Determination of Unfiltered In-Leakage by ATD and AIMS E 741 Techniques

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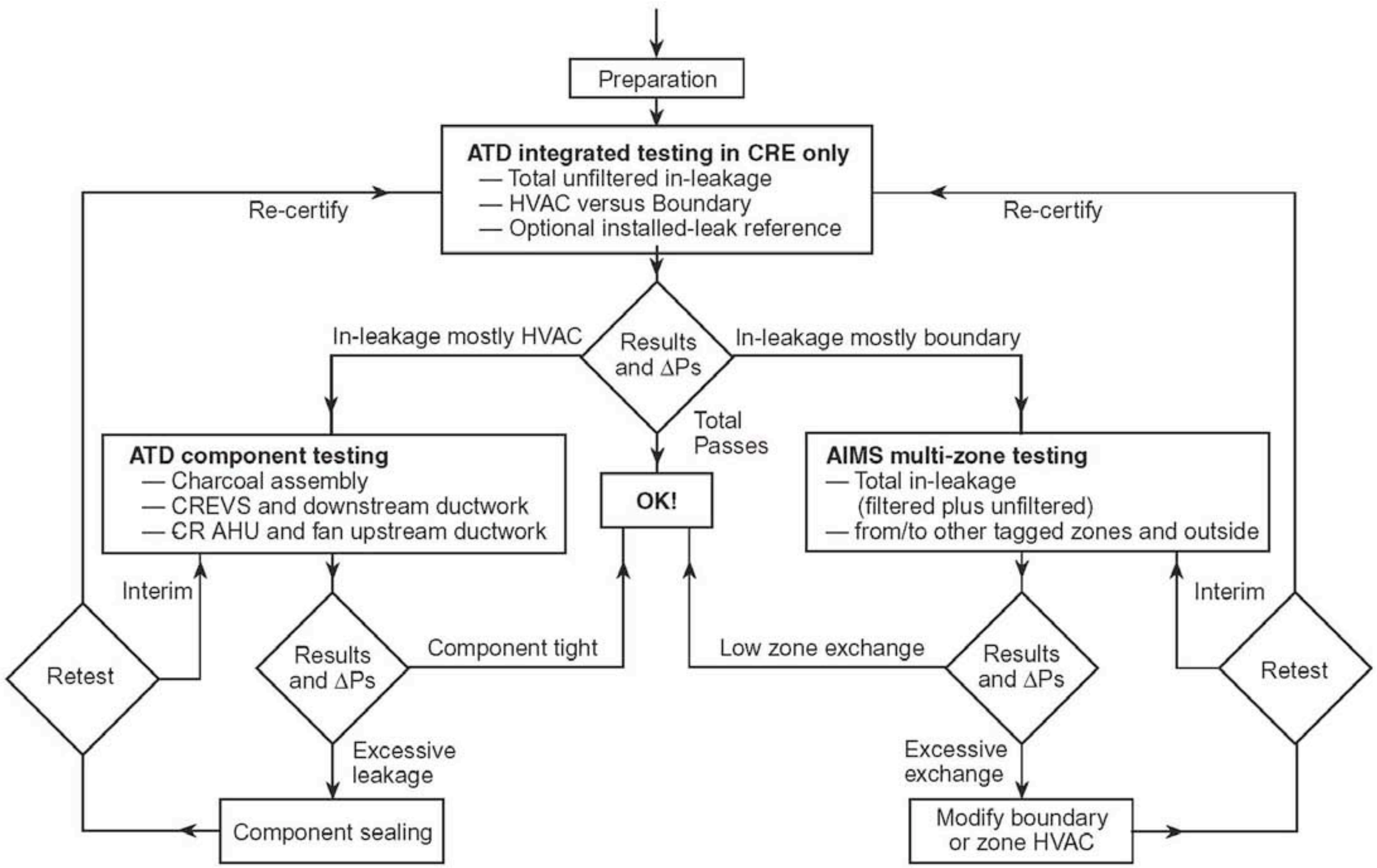
Control Room In-Leakage by ATD and AIMS Techniques

Outline

1. Suggested industry approach
2. Brief look at the 4 tracer techniques
   - Applicability of E 741 to all 4
3. AIMS (Air Infiltration Measurement System)
   - Calvert Cliff results and uncertainties
4. New ATD (Atmospheric Tracer Depletion)
   - Mathematics of the direct measurement of unfiltered in-leakage
   - Results of laboratory tests
   - Expected uncertainties
5. Current status
   - Audit by Dominion Energy of QAP (8/4 –8/03)
   - Testing at 3 Dominion stations and Pilgrim Nuclear
6. Special issues regarding contracting to a National Laboratory

Suggested Industry Approach Using ATD and AIMS



Applicability of ASTM E 741 to Four Techniques for Measuring Unfiltered In-Leakage

Major elements in E 741: 18

- Specifically applicable: 14[a]

Total specific sub-elements: 108

Technique	SF_6 Decay	SF_6 Inject	AIMS	ATD
Conforms to specific sub-elements:	81	83	84	66
(percentage of subtotal)	(89%)	(89%)	(91%)	(92%)
- does not conform	9	9	8	5
- uncertain (element 3.1.7.1)[b]	1	1	--	1
Subtotal:	91	93	92	72[c]
Not applicable:	17	15	16	36
Direct unfiltered in-leakage:	No	No	No	Yes
Individual components testable:				
- easily	No	No	No	Yes
- with special tagging	No	Yes	Yes	na
- defined in E 741	No	No	No	No

[a] Others are general to all 4 techniques or to none

[b] Adequately handles single and multi-zone CREs within multi-zone facilities

[c] Lower number of sub elements due to no need for tracer injection.

APPENDIXES

(Nonmandatory Information)

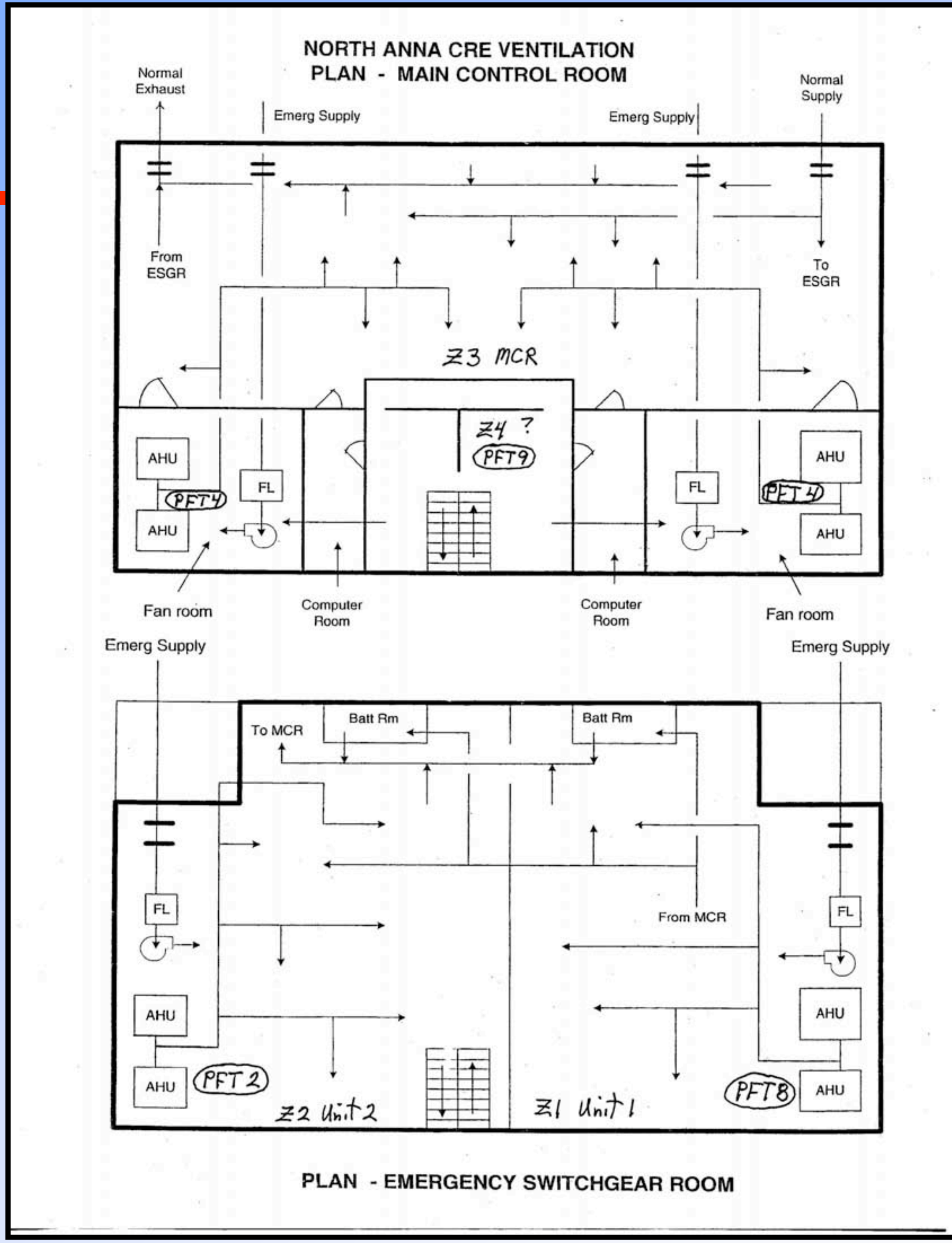
X1. TRACER GASES USED TO DETERMINE AIR CHANGE

X1.1 Tables X1.1 and X1.2 list tracer gases that are used to determine air change. They include only those gases that have an established personal exposure limit (PEL, see Section 7). Table X1.1 describes the safety properties of gases. Table X1,2 highlights the concentration analysis of gases.

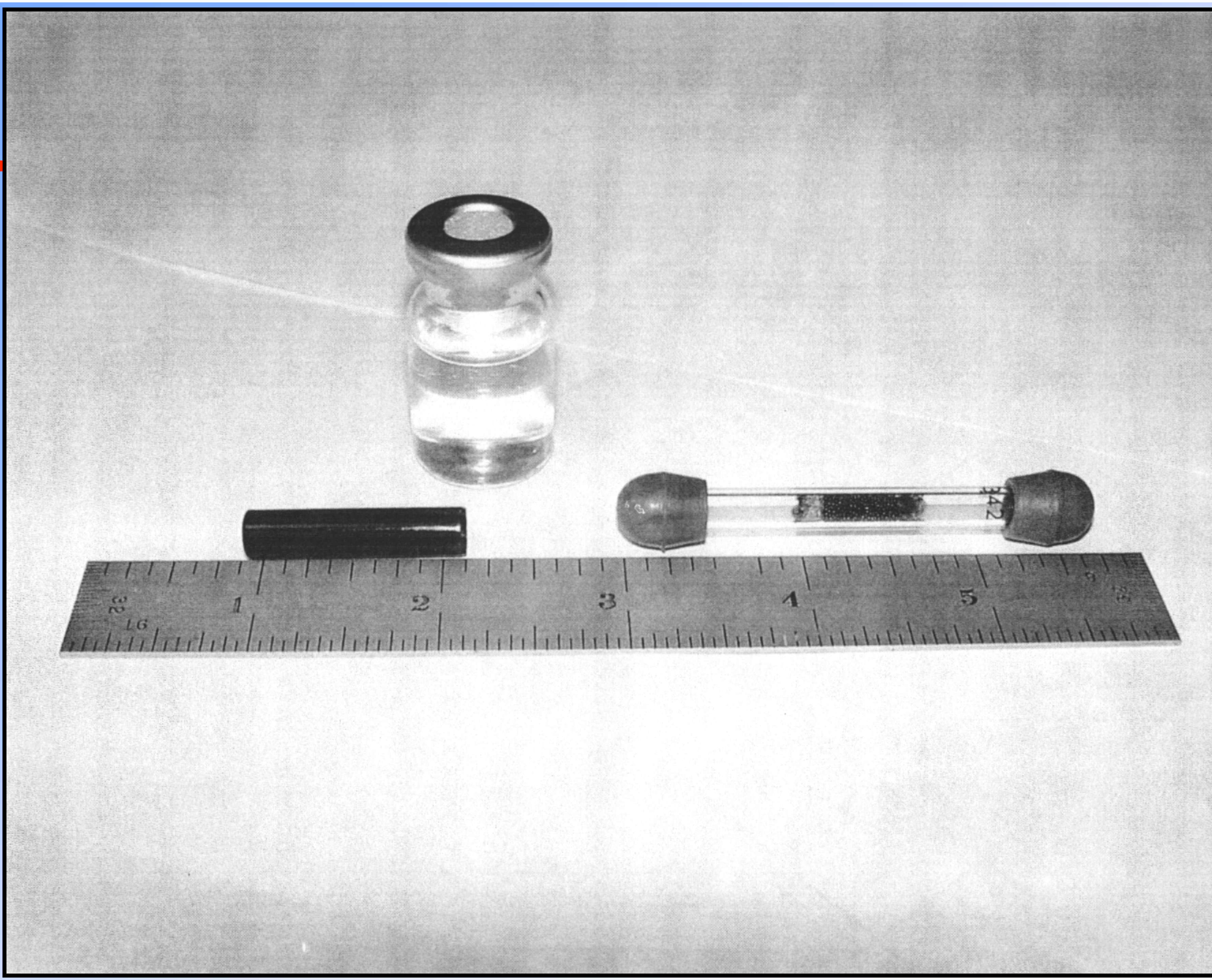
TABLE X1.1 Tracer Gases and Safety Issues

Tracer Gas	PEL	Toxicology	Chemical Reactivity	Comments
Hydrogen	Asphyxiant	Non-toxic	Highly reactive in presence of heat, flame, or O_2	Fire and explosion hazard when exposed to heat, flame, or O_2
Helium	Asphyxiant	Non-toxic	Inert	
Carbon Monoxide	50 ppm	Combines with hemoglobin to cause anoxia	Highly reactive with O_2	Fire and explosion hazard when exposed to heat or flame
Carbon Dioxide	5000 ppm	Can be eye irritant	Reacts vigorously with some metals; soluble in water	
Sulfur Hexafluoride	1000 ppm	Non-toxic	Inert	Thermal decomposition yields highly toxic compounds
Perfluorocarbon tracers (PFTs)[1]	Asphyxiant	Non-toxic	Inert	Thermal decomposition may produce toxic compounds
Nitrous Oxide	25 ppm	Moderately toxic by inhalation	Violent reaction with aluminum; water soluble	Can form explosive mixture with air; ignites at high temperature
Ethane	Asphyxiant	Non-toxic	Flammable	Incompatible with chlorine and oxidizing materials
Methane	Asphyxiant	Non-toxic	Flammable	Incompatible with halogens and oxidizing materials
Octafluorocyclobutane (Halocarbon C-318)	1000 ppm	Low toxicity	Nonflammable	Thermal decomposition yields highly toxic compounds
Bromotrifluoromethane (Halocarbon 13B1)	500 ppm	Moderately toxic by inhalation	Incompatible with aluminum	Dangerous in a fire
Dichlorodifluoromethane (Halocarbon 12)	1000 ppm	Central nervous system and eye irritant; can be narcotic at high levels	Nonflammable; can react violently with aluminum	Thermal decomposition yields highly toxic fumes
Dichlorotetrafluoromethane (Halocarbon 116)	1000 ppm	Can be asphyxiant, mildly irritating, narcotic at high levels	Can react violently with aluminum	Thermal decomposition yields highly toxic fumes

[1] There are a family of 9 PFTs available for multi-zone testing.



NORTH ANNA CRE VENTILATION
PLAN - MAIN CONTROL ROOM
Normal Exhaust
Emerg Supply
Emerg Supply
Normal Supply
From ESGR
To ESGR
Z3 MCR
Z4 ?
PFT9
AHU
AHU
PFT4
FL
FL
PFT4
AHU
AHU
Fan room
Computer Room
Computer Room
Fan room
Emerg Supply
Emerg Supply
To MCR
Batt Rm
Batt Rm
From MCR
FL
FL
AHU
AHU
PFT2
AHU
AHU
PFT8
Z2 Unit 2
Z1 Unit 1
PLAN - EMERGENCY SWITCHGEAR ROOM


342
16
1
2
3
4
5

PFT Testing at Calvert Cliffs

Benchmark Results

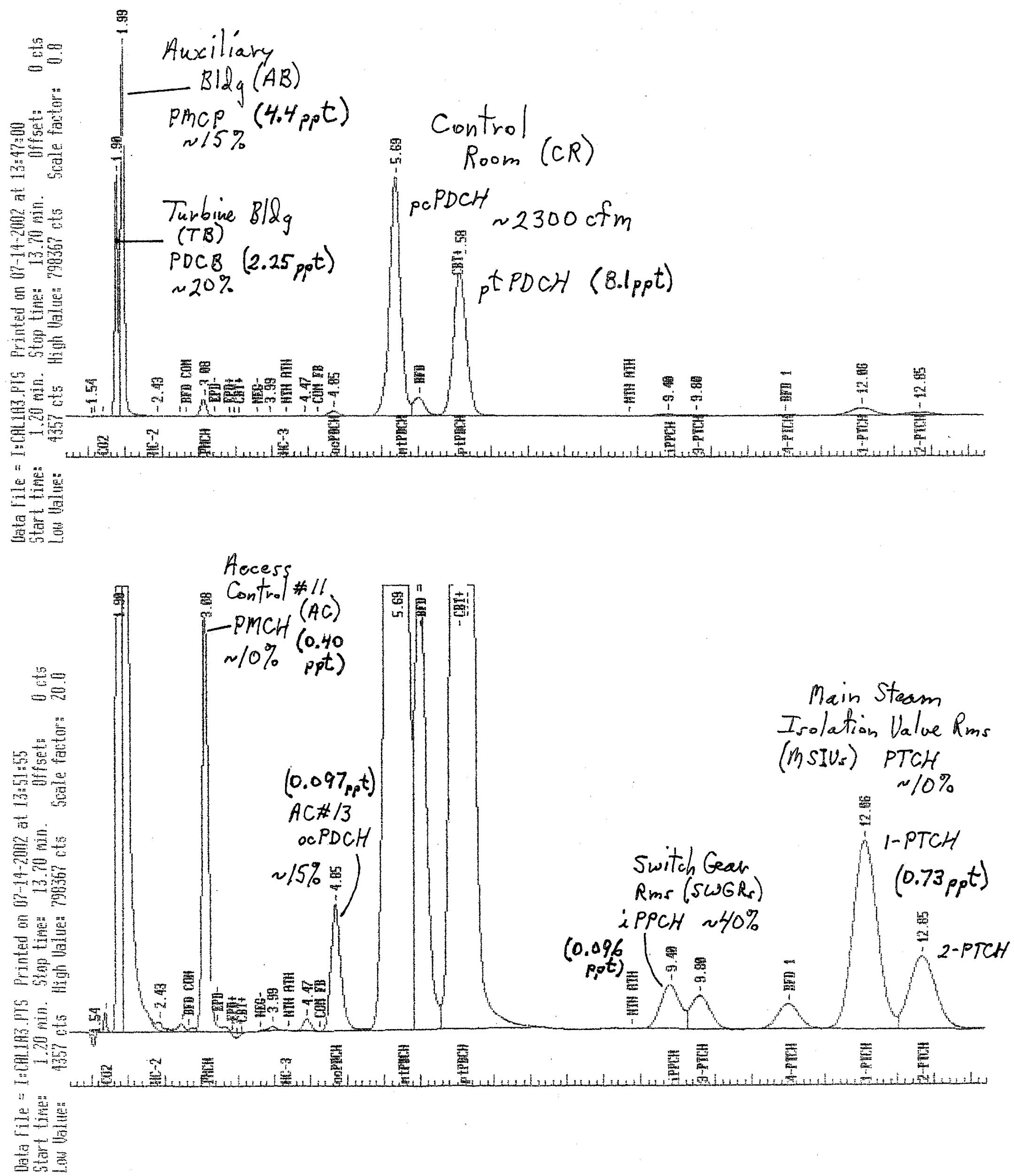
SF6 Test Data (Jan 2000)

- 11 Train – 3000 CFM +/- 250 CFM
- 12 Train – 2600 CFM +/- 200 CFM

PFT Test Data (June 2002)

- 11 Train – 2930 CFM +/- 185 CFM

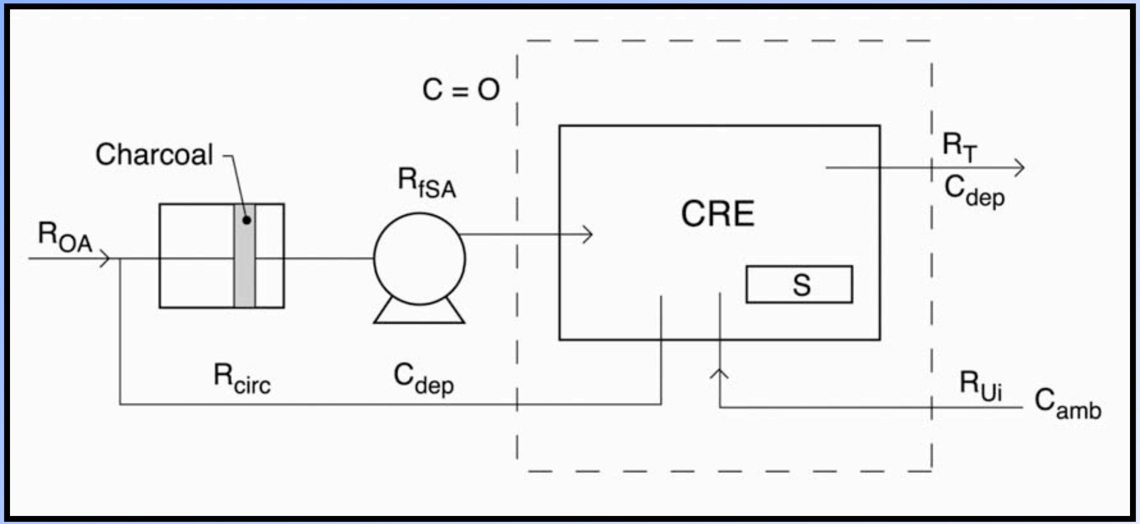
MULTI-TRACER CONTROL ROOM AIR INLEAKAGE



Calvert Cliffs Total Inleakage was 2930 ± 185 cfm. Other flows, in cfm, were:

Zone	From/To	CR Inleakage	% of total	CR Outleakage	% of total
0	Outside	275 ± 185	9	1966 ± 470	64
2	AB	436 ± 157	15	366 ± 248	13
3	TB	466 ± 172	16	599 ± 415	20
4	MSIVs	272 ± 134	9	44 ± 33	2
5	AC11	274 ± 33	9	19 ± 3	1
6	AC13	387 ± 38	13	11 ± 8	0
7	SWGRs	818 ± 114	28	21 ± 10	1

Comparison of E 741 ATD and Injection Mathematics



Material balance around CRE:

E 741 ATD:

$R_{FSA} + R_{ui} = R_T + R_{circ}$

$C = 0 \quad C_{amb} \quad C_{dep} \quad C_{dep}$

$S_{in} = S_{out} = R \times C$

$R_{ui}\, C_{amb} = C_{dep}\,(R_T + R_{circ})$

$= C_{dep}\,(R_{fSA} + R_{Ui})$

$R_{ui}\,(C_{amb} - C_{dep}) = R_{fSA}\, C_{dep}$

$R_{ui} = R_{fSA}\, C_{dep}/(C_{amb} - C_{dep})$

$= R_{fSA}/(C_{amb}/C_{dep} - 1)$

E 741 injection:

(after charcoal saturated with SF_6)

$R_{OA} + R_{ui} = R_T$

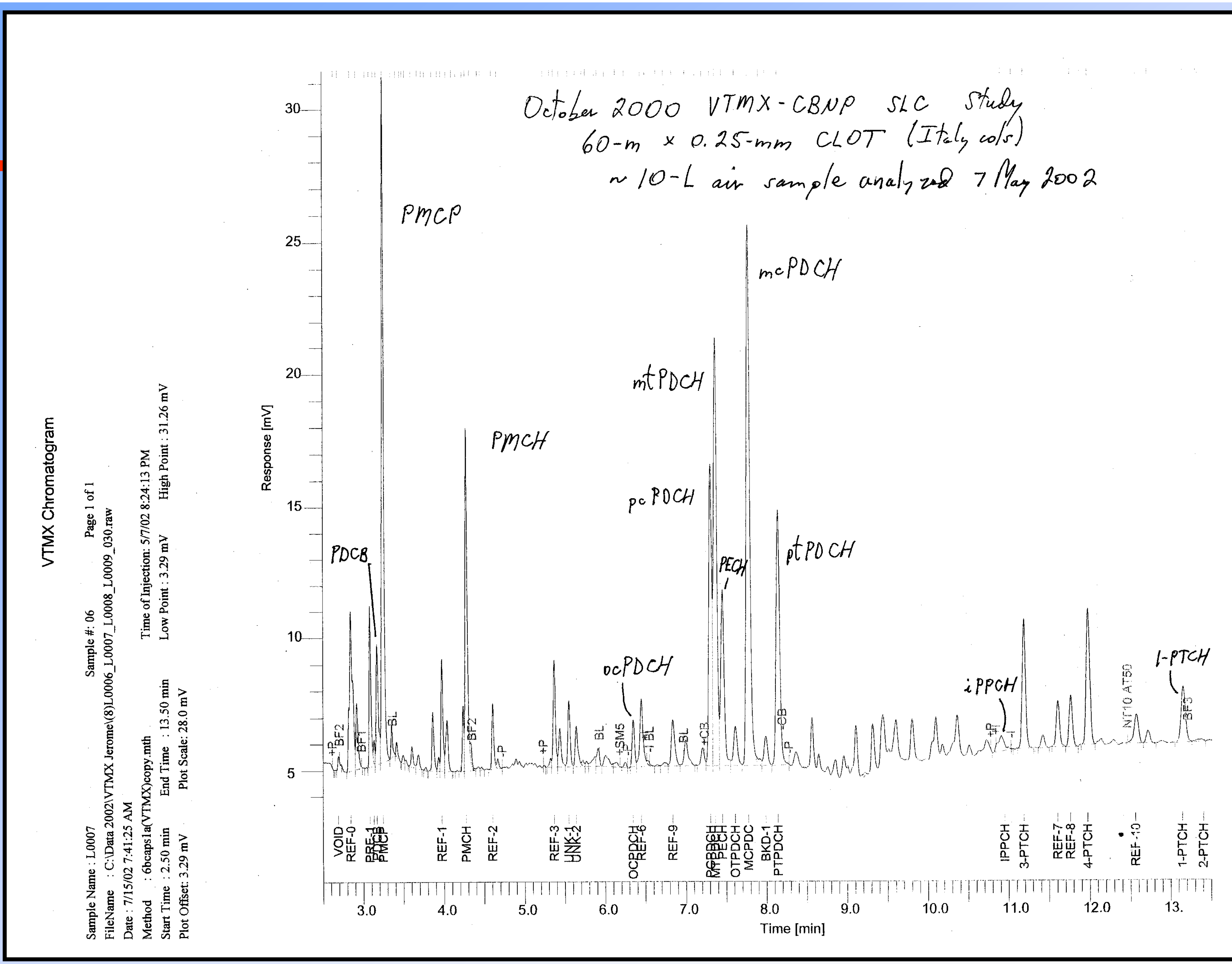
$C = 0 \quad C.0 \; C_S$

$S_{in} = S_{out} = R \times C$

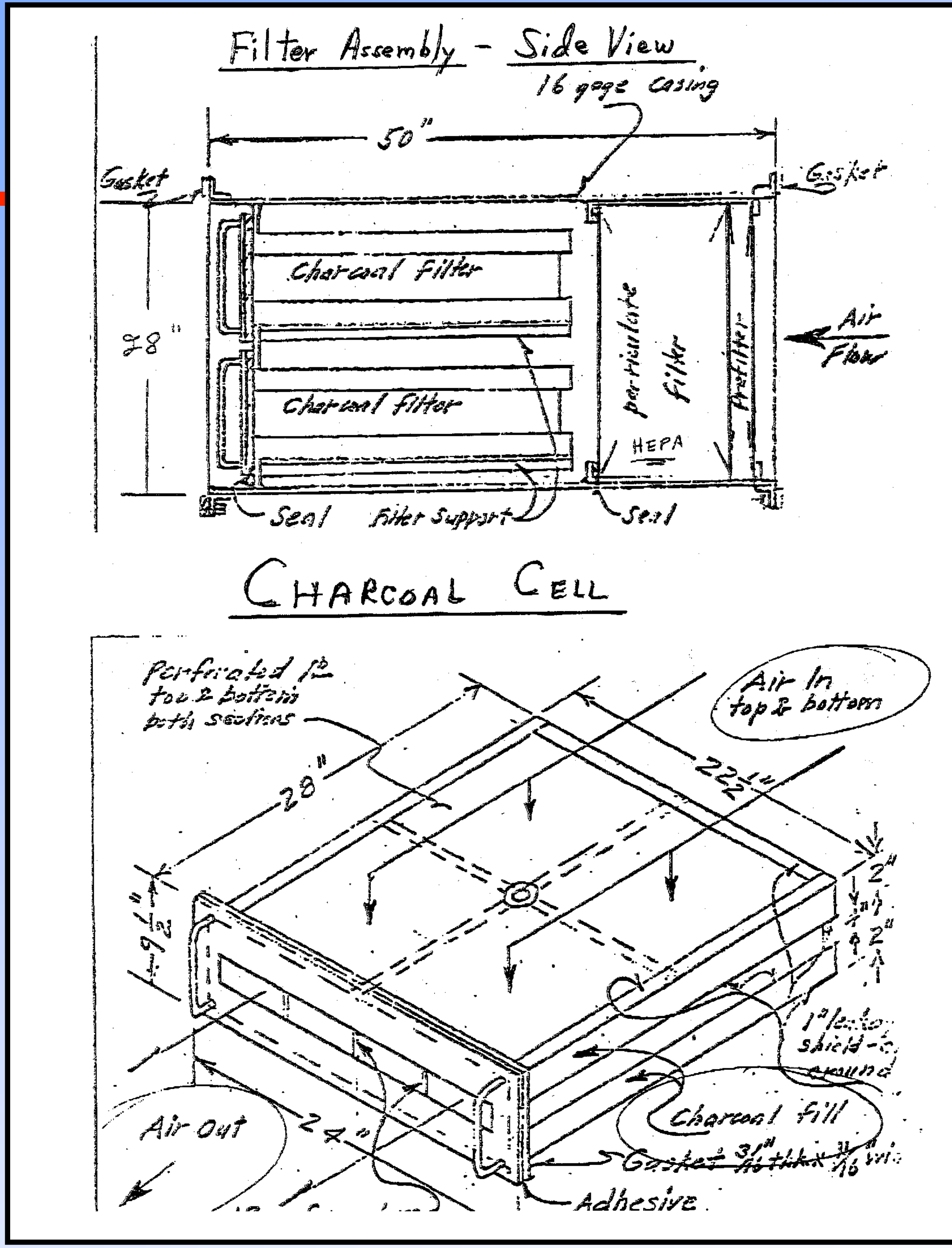
$S = R_T\, C_S$

$R_T = S/C_S$

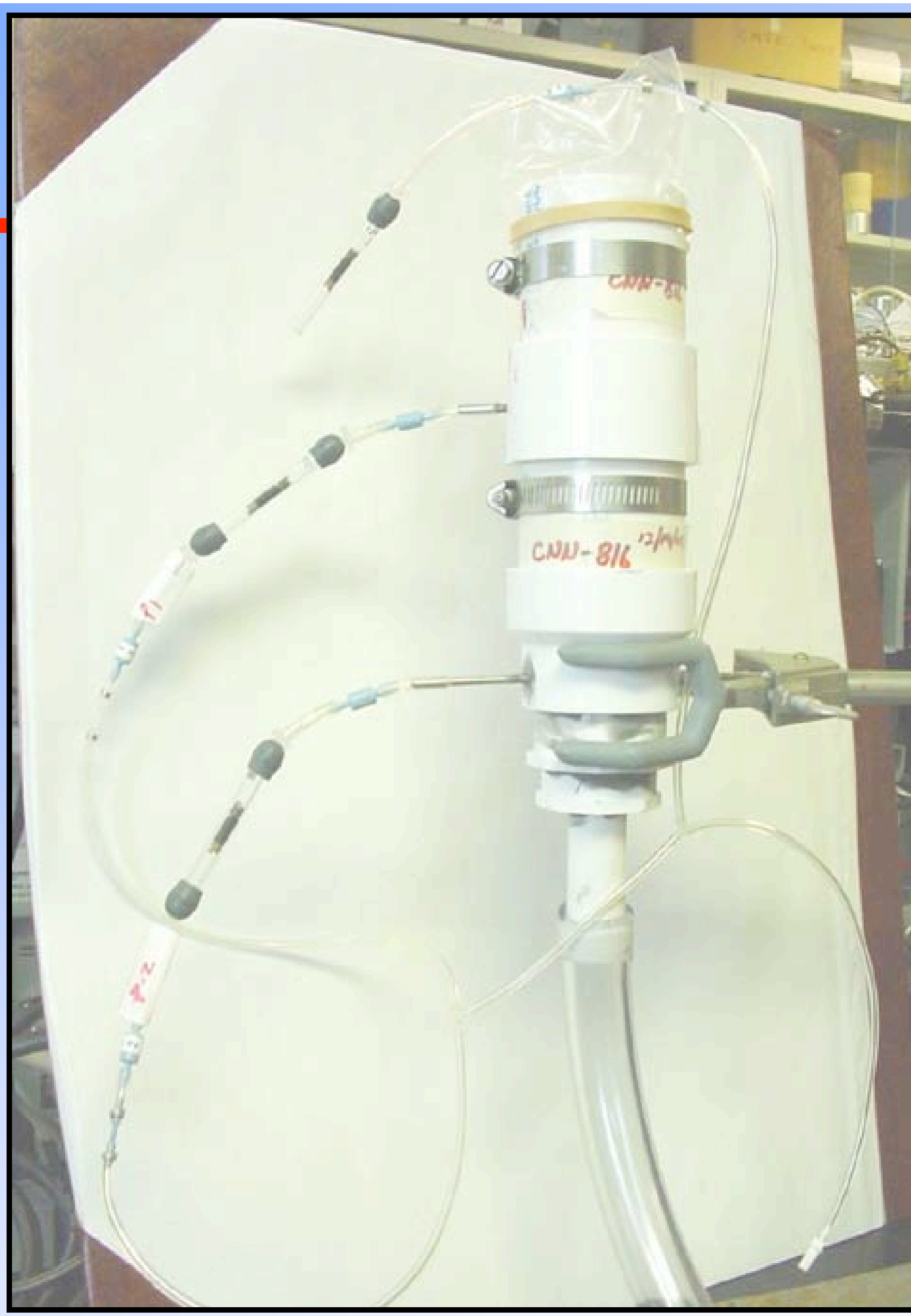
$R_{ui} = S/C_S - R_{OA}$

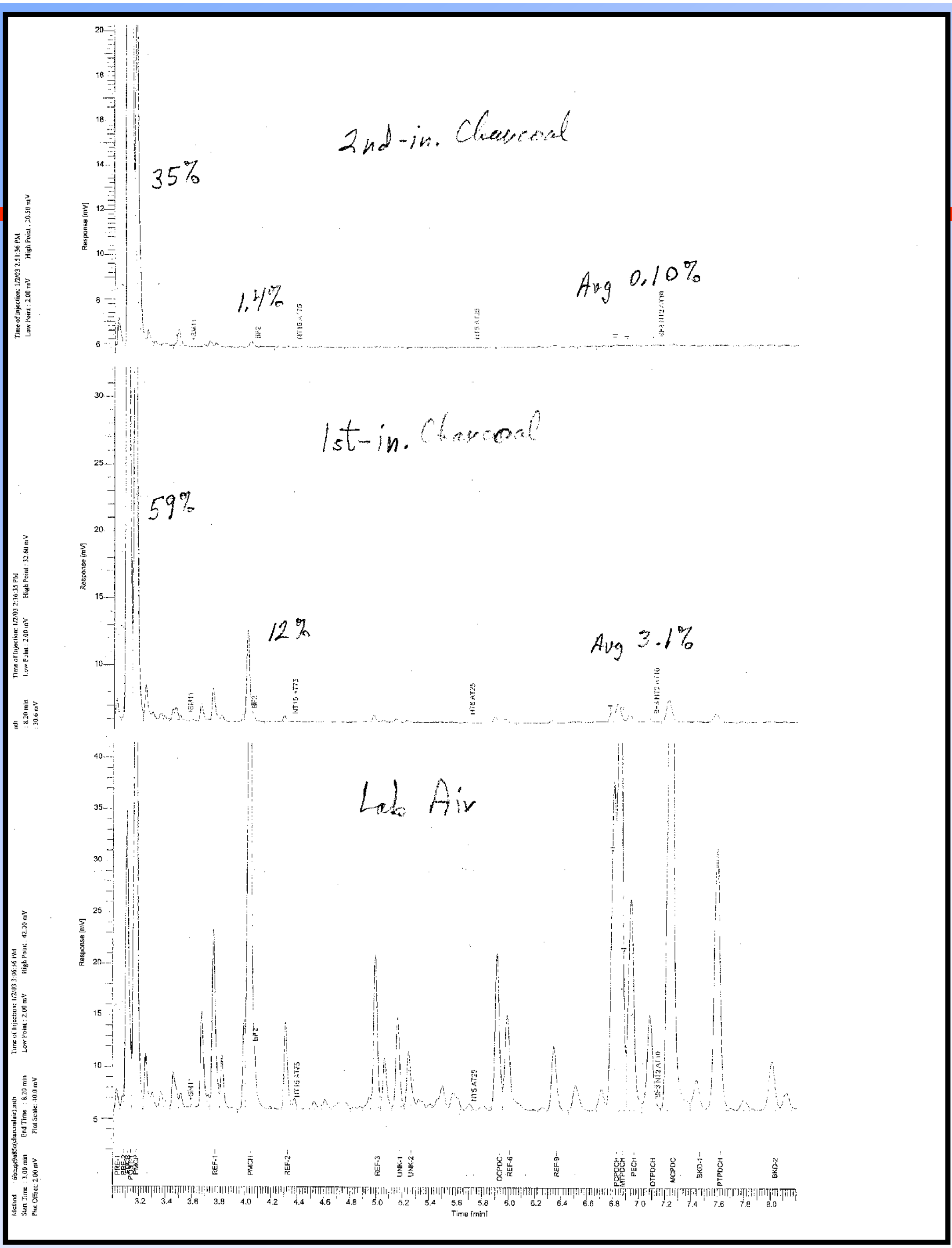


VTMX Chromatogram
Sample Name : L0007
Sample #: 06
Page 1 of 1
FileName : C:\Data 2002\VTMX Jerome\(8)L0006_L0007_L0008_L0009_030.raw
Date : 7/15/02 7:41:25 AM
Method : 6bcaps1a(VTMX)copy.mth
Time of Injection: 5/7/02 8:24:13 PM
Start Time : 2.50 min
End Time : 13.50 min
Low Point : 3.29 mV
High Point : 31.26 mV
Plot Offset: 3.29 mV
Plot Scale: 28.0 mV
October 2000 VTMX-CBNP SLC Study
60-m × 0.25-mm CLOT (Italy cols)
~10-L air sample analyzed 7 May 2002
Response [mV]
Time [min]
PMCP
PMCH
PDCB
mcPDCH
mtPDCH
pcPDCH
PECH
ptPDCH
ocPDCH
iPPCH
1-PTCH
VOID
REF-0
PMCP
REF-1
PMCH
REF-2
REF-3
UNK-1
UNK-2
REF-6
REF-9
OTPDCH
MCPDC
BKD-1
PTPDCH
IPPCH
3-PTCH
REF-7
REF-8
4-PTCH
REF-10
1-PTCH
2-PTCH



Filter Assembly - Side View
16 gage casing
50"
Gasket
Gasket
Charcoal Filter
Charcoal filter
28"
particulate filter
HEPA
Prefilter
Air Flow
Seal
Filter Support
Seal
CHARCOAL CELL
Air In top & bottom
28"
22 1/2"
9 1/2"
2"
2"
Air Out
24"
Charcoal fill
Adhesive


CNN-816



2nd-in. Charcoal
35%
1.4%
Avg 0.10%
1st-in. Charcoal
59%
12%
Avg 3.1%
Lab Air
Response [mV]
Time [min]

Example Precision of Atmospheric PFT Background Measurements

(taken from October 2000 Salt Lake City – SLC -- tests)

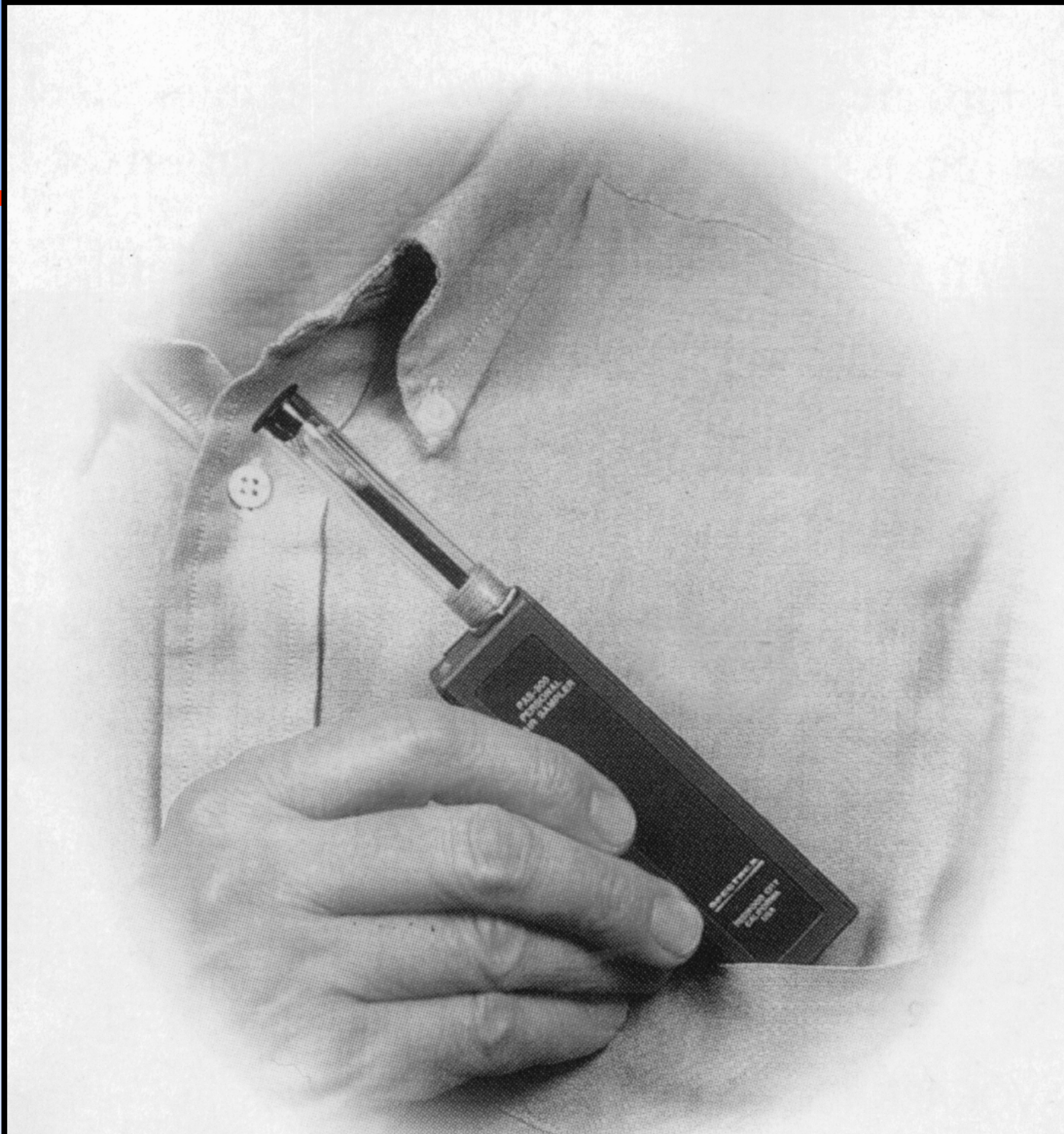
a. ATD control room envelope sample volumes will be ~18 to 50 L

-- depleted concentrations to be measured down to 1 to 3% remaining

b. SLC sample volumes were ~0.5 L (~3% of CRE sample vol.)

-- area ratios used to normalize for variable sample volumes between 480 sampling pumps

Expected ATD Precision (SLC PFT Peak Area Ratios)			
	pc/pt	mt/pt	mc/pt
Area ratio:	0.918	1.524	2.142
Uncertainty:	±0.041	±0.050	±0.104
Ref. Std. Dev:	±4.5%	±3.3%	±4.9%
No. of samples:	1424	783	1086



PAS-500 Micro Air Sampler

Atmospheric PFT Background Measurements at Four Nuclear Stations (March 2003)[a]

Station	Room	Area Ratio to ptPDCH		
		pc/mt	PECH	mc
North Anna	SWGR (U2 RA)	2.500	0.766	2.199
North Anna	MCR (U1 RA)	2.439	0.768	2.151
Surrey	SWGR (U2 RA)	2.474	0.819	2.186
Surrey	MCR (U2 RA)	2.447	0.805	2.153
Point Beach	Comp. Room	2.485	0.779	2.207
Point Beach	MCR	2.419	0.758	2.131
Kewaunee	MCR	2.488	0.784	2.190
Kewaunee	Equip. Room	2.496	0.799	2.237
	Average	2.468	0.785	2.181
	Rel. Std. Dev.	± 1.2%	± 2.7%	± 1.6%
	n = 8			
Salt Lake City[b]	Average	2.442	-	2.142
	Rel. Std. Dev.	± 3.9%	-	± 4.9%
	n	~800	-	1086

[a] Control room samples were between 15 to 25 L of air.

[b] Salt Lake City samples were about 0.5 L of air.

Fractional Penetration* of Ambient Air PFTs Through NCS Corp. Charcoal

-- Testing at 23°C and 1.91 cfm through 2.07-in diameter test cell – (equivalent to 24.7 m/min or 120% of maximum typical plant use)

Time from Flow start	Duration Test	Test Port	0.49 atm** PDCB	0.44 PMCP	0.142 PMCH	0.047 atm pc/mt	PECH	mc	pt
2.2 h	1.8 h	Meas. 1– in.	6.5	0.362	0.0646	0.0178	0.0147	0.0165	0.0115
		Calc. 2– in.	--	0.131	0.0042	0.0003	0.0002	0.0003	0.0001
		Meas. 2– in.	15.7	0.086	0.0130	0.0036	0.0065	0.0037	0.0078
5.3 h	4.3 h	Meas. 1– in.	1.9	0.385	0.0653	0.0159	0.0151	0.0153	0.0157
		Calc. 2– in.	--	0.148	0.0043	0.0003	0.0002	0.0002	0.0002
		Meas. 2– in.	3.7	0.071	0.0029	0.0006	0.0001	0.0004	0.0010
20 h	3.5 h	Meas. 1– in.	4.9	0.524	0.0736	0.0289	0.0290	0.0268	0.0271
		Calc. 2– in.	--	0.275	0.0054	0.0008	0.0008	0.0007	0.0007
		Meas. 2– in.	11.4	0.161	0.0056	0.0041	0.0019	0.0038	0.0004
48 h***	4.2 h	Meas. 1– in.	3.1	0.716	0.118	0.0329	0.0299	0.0312	0.0304
		Calc. 2– in.	--	0.512	0.0138	0.0011	0.0009	0.0010	0.0009
		Meas. 2– in.	8.0	0.349	0.0067	0.0014	0.0019	0.0010	0.0016
72 h***	4.1 h	Meas. 1– in.	3.5	0.838	0.127	0.0339	0.0318	0.0322	0.0268
		Calc. 2– in.	--	0.702	0.0160	0.0011	0.0010	0.0010	0.0007
		Meas. 2– in.	9.3	0.641	0.0094	0.0040	0.0052	0.0007	0.0042

* Dual 1-in test cells and procedures were according to ASTM D 3803-91 (Standard Test Method for Nuclear-Grade Activated Carbon).

** Vapor pressure at 25°C of each PFT, atm

*** **Over 48 to 72 h, calculated penetration for 4 low vapor pressure PFTs averaged 0.097 ± 0.051%.**

Fractional Penetration* of Ambient Air PFTs Through NCS Corp. Charcoal

-- Testing at 23°C and 9.6 m/min (~47% of typical cell face velocity)

-- Charcoal use: 7.4 days in end December 2002 and 1.4 days for this end-May 2003 testing

			B.P. ~46° C**		76° C	102° C			
Test	Duration	Test Port	PDCB	PMCP	PMCH	pc/mt	PECH	mc	pt
1	7.0 h	Meas. 1-in.	3.0	0.56	0.091	0.0224	0.0220	0.0212	0.0188
		Calc. 2-in.	--	0.31	0.008	0.0005	0.0005	0.0005	0.0004
		Meas. 2-in.	4.2	0.26	0.004	0.0011	0.0010	0.0012	0.0014
2	8.2 h	Meas. 1-in.	2.3	0.52	0.092	0.0241	0.0239	0.0234	0.0213
		Calc. 2-in.	--	0.27	0.009	0.0006	0.0006	0.0006	0.0004
		Meas. 2-in.	3.4	0.26	0.004	0.0008	0.0015	0.0008	0.0009
3	7.0 h	Meas. 1-in.	2.0	0.51	0.106	0.0271	0.0249	0.0257	0.0232
		Calc. 2-in.	--	0.33	0.011	0.0007	0.0006	0.0007	0.0005
		Meas. 2-in.	2.9	0.29	0.005	0.0008	0.0009	0.0009	0.0012
4	4.7 h	Meas. 1-in.	1.8	0.52	0.103	0.0270	0.0281	0.0248	0.0227
		Calc. 2-in.	--	0.27	0.011	0.0007	0.0008	0.0006	0.0005
		Meas. 1-in.	2.6	0.27	0.004	0.0004	0.0006	0.0002	0.0005

* Dual 1-in test cells and procedures were according to ASTM D 3803-91 (Standard Test Method for Nuclear-Grade Activated Carbon).

** Boiling points of 300-, 350-, and 400-molecular weight PFTs, respectively

*** **Over all 4 tests, calculated penetration of 4 high-boiler PFTs averaged 0.057 ± 0.012%**

ATD Determination of Intentional Unfiltered In-Leakage in Charcoal Cell Test Apparatus

Tested at 23° C and 9.6 m/min (~47% of typical cell face velocity)

Test	R_{fSA}, L/min	Rate of Unfiltered In-Leakage (R_{ui}), L/min						Intentional Leak, L/min
		pc	PECH	mc	pt	Avg ± SD	net	
1	22.6	0.69	0.22	0.83	0.27	0.50 ± 0.30	---	None
2	22.3	1.19	1.06	1.84	1.25	1.33 ± 0.35	0.83 ± 0.46	0.75 ± 0.02
3	19.7	4.17	4.07	4.84	4.34	4.35 ± 0.34	3.85 ± 0.45	3.72 ± 0.03
4	21.7	1.79	1.70	2.18	1.82	1.87 ± 0.21	1.37 ± 0.37	1.45 ± 0.02

Proportioned to Full-Scale Rates, cfm

Test	Filtered SA	Unfiltered In-Leakage	
		Net Meas.	Set
1	2260 ± 23	--	None
2	2230 ± 22	83 ± 46	75 ± 2
3	1970 ± 20	385 ± 45	372 ± 3
4	2170 ± 22	137 ± 37	145 ± 2

Minimal Uncertainty Elements for ATD Measurements

Relevant uncertainty elements:

		Typical Uncertainty
1.	Volume of air sampled	±3%
	… pumping rate times time	
2.	Reproducibility of identical samples	±5%
	… desorption and GC analysis	
3.	Linearity of GC response	±2%
	… from 50-L sample down to LOD	
4.	GC limit of detection (LOD)	±1% ±50 counts
		±6% ± 50 counts

CR Unfiltered In-Leakage Rate by ATD

Rate (R_{UI}) and Uncertainty (ΔR_{UI})

$$R_{UI} = R_{fSA} F_{dep}/(1-F_{dep})$$

Where R_{fSA} = the total filtered supply air rate (cfm)

F_{dep} = fraction of original PFT after depletion (PFT signal after/PFT signal before depletion)

Examples:

	1	2	3
R_{fSA} (cfm)*	1200 ± 70	2000 ± 140	4700 ± 330
F_{dep}	0.140	0.0150	0.0101
R_{UI} (cfm)	195 ± 23 (12%)	30 ± 4 (14%)	48 ± 7 (15%)

* Separately determined by pitot traverses

Control Room In-Leakage by ATD and AIMS Techniques

<u>Current Status</u>

1. Audit by Dominion Energy of QAP
   - Week of 4 August 2003
   - New plan but built on BNL QAP
   - To meet the intent of 10 CFR 50 (Appendix B) and 10 CFR21
2. Proposed testing at Dominion Energy

- North Anna	AIMS	Sept/Oct
- Surry	AIMS/ATD	Nov/Dec
- Millstone	?	Jan/Feb

3. Testing at Pilgrim Nuclear (Nov. 14-16)
   - Two 8-h days of ATD with simultaneous SF_6
   - Third 8-h day of ATD, AIMS (1-zone), and SF_6
   - Potential benchmark of 3 techniques simultaneously

Special Issues Regarding Contracting to a National Laboratory

Requirement to Work for Others (WFO) than DOE:

DOE encourages their resources be made available; however:

1. The techniques and/or tools must be unique and not commercially available
   - Both ATD and AIMS are unique techniques to BNL
   - The Sampling and analysis capability are unique to BNL
2. As a result of direct contact with licensees:
   - We can attend pre-bid meetings/discussions
   - We can submit unsolicited proposals (direct contact requests)
     - … Before an RFP is issued
     - … Based on our unique capability
3. BNL, as a GOCO research facility, cannot respond to RFPs
   - We cannot compete with private industry
   - If no responders are selected, we can submit an unsolicited proposal
4. BNL will eventually license to vendors or subcontract the capability

Unfiltered In-Leakage Quantified by PFT Measurements

Overview

1. Importance of new ATD method:
   a. provides direct precise determination of unfiltered in-leakages
   … with minimal uncertainty
   b. no tracer release required, no ceiling tiles removed, no mixing fans (as-is testing preferred)
   c. negligible intrusion in CR using only pocket-sized samplers
   d. applicable to pressurized and neutrally-balanced CRE with charcoal-filtered emergency air
   e. can provide indication of in-leakage locations directly into CR by using many samplers throughout CR
   f. sampling at charcoal-filtered SA grill will separately quantify unfiltered in-leakage in that system

Unfiltered In-Leakage Quantified by PFT Measurements

Overview

1. Importance of new ATD method: (continued)

   g. Gives direct/average measure of estimated outside air-exposure concentrations at operator locations (eliminates concern for mixing, dead zones above ceiling tiles, etc.)

   h. Sampling along the emergency ventilation system quantifies negative-pressure component in-leakage pathways (components outside the CRE):

   … Filtration/fan system housing and downstream duct work locations

   … CR AHU system housing and its upstream duct work locations

   i. With 4 PFTs effectively depleted, gives replicate determinations for every sample

   j. Intentional or incidental prior exposure of the charcoal to a PFT will preclude the method for that PFT

   … Fresh, laboratory-tested charcoal would restore the method for that PFT

Unfiltered In-Leakage Quantified by PFT Measurements

Overview

2. The importance of BNL-AIMS method:

   a. quantify in-leakages from other tagged zones to facilitate mitigating strategies

   b. no mixing fans (actually not desired)

   c. negligible intrusion from miniature PFT sources and passive samplers

      … some testing will require using programmable BATS samplers

   d. tagging and sampling strongly dependent on emergency system operations

   e. better estimates of exposure dose at operator locations from other zonal PFT concentrations