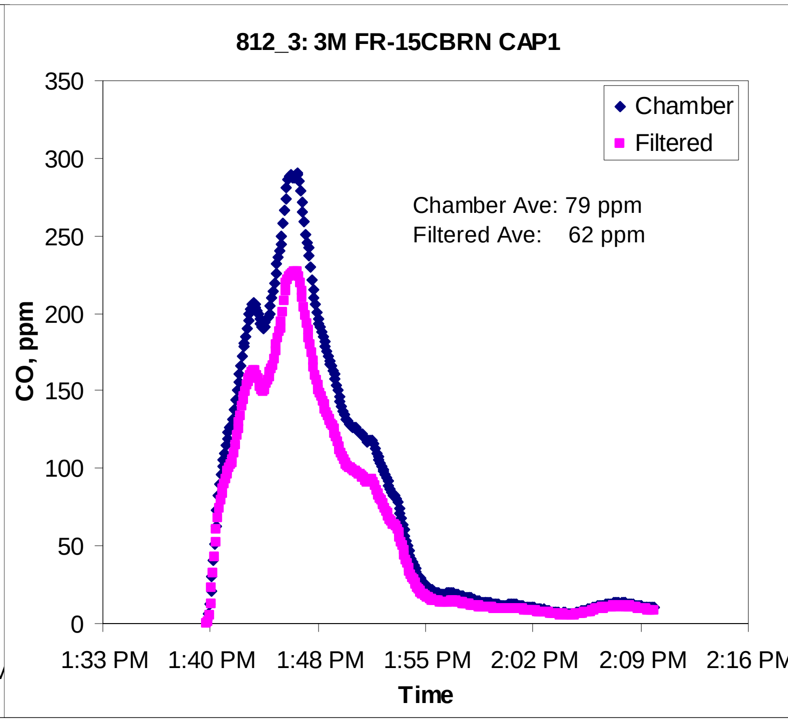
254
300

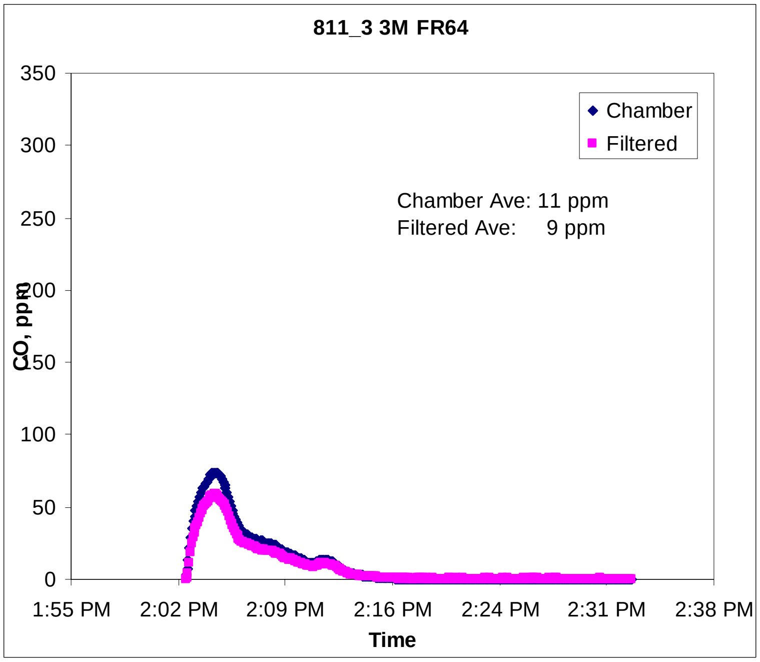
August Carbon Monoxide Time Series Data

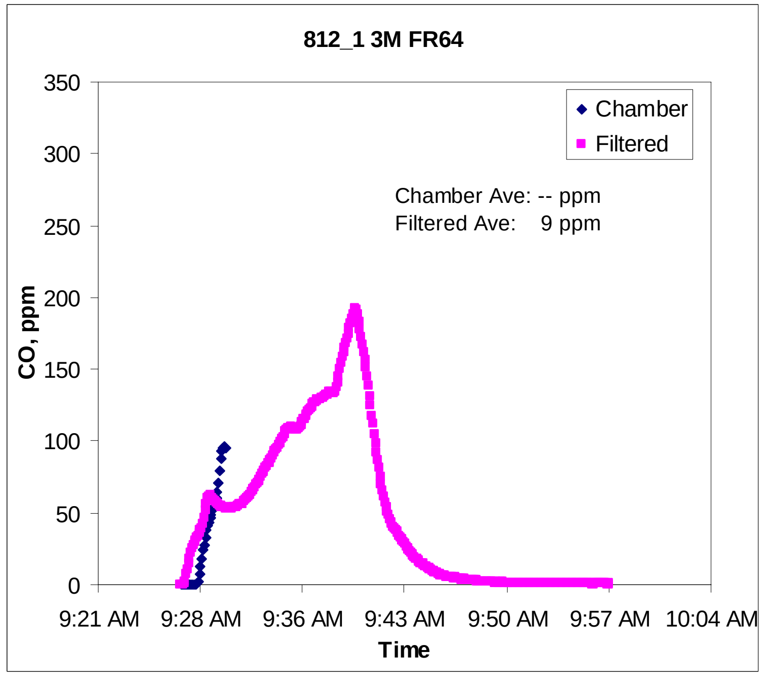


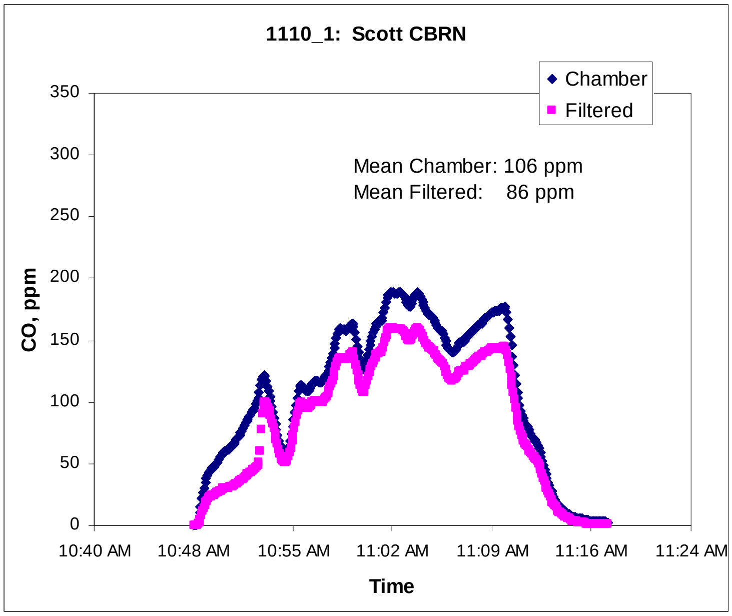


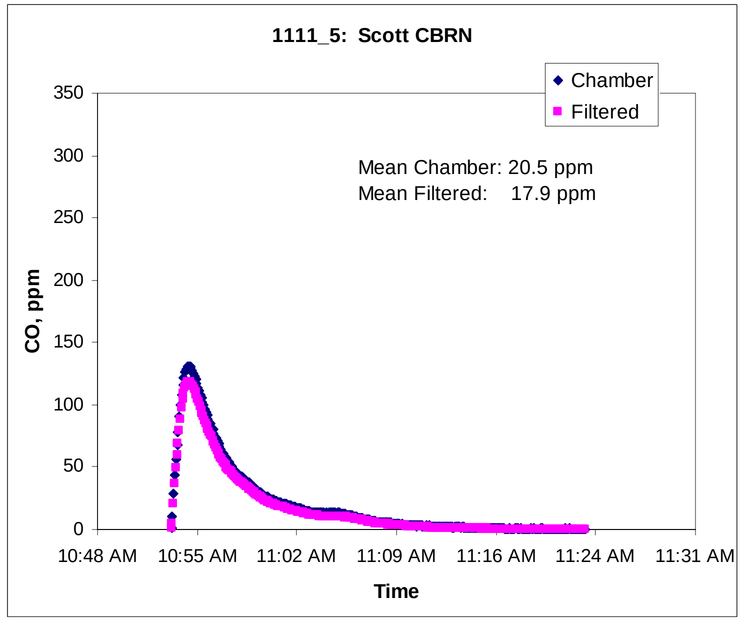


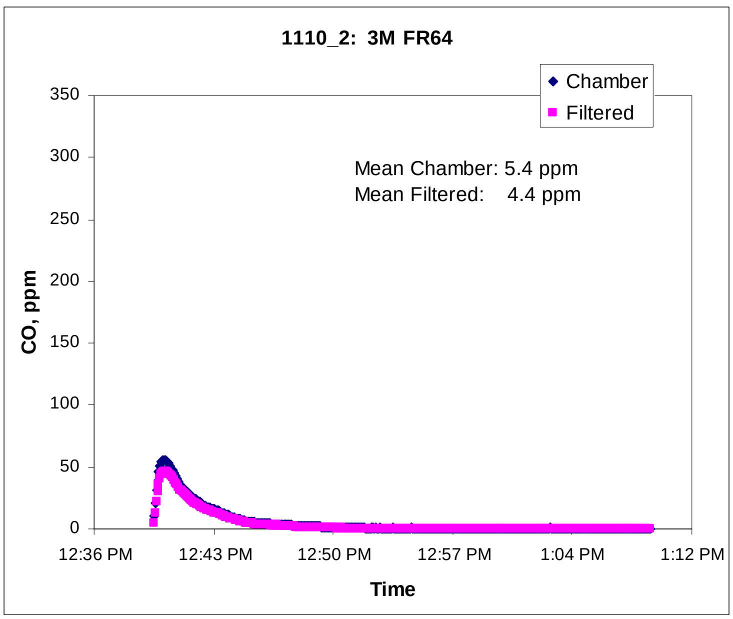


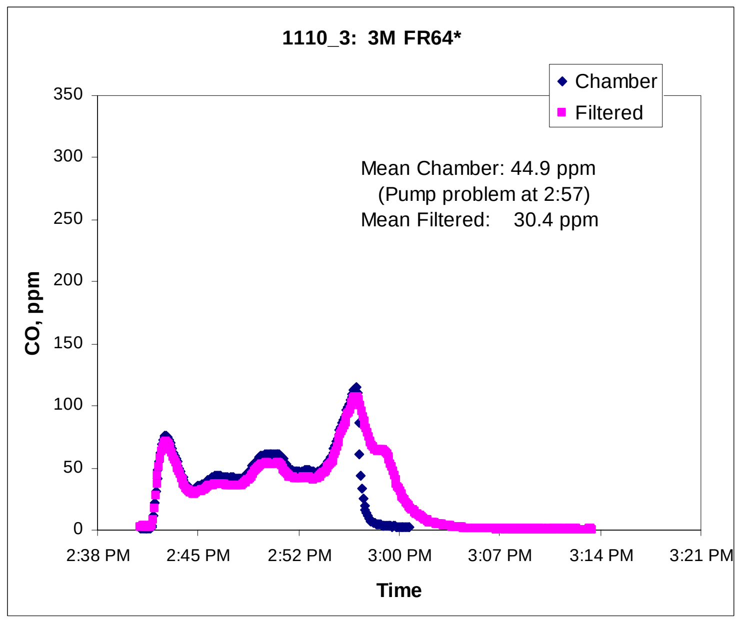

811_3 3M FR64
350
300
250
200
150
100
50
0
CO, ppm
Chamber
Filtered
Chamber Ave: 11 ppm
Filtered Ave: 9 ppm
1:55 PM
2:02 PM
2:09 PM
2:16 PM
2:24 PM
2:31 PM
2:38 PM
Time

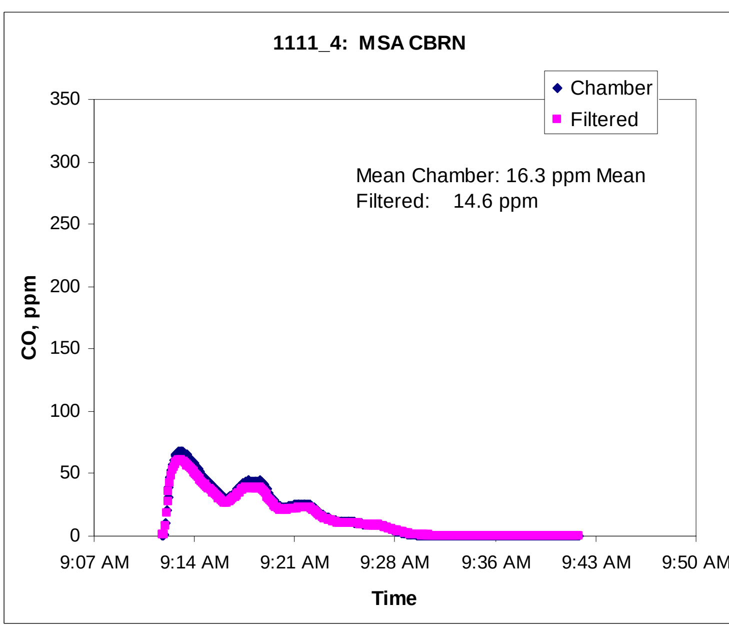

812_1 3M FR64
350
300
250
200
150
100
50
0
CO, ppm
Chamber
Filtered
Chamber Ave: -- ppm
Filtered Ave: 9 ppm
9:21 AM
9:28 AM
9:36 AM
9:43 AM
9:50 AM
9:57 AM
10:04 AM
Time

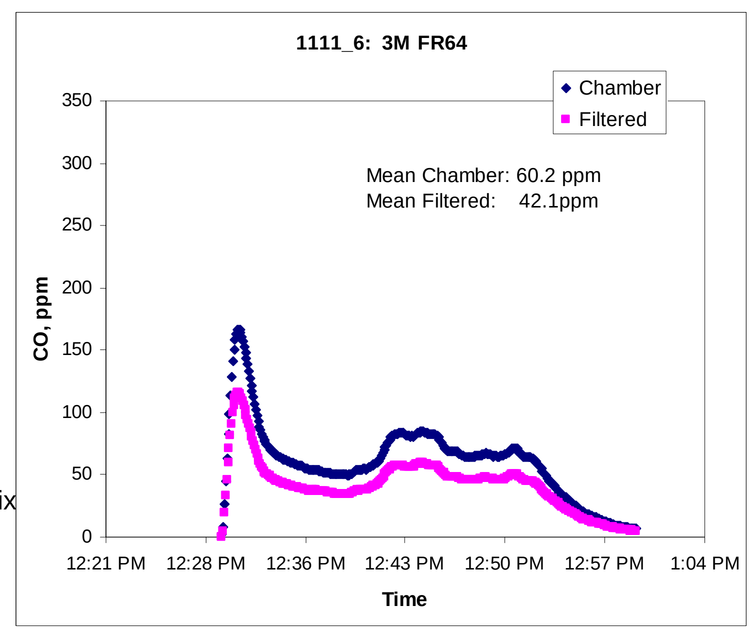

1110_1: Scott CBRN
Chamber
Filtered
Mean Chamber: 106 ppm
Mean Filtered: 86 ppm
CO, ppm
0
50
100
150
200
250
300
350
10:40 AM
10:48 AM
10:55 AM
11:02 AM
11:09 AM
11:16 AM
11:24 AM
Time


1111_5: Scott CBRN
Chamber
Filtered
Mean Chamber: 20.5 ppm
Mean Filtered: 17.9 ppm
CO, ppm
0
50
100
150
200
250
300
350
10:48 AM
10:55 AM
11:02 AM
11:09 AM
11:16 AM
11:24 AM
11:31 AM
Time

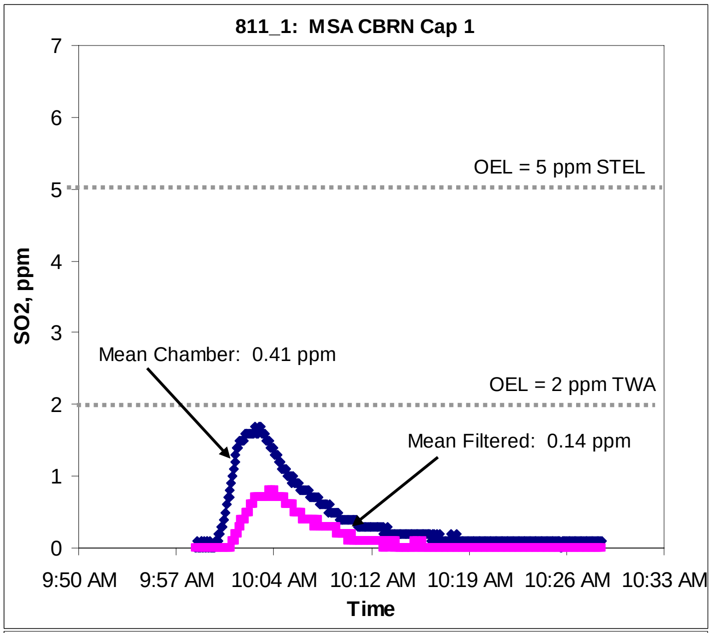

1110_2: 3M FR64
Chamber
Filtered
Mean Chamber: 5.4 ppm
Mean Filtered: 4.4 ppm
CO, ppm
0
50
100
150
200
250
300
350
12:36 PM
12:43 PM
12:50 PM
12:57 PM
1:04 PM
1:12 PM
Time

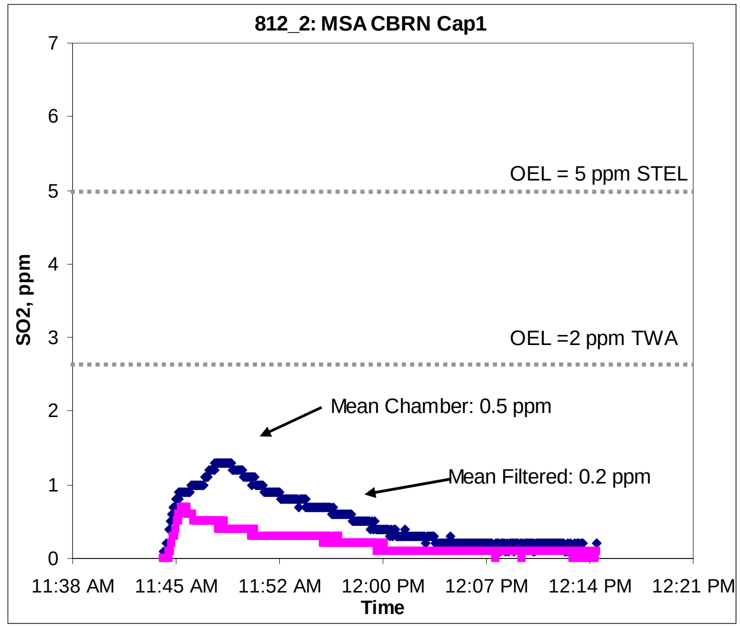

1110_3: 3M FR64*
Chamber
Filtered
Mean Chamber: 44.9 ppm
(Pump problem at 2:57)
Mean Filtered: 30.4 ppm
CO, ppm
0
50
100
150
200
250
300
350
2:38 PM
2:45 PM
2:52 PM
3:00 PM
3:07 PM
3:14 PM
3:21 PM
Time

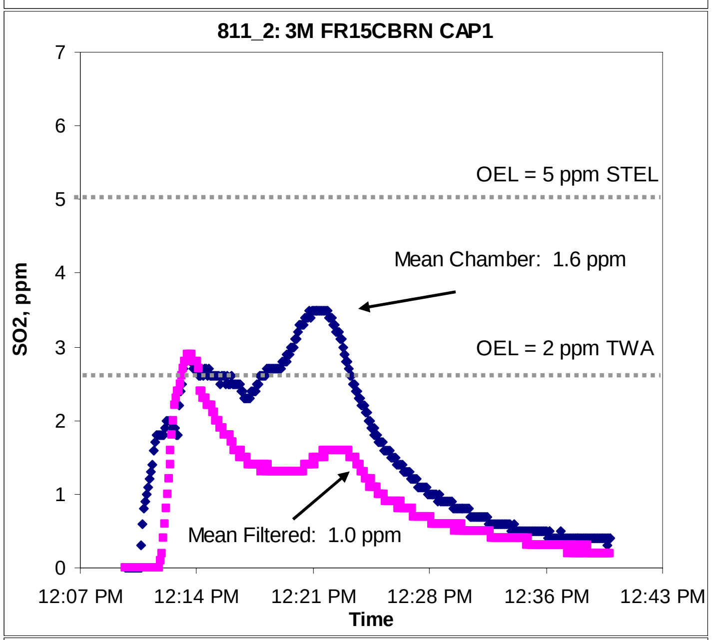

1111_4: MSA CBRN
Chamber
Filtered
Mean Chamber: 16.3 ppm Mean
Filtered: 14.6 ppm
CO, ppm
0
50
100
150
200
250
300
350
9:07 AM
9:14 AM
9:21 AM
9:28 AM
9:36 AM
9:43 AM
9:50 AM
Time

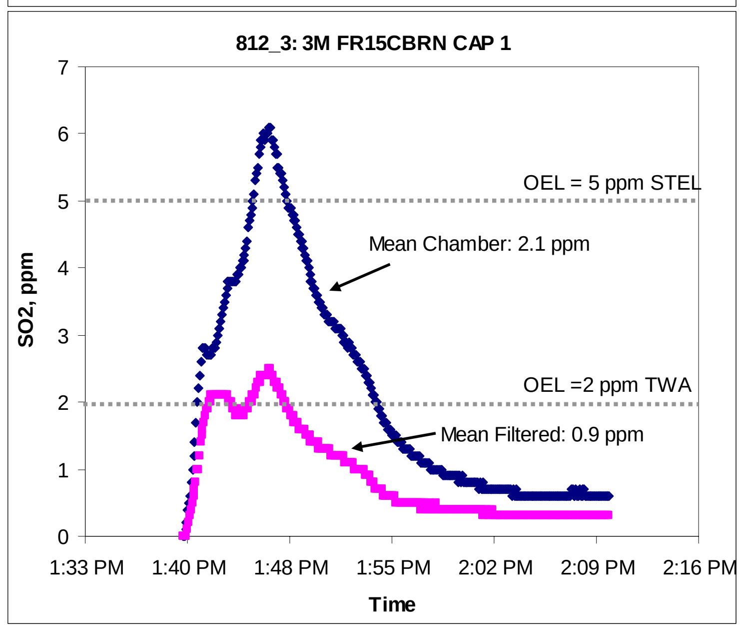

1111_6: 3M FR64
Chamber
Filtered
Mean Chamber: 60.2 ppm
Mean Filtered: 42.1ppm
CO, ppm
0
50
100
150
200
250
300
350
12:21 PM
12:28 PM
12:36 PM
12:43 PM
12:50 PM
12:57 PM
1:04 PM
Time

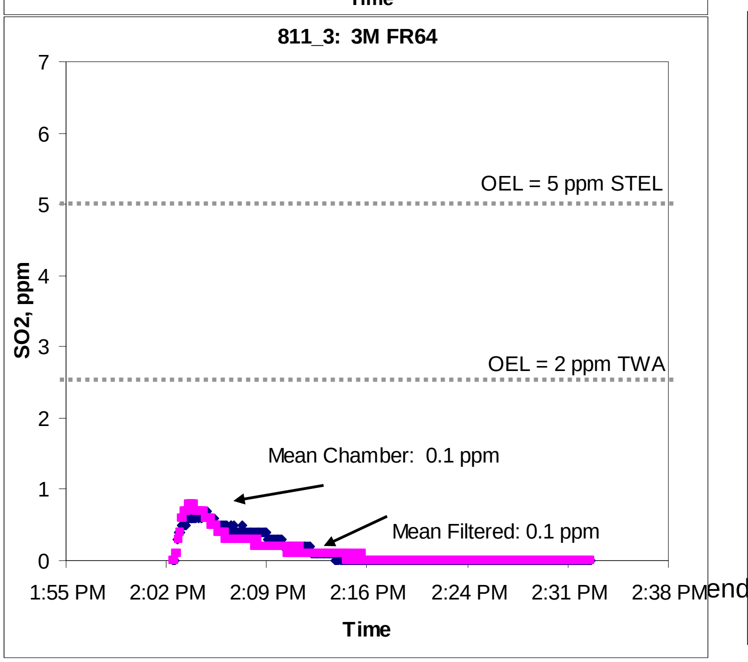
endix

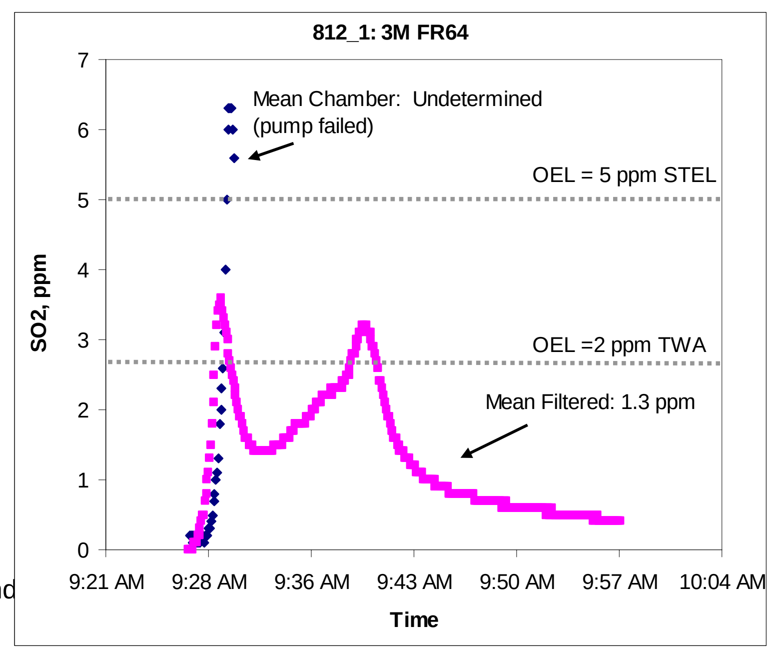

811_1: MSA CBRN Cap 1
SO2, ppm
7
6
5
4
3
2
1
0
OEL = 5 ppm STEL
Mean Chamber: 0.41 ppm
OEL = 2 ppm TWA
Mean Filtered: 0.14 ppm
9:50 AM
9:57 AM
10:04 AM
10:12 AM
10:19 AM
10:26 AM
10:33 AM
Time

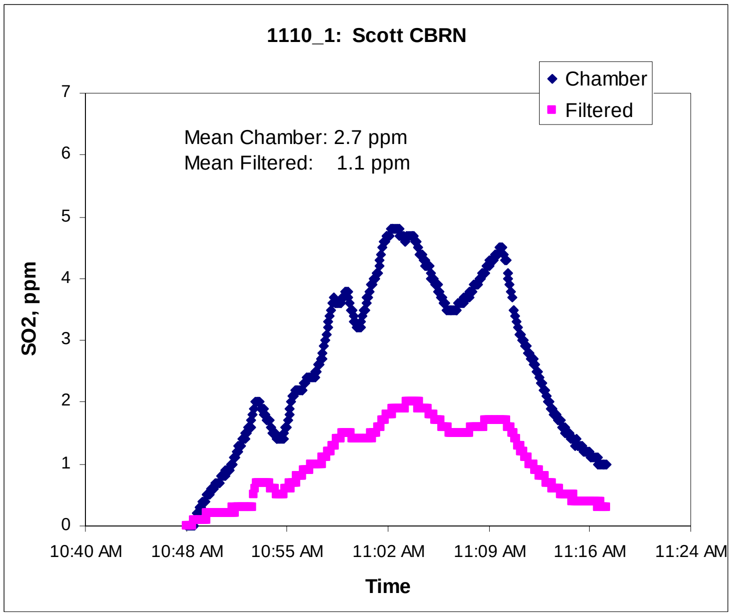

812_2: MSA CBRN Cap1
SO2, ppm
7
6
5
4
3
2
1
0
OEL = 5 ppm STEL
OEL =2 ppm TWA
Mean Chamber: 0.5 ppm
Mean Filtered: 0.2 ppm
11:38 AM
11:45 AM
11:52 AM
12:00 PM
12:07 PM
12:14 PM
12:21 PM
Time

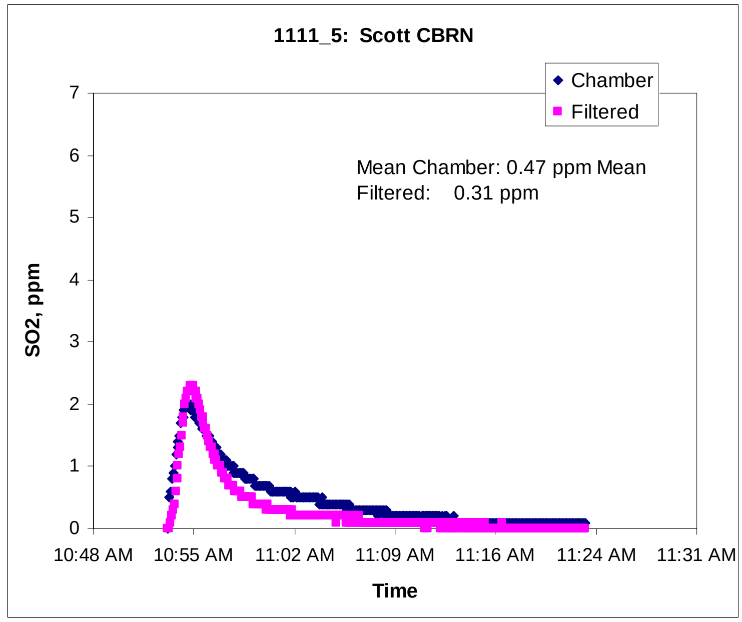

811_2: 3M FR15CBRN CAP1
SO2, ppm
7
6
5
4
3
2
1
0
OEL = 5 ppm STEL
Mean Chamber: 1.6 ppm
OEL = 2 ppm TWA
Mean Filtered: 1.0 ppm
12:07 PM
12:14 PM
12:21 PM
12:28 PM
12:36 PM
12:43 PM
Time

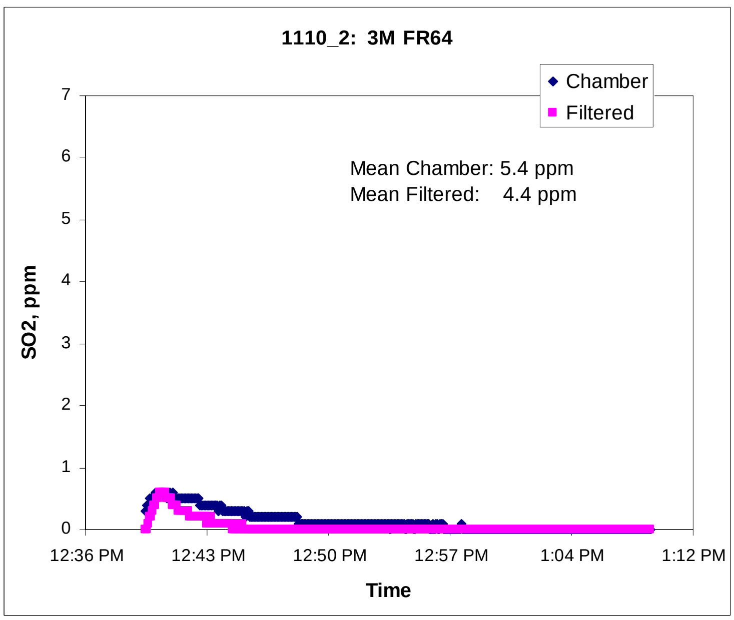

812_3: 3M FR15CBRN CAP 1
SO2, ppm
7
6
5
4
3
2
1
0
OEL = 5 ppm STEL
Mean Chamber: 2.1 ppm
OEL =2 ppm TWA
Mean Filtered: 0.9 ppm
1:33 PM
1:40 PM
1:48 PM
1:55 PM
2:02 PM
2:09 PM
2:16 PM
Time

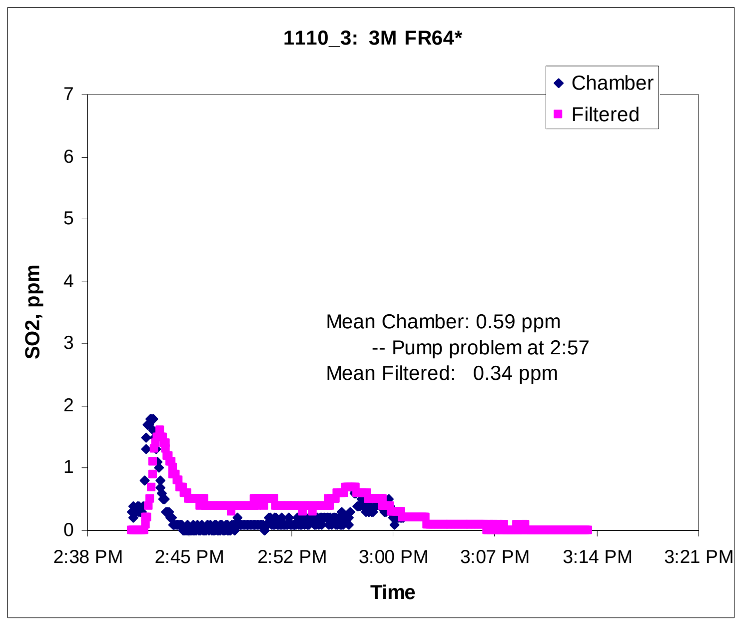

811_3: 3M FR64
SO2, ppm
7
6
5
4
3
2
1
0
OEL = 5 ppm STEL
OEL = 2 ppm TWA
Mean Chamber: 0.1 ppm
Mean Filtered: 0.1 ppm
1:55 PM
2:02 PM
2:09 PM
2:16 PM
2:24 PM
2:31 PM
2:38 PMend
Time

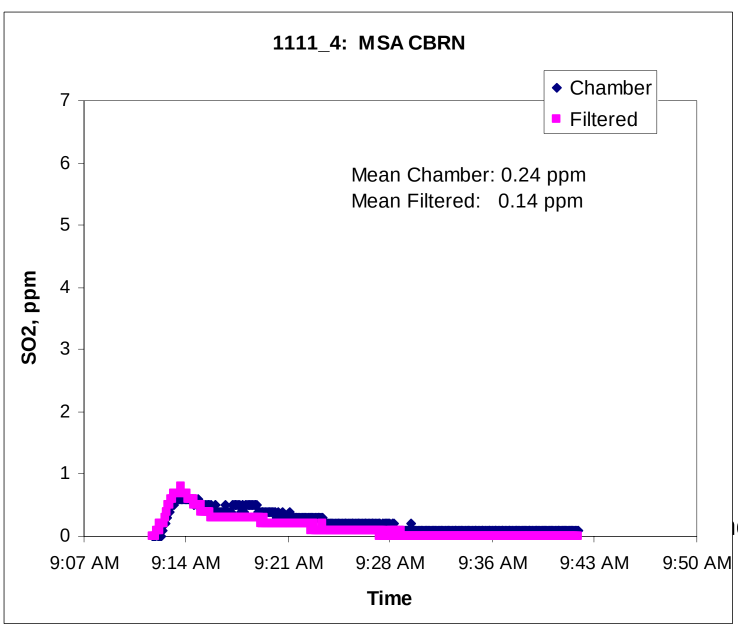

812_1: 3M FR64
SO2, ppm
7
6
5
4
3
2
1
0
Mean Chamber: Undetermined
(pump failed)
OEL = 5 ppm STEL
OEL =2 ppm TWA
Mean Filtered: 1.3 ppm
9:21 AM
9:28 AM
9:36 AM
9:43 AM
9:50 AM
9:57 AM
10:04 AM
Time

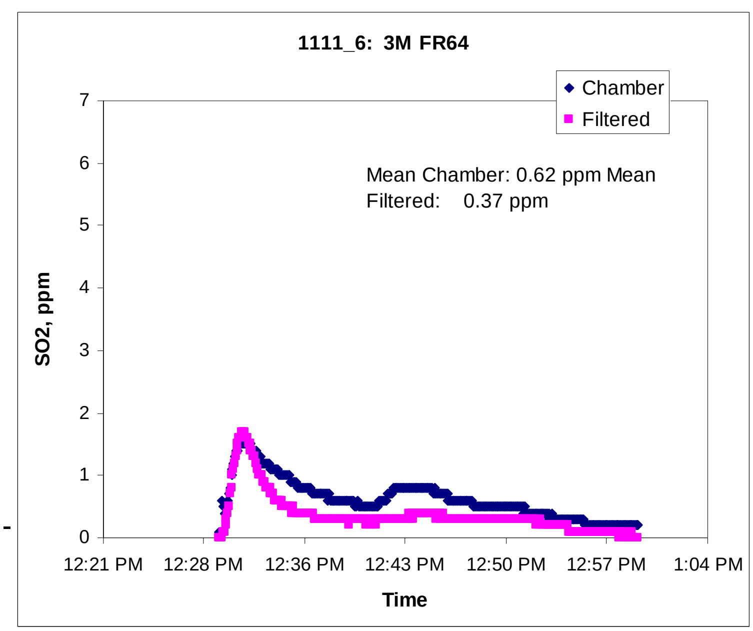

1110_1: Scott CBRN
Chamber
Filtered
Mean Chamber: 2.7 ppm
Mean Filtered: 1.1 ppm
SO2, ppm
0
1
2
3
4
5
6
7
10:40 AM
10:48 AM
10:55 AM
11:02 AM
11:09 AM
11:16 AM
11:24 AM
Time


1111_5: Scott CBRN
Chamber
Filtered
Mean Chamber: 0.47 ppm Mean
Filtered: 0.31 ppm
SO2, ppm
0
1
2
3
4
5
6
7
10:48 AM
10:55 AM
11:02 AM
11:09 AM
11:16 AM
11:24 AM
11:31 AM
Time


1110_2: 3M FR64
Chamber
Filtered
Mean Chamber: 5.4 ppm
Mean Filtered: 4.4 ppm
SO2, ppm
0
1
2
3
4
5
6
7
12:36 PM
12:43 PM
12:50 PM
12:57 PM
1:04 PM
1:12 PM
Time


1110_3: 3M FR64*
Chamber
Filtered
Mean Chamber: 0.59 ppm
-- Pump problem at 2:57
Mean Filtered: 0.34 ppm
SO2, ppm
0
1
2
3
4
5
6
7
2:38 PM
2:45 PM
2:52 PM
3:00 PM
3:07 PM
3:14 PM
3:21 PM
Time


1111_4: MSA CBRN
Chamber
Filtered
Mean Chamber: 0.24 ppm
Mean Filtered: 0.14 ppm
SO2, ppm
0
1
2
3
4
5
6
7
9:07 AM
9:14 AM
9:21 AM
9:28 AM
9:36 AM
9:43 AM
9:50 AM
Time


1111_6: 3M FR64
Chamber
Filtered
Mean Chamber: 0.62 ppm Mean
Filtered: 0.37 ppm
SO2, ppm
0
1
2
3
4
5
6
7
12:21 PM
12:28 PM
12:36 PM
12:43 PM
12:50 PM
12:57 PM
1:04 PM
Time

Appendix D
APR Canister Information from Manufacturer

3M FR-64 Cartridge

User Instructions

Use For

Respiratory protection from certain organic vapors, sulfur dioxide, chlorine, hydrogen chloride, chlorine dioxide, hydrogen fluoride, ammonia, methylamine, formaldehyde, hydrogen sulfide (escape only), phosphine, chloroaceteophenone (CN) or o-chlorobenzylidene malononitrile (CS) and P100 particulates when used with the 3M™ FR-M40 Full Facepiece, 3M™ 6000DIN Series Full Facepiece and 3M™ 7800S Full Facepiece Respirators in accordance with all use and limitation instructions and applicable safety and health regulations. The respirator may be used at concentrations up to 50 times the PEL or airborne exposure limit if quantitative fit testing (QNFT) is utilized. The respirator may be used at concentrations up to 10 times the PEL or airborne exposure limit if qualitative fit testing (QLFT) is utilized. The respirator must be used at concentrations lower than the immediately dangerous to life or health (IDLH) limit.

3M Canister FR-15-CBRN

User Instructions

Table 1. Canister Test Challenge and Test Breakthrough Concentrations

	Test Concentration (ppm)	Breakthrough Concentration (ppm)
Ammonia	2500	12.5
Cyanogen Chloride	300	2
Cyclohexane	2600	10
Formaldehyde	500	1
Hydrogen Cyanide	940	4.7[1]
Hydrogen Sulfide	1000	5.0
Nitrogen Dioxide	200	1 ppm NO_2 or 25 ppm NO[2]
Phosgene	250	1.25
Phosphine	300	0.3
Sulfur Dioxide	1500	5

[1] Sum of HCN and C_2N_2.

SCOTT HEALTH & SAFETY

M120 CBRN FACEPIECE

M120 Canister Test Challenge and Test Breakthrough Concentrations*		
	Test Concentration (PPM)	Breakthrough Concentration (PPM)
Ammonia	2500	12.5
Cyanogen Chloride	300	2
Cyclohexane	2600	10
Formaldehyde	500	1
Hydrogen Cyanide	940	4.7(1)
Hydrogen Sulfide	1000	5.0
Nitrogen Dioxide	200	1 ppm NO_2 or 25 ppm NO(2)
Phosgene	250	1.25
Phosphine	300	0.3
Sulfur Dioxide	1500	5

(1) Sum of HNC and C_2N_2

(2) Nitrogen Dioxide breakthrough is monitored for both NO_2 and NO. The breakthrough is determined by which quantity, NO_2 or No, reaches breakthrough first.

* Time for breakthrough for CBRN APR negative pressure is a minimum of 15 minutes.

MSA

CBRN Ultra Elite® Gas Mask

Setting a New Standard for the Fire Service

Canister Test Challenge and Test Breakthrough Concentrations*

	Test Concentration (ppm)	NIOSH Allowable Breakthrough*
HD-Vapor	50 mg/m^3	3 mg/m^3
GB	210 mg/m^3	1.05 mg/m^3
Ammonia	2500	12.5 ppm
Cyanogen chloride	300	2 ppm
Cyclohexane	2600	10 ppm
Formaldehyde	500	1 ppm
Hydrogen cyanide	940	4-7 ppm[1]
Hydrogen sulfide	1000	5 ppm
Nitrogen dioxide	200	1 ppm NO[2] or 25 ppm NO[2]
Phosgene	250	1.25 ppm
Phosphine	300	0.3 ppm
Sulfur dioxide	1500	5 ppm

1. Sum of HCN and CaN2.
2. Nitrogen Dioxide breakthrough is monitored for both NO2 and NO. The breakthrough is determined by which quantity, NO2 or NO, reaches breakthrough first.

* Table 3 from "Statement of Standard for Chemical, Biological, Radiological and Nuclear (CBRN) Full Facepiece Air Purifying Respirator (APR)," revision 1; March 17, 2003.

Appendix E: Paper from Method Development Study