Title

RADON AND REMEDIAL ACTION IN SPOKANE RIVER VALLEY HOMES. VOLUME 2: APPENDICES TO LBL-23430

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Radon and Remedial Action in Spokane River Valley Homes

Volume 2: Appendices to LBL-23430

Final Report

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B.A. Moed, and R.G. Sextro

December 1987

APPLIED SCIENCE DIVISION

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RADON AND REMEDIAL ACTION IN SPOKANE RIVER VALLEY HOMES

VOLUME 2: APPENDICES TO LBL-23430

FINAL REPORT

TO THE

BONNEVILLE POWER ADMINISTRATION

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with

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VOLUME 2 APPENDICES TABLE OF CONTENTS

INTRODUCTION AND OVERVIEW OF APPENDICES

This collection of appendices supports the text in Volume I, Lawrence Berkeley Laboratory Report No. 23430. Volume II contains detailed information that is not contained in Volume I, including the following: 1) a description of radon measurement techniques; 2) a comprehensive chronology of house operating conditions, mitigation systems configurations and corresponding radon concentrations; 3) a summary of indoor and outdoor formaldehyde, water vapor, and respirable suspended particle concentrations, and ventilation rates; 4) a floor plan for each house detailing sampling sites and mitigation system installations; and 5) diagnostic maps of radon grab sampling. A brief summary of the study is provided below, followed by a description of each of the appendices and succeeded by the individual appendices.

Indoor air quality surveys conducted in the Spokane River Valley/Rathdrum Prairie Region of eastern Washington and northern Idaho identified a significant number of houses with indoor radon concentrations above the Bonneville Power Administration (BPA) and Environmental Protection Agency (EPA) guidelines. A detailed study was conducted to develop and evaluate radon mitigation techniques and strategies.

Fourteen houses in the Spokane, Washington region and one house in Vancouver, Washington were selected to participate in the study. The fourteen homes were typical of the housing stock in the region and spanned a wide range of age, size, substructure type and energy conserving construction. Two of the homes served as Controls during the term of the study and were subsequently mitigated at the termination of the project.

The primary objectives of the study were:

1) To examine the efficacy of selected, previously utilized radon control techniques in various configurations.

2) To develop, test, and evaluate innovative radon control techniques and strategies.

3) To gain additional understanding of radon entry mechanisms and the subsequent effect of control techniques, and combination of techniques, on these mechanisms.

4) To collect data on detailed installation and operation costs for the various control techniques, and

5) To achieve effective, long-term reduction of indoor radon concentrations in each of the study houses such that the average heating season concentrations are below 5 pCi/l.

Pressure-driven flow of soil gas containing moderate concentrations of radon (283-673 pCi/L) was found to be the primary source of indoor radon. Highly permeable (10^{-10} to 10^{-13} m^2) soils in the Spokane River Valley and Rathdrum Prairie areas provided the necessary condition for relatively large volumes of radon-laden soil gas to enter the homes through below grade substructure holes and cracks.

Several promising techniques for reducing excess radon concentrations in houses were identified. These include basement overpressurization, subsurface ventilation (SSV) by depressurization (SSD) and overpressurization (SSP), and crawlspace ventilation. All techniques, properly applied, reduced radon levels in these homes below the BPA guideline for radon concentrations.

Subsurface ventilation (SSV) was evaluated in both the depressurization and pressurization modes. Subsurface depressurization (SSD) consisted of drawing air from beneath the substructure via a pipe (or pipes) installed either through the basement slab floor or under the foundation footing. Substructure pressurization (SSP) systems were identical to SSD systems except that outside air was forced beneath the basement slab floor or foundation footings. Many of the SSV systems were operated in both the SSD and SSP modes. In all cases, the SSP configuration provided the greatest reduction in indoor radon concentrations.

Ventilation of crawlspaces was very effective in reducing the radon concentration in the crawlspaces. Only partial reductions in radon levels in the living areas of the homes were achieved due to the presence of adjoining basements in these homes.

Air-to-air heat exchangers (AAHX) were installed in two homes having low to moderate radon concentrations. We found that the radon levels in these houses varied in proportion to the reciprocal of the ventilation rate as expected from mass balance considerations. Substantial radon reductions were achieved after the configuration of the supply and return ducts were modified in a third home with an existing AAHX.

Sealing of substructure cracks and holes below grade was generally ineffective in reducing radon entry in these homes. Full or partial interior finishing of the basements limited or prevented access to many areas and surfaces.

Mitigation system selection for each home was based on experimental diagnostic techniques. These techniques were used to identify major radon entry points. Researchers were then able to produce a radon "map" for each house and subsequently select and design an appropriate radon mitigation system.

After systems were installed and their performance monitored they were modified or "tuned" in successive stages to optimize their performance. Each mitigation system in its final configuration successfully reduced radon concentrations to below the BPA guidelines in all study homes with the exception of one, which dropped out of the project prematurely.

A brief description of each appendix is provided below:

(1) Appendix A describes the continuous radon monitoring instrument and includes a schematic drawing.

(2) Appendix B describes the technique used to measure radon concentrations in soil gas taken from soil probes installed near each of the study structures. A table is provided to allow comparison of radon concentrations over time and between various probes and houses.

(3) A chronology detailing the operating condition of each house during each stage of mitigation is described in Appendix C. The mitigation system operating specifications and corresponding radon concentration for each stage are listed. Radon concentrations are plotted against time so that the effects of each configuration can be easily visualized.

(4) Appendix D contains elevation and plan views of each structure. The mitigation system(s), sampling locations, soil gas sampling probe locations and other significant features are detailed.

(5) Indoor/outdoor pollutant concentrations and PFT ventilation measurements are summarized in Appendix E. The results of the pollutant, ventilation and blower door leakage measurements are presented for each test period. The test periods correspond to different house conditions and/or mitigation system configurations.

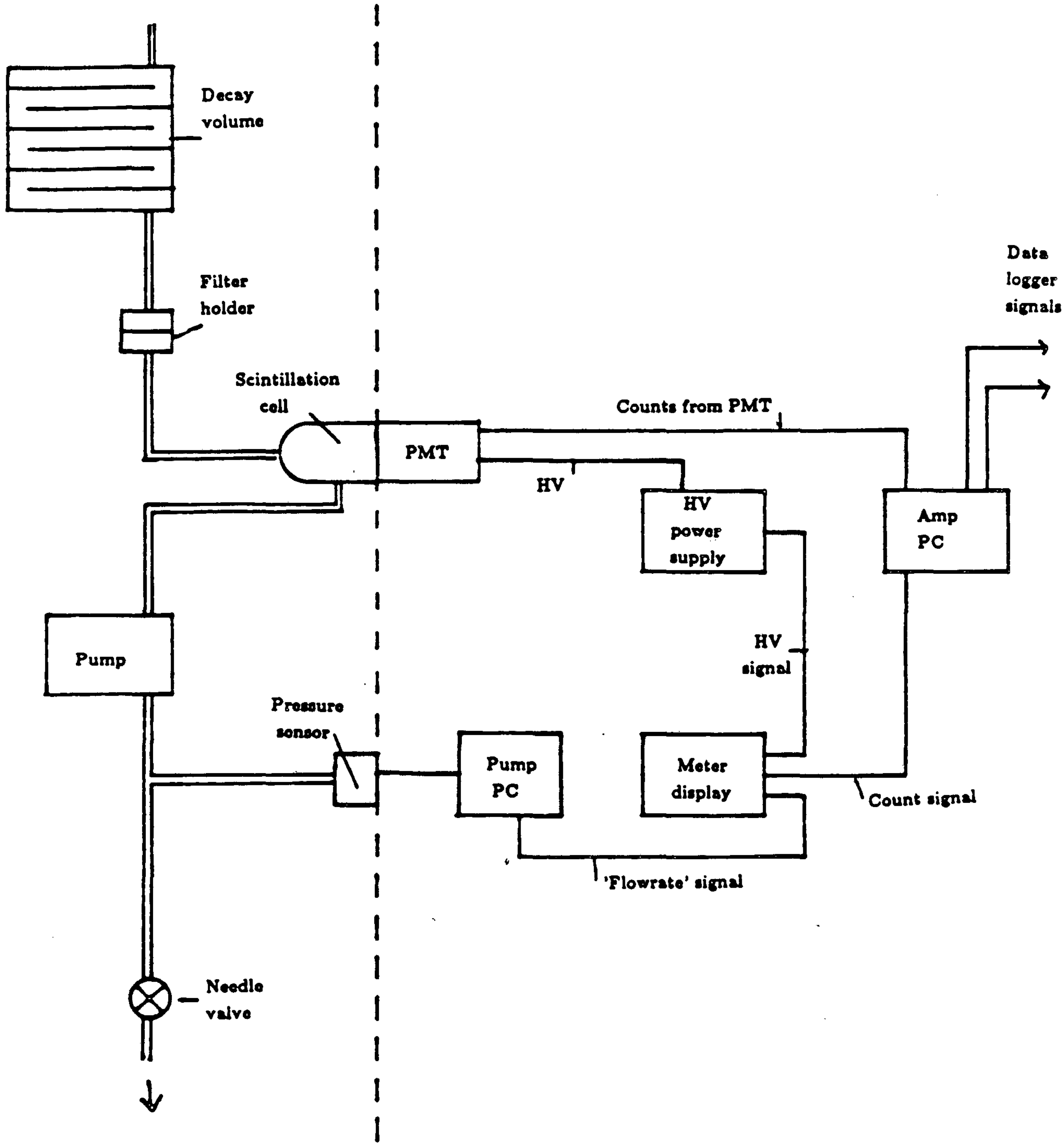
(6) Preliminary diagnostics were employed to aid in the identification of potential radon entry points, selection of mitigation systems and placement of systems within the structures. The maps contained in Appendix F detail the results of these diagnostic measurements.

APPENDIX A

CONTINUOUS RADON MONITOR DIAGRAM

Figure A-1 is a box diagram showing the basic operating system for the Lawrence Berkeley Laboratory (LBL) - built continuous radon monitor (CRM). To the left of the dashed line is the flow system. A small DC pump continuously pulls sample air at 200 CCM through a volume to allow thoron (^{220}Rn) to decay. It then passes through a filter to remove particles before reaching the zinc sulfide - coated scintillation cell. Here, alpha decays from radon (^{222}Rn) and its progeny cause the cell coating to scintillate before being exhausted from the system. High concentration soil gas exhaust was vented to the outdoors. Flow is regulated with a needle valve. The pressure sensor is no longer used in the flow control system.

On the right of the dashed line, the signal and power supply wiring are diagrammed. The photomultiplier tube, which is optically coupled to the scintillation cell, generates an amplified signal in response to each flash. This signal is then processed and shaped and sent to the on-board counter display(s) or to an external data logger.



Decay volume
Filter holder
Scintillation cell
PMT
Counts from PMT
HV
Data logger signals
HV power supply
Amp PC
Pump
HV signal
Pressure sensor
Pump PC
Meter display
Count signal
'Flowrate' signal
Needle valve

APPENDIX B

RADON CONCENTRATIONS IN SOIL GAS GRAB SAMPLES

Grab samples of soil gas were periodically collected from pipe probes placed in the soil surrounding each house. The samples were collected in evacuated lucas-type scintillation flasks after two to three sample volumes were drawn through a sample tube and fittings by means of a hand pump. The activity was counted after equilibrium was reached. Table B-1 compiles these data by house, date, and probe identification. Concentrations are generally similar between houses and at the same house over time, except in those instances where an SSV mitigation system may have depleted radon in the soil (Vol. I, Figure 40a, b, c).

APPENDIX B

TABLE B-1 RADON CONCENTRATIONS IN SOIL GAS GRAB SAMPLES (pCi/L)

ECD026C

Date	#1	#2
11/2/85	237.5	189.3
11/18/85	97.0	405.2
12/2/85	402.8	460.7
12/9/85	277.5	395.0
1/16/86	386.2	218.3
1/30/86	421.9	467.5
2/11/86	315.4	566.5
2/20/86	223.1	306.1
3/6/86	529.0	584.1
3/20/86	444.2	478.4

ECD027

Date	#1	#2
11/2/85	419.1	335.7
12/31/85	466.3	294.0
2/28/86	318.0	166.6

ECD153

Date	#1	#2
11/20/85	638.5	672.9
12/4/85	659.4	629.6
3/11/86	598.8	551.3

ESP101

Date	#1	#2
11/7/85	313.7	
12/16/85	454.8	210.8

ESP108C

Date	#1	#2
11/7/85	531.5	628.7
12/4/85	329.8	498.5
12/19/85	339.7	487.2
1/16/86	371.5	547.8
1/25/86	304.9	355.9
2/10/86	132.2	523.4
2/18/86	183.2	447.3
2/25/86	67.5	419.5
3/3/86		597.1
3/11/86	165.2	528.7

ESP109

Date	#1	#2
2/10/86	34.5	228.0
2/11/86	3.7	
3/10/86		523.8

ESP111

Date	#1	#2
11/5/85	284.4	299.5
11/30/86	327.6	364.7
12/20/85	305.9	353.0
3/19/86	2.2	70.4

ESP113

Date	#1	#2
11/16/85	525.1	571.1
12/30/85	425.7	420.5
3/10/86	153.0	20.9
3/24/86	33.8	13.5

ESP116

Date	#1	#2
11/16/85	372.7	512.2
3/12/86	474.1	358.7

ESP119

Date	#1	#2
11/8/85	446.0	441.5
12/3/85	268.3	309.8
1/17/86	124.0	217.5
1/10/86	400.5	396.4
3/13/86	159.6	324.1

ESP120

Date	#1	#2
10/24/85	315.9	536.5
11/6/85	310.8	610.0
1/14/86	461.6	23.0
1/23/86	408.2	40.2
3/12/86	132.3	28.8

ESP121

Date	#1	#2
2/10/86	118.9	288.9
3/10/86	536.3	356.2

EVA604

Date	#1	#2
12/15/85	620.1	625.7
1/18/86	644.1	607.5

NCD077

Date	#1	#2
1/20/86		545.5
1/30/86	568.6	474.0
3/18/86	242.3	410.2

NSP204

Date	#1	#2
1/6/86	5.3	407.3
2/17/86	44.2	350.1
3/25/86	49.2	296.0

Date - Date sample was collected
#1 - Soil pipe No.1 (see floor plan)
#2 - Soil pipe No.2 (see floor plan)

soilgas.wks

APPENDIX C

CHRONOLOGY OF HOUSE OPERATING CONDITIONS, MITIGATION CONFIGURATIONS, AND RADON CONCENTRATIONS

Appendix C is a detailed account of the operating condition of each house throughout the period of monitoring activities. A brief chronology of conditions, description of mitigation systems that were in use, and radon levels and hours of monitoring is followed by a continuous plot of one-day average radon concentrations. By referencing the date in the text with the figure, one can observe the effects of changes in mitigation on indoor radon levels. Detailed information on mitigation system operating specifications (flows and pressures) is included in the text. Some specifications are missing, because the data was not collected. Others have been estimated from previous measurements made at the house.

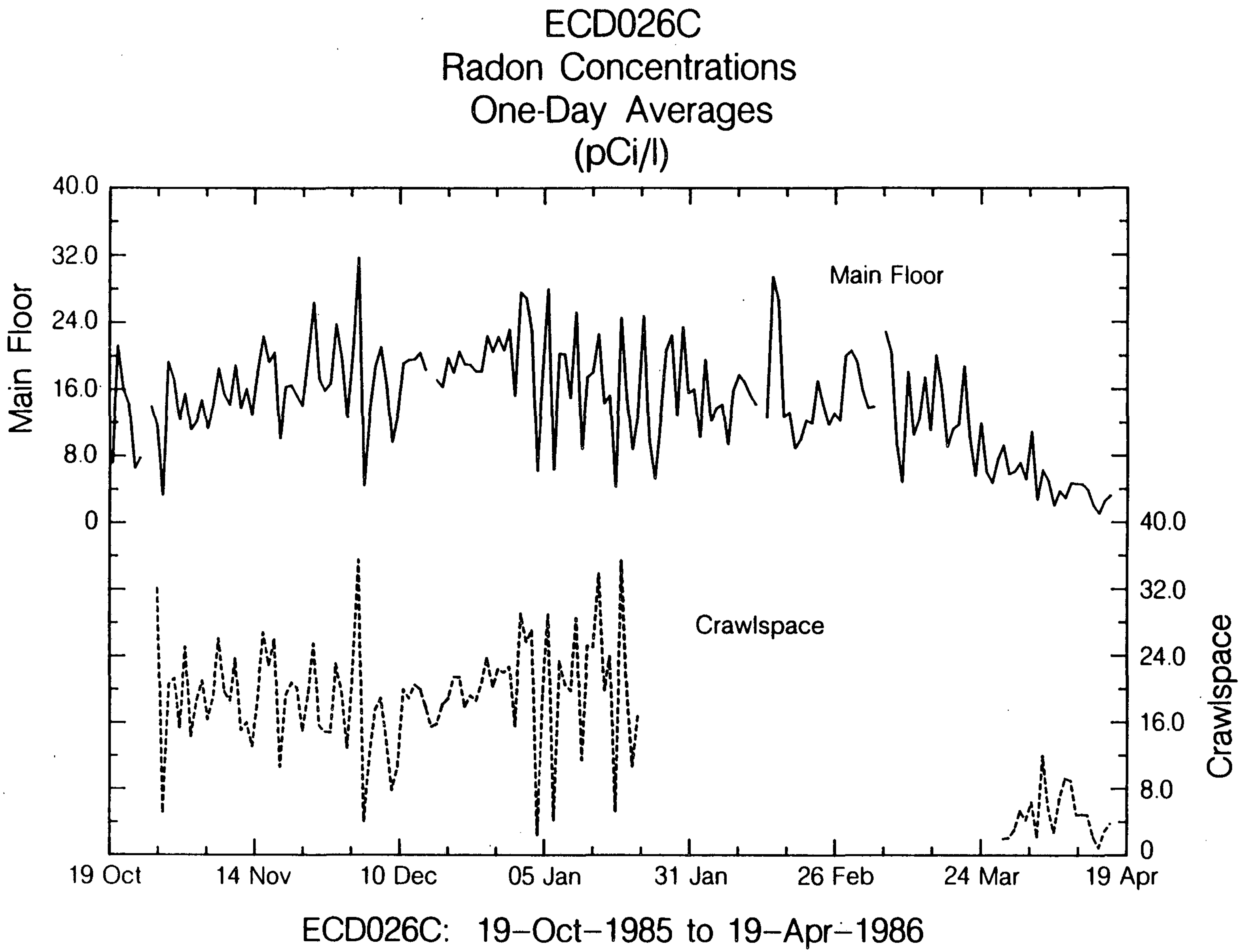
APPENDIX C

Chronology of House Operating Conditions, Mitigation Configurations, and Radon Concentrations

ECD 026C

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (CRAWLSPACE)	HOURS
BASELINE A	17.9	19.8	1926.5 CRM-1 1877.0 CRM-2
MITIGATION A			
<u>3/7/86</u> Open existing crawl vents.	8.0	-	51.0
BASELINE B			
<u>3/9/86</u> Close existing crawl vents. (Return to "baseline" condition)	14.7	-	259.5
MITIGATION B			
Opened existing crawl vents, added additional crawl vents, sealed crawlspace from house, installed tight fitting hatch door. Wrapped ducts and pipes with insulation.			
<u>3/20/86</u> All vents open (passive).	9.0	-	126.0
<u>3/25/86</u> All vents open. Added 2 fans in pressurization mode. Flow = 71 L/s (total)	8.8	-	42.0
MITIGATION B			
Installed subsurface ventilation system in one location in 1/2-depth basement.			
<u>3/28/86</u> Subsurface ventilation system on pressurization, ΔP = +500 Pa Crawlspace vents open (passive), fans off.	4.4	7.3	180.5

<u>4/3/86</u>			
Subsurface ventilation system on pressurization, ΔP = +500 Pa Crawlspace vents open and fans on, pressurizing with Flow = 71 L/s (total)	2.6	2.9	99.5

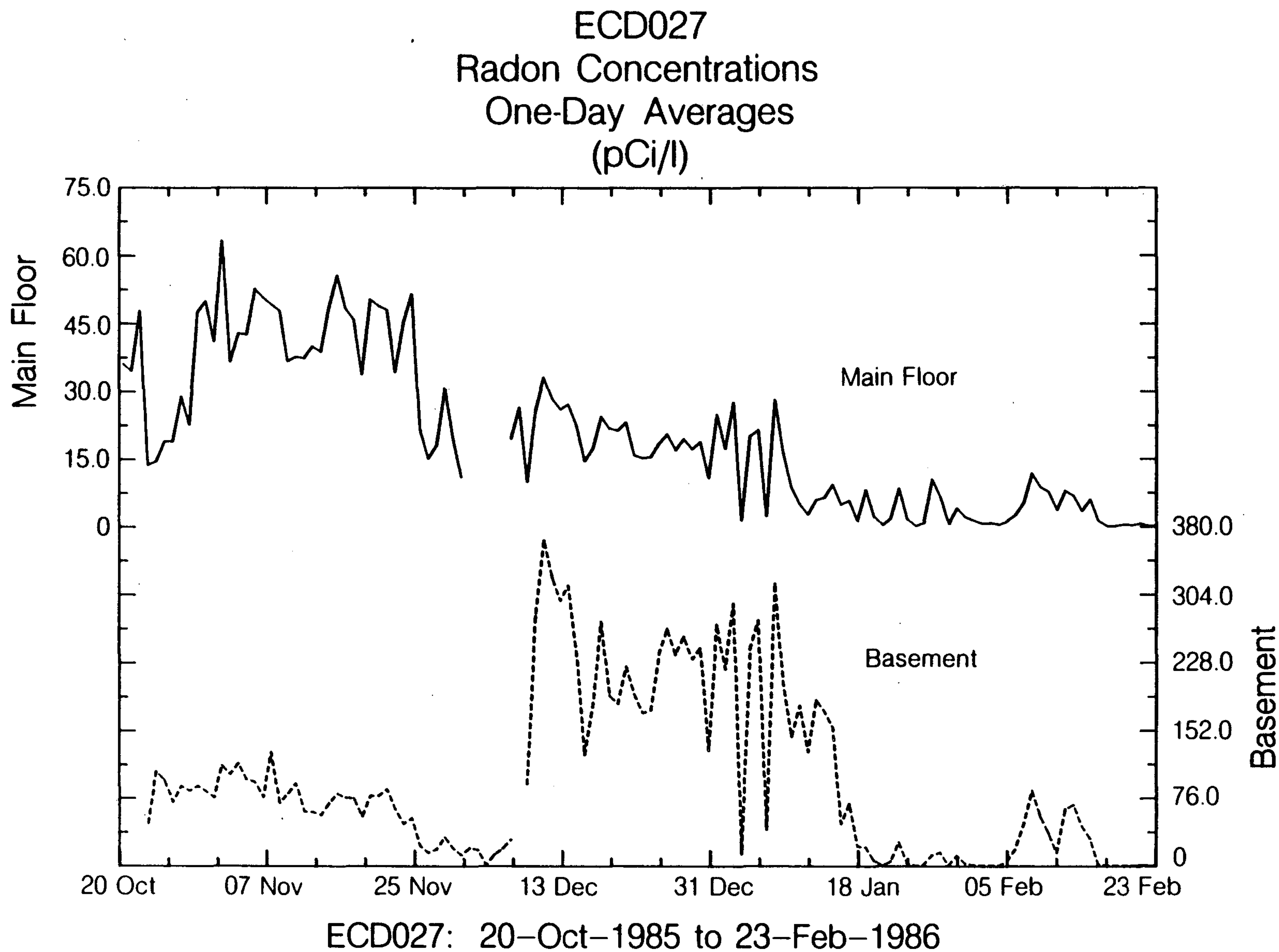


XBL 8711-9350

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE	45.0	85.0	527.0 CRM-1 332.0 CRM-2
MITIGATION A			
Sealed floor between basement and main level, installed basement vents. Removed wood furnace.			
12/6/85 Vents closed.	24.5	307	169
12/13/85 Vents open (passive).	21.2	208	164.5
MITIGATION B			
Installed fans to ventilate basement.			
12/20/85 Installed 3" axial fan to exhaust at 24 L/s. Vents open.	17.0	185	337.0
1/7/86 Installed centrifugal fan to exhaust at 80 L/s 3" axial fan also on 24 L/s. Basement depressurized, $\Delta P \sim -3.5$ Pa	5.3	167	96.5
1/14/86 Centrifugal fan exhausting at 80 L/s. Basement door open to create neutral pressure. 3" axial fan removed.	5.4	59.3	48.5

MITIGATION B (cont'd)

1/17/86 Reversed centrifugal fan to to pressurize basement. Flow approximately 80 L/s. ΔP ~ +2.5 Pa to +3.8 Pa.	3.9	8.1	295.0
1/30/86 Installed 10" axial fan to pressurize at unknown flow. Centrifugal fan at 80 L/s pressurization mode. ΔP unknown.	0.9	1.2	104.0
2/4/86 L/s pressurization mode. ΔP unknown. 10" axial fan in pressurization mode. Removed centrifugal fan.	6.9	52.8	91.0
2/8/86 Moved 10" axial fan to different duct configuration. 10" axial on pressurization mode. ΔP ~ +1.9 Pa	6.1	43.9	145.5
2/14/86 Installed 10" axial fan between garage and basement. Unconditioned garage air blown into basement to pressurize to ΔP ~ +5.0 Pa to +9.0 Pa. Flow ~ 189 L/s to 236 L/s (mfg. spec.)	0.6	1.3	511.5



XBL 8711-9352

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE A	24.2	799.5
MITIGATION A		
<u>11/21/85</u> Sealed crawlspace floor to top of crawlspace concrete walls with membrane. Crawlspace vents closed.	25.2	335.5
<u>12/10/85</u> Same as above, but crawlspace vents open.	23.3	318.5
MITIGATION B		
Pressurized basement using furnace fan. Install manual switch on furnace fan. Sealed main floor 1/2-depth basement membrane: pipe penetrations, ducts, weatherstrip door, etc:		
<u>1/6/86</u> 1/2-depth basement pressurized with forced air furnace fan on manual. Existing furnace filter dirty. Basement overpressure ~ +6.7 Pa compared to soil.	1.0	40.5
<u>1/8/86</u> 1/2-depth basement pressurized with forced air furnace fan on manual. New furnace filter installed. Basement overpressure ~ +14.5 Pa compared to soil.	0.5	165.0
<u>1/15/86</u> 1/2-depth basement pressurized with forced air furnace fan on manual. Basement overpressure ~ +6 Pa compared to soil.	0.29	65.5
<u>1/18/86</u> 1/2-depth basement pressurized with forced air furnace fan on manual. Basement overpressure ~ +2.5 Pa compared to soil.	1.19	42.5
BASELINE B		
<u>1/20/86</u> Forced air furnace fan to auto mode. Basement door open. Return to "Baseline".	24.0	145.4

MITIGATION C

1/31/86 Pressurized basement with a 10" axial fan installed in forced air furnace return plenum. Basement door fitted with spring closure hinges. Forced air furnace fan on auto mode. ΔP ~ +1 Pa	6.8	181.0
2/8/86 Same as above, but with temporary backdraft damper installed over the 10" axial fan exhaust. ΔP ~ +1Pa	5.5	275.5

MITIGATION D

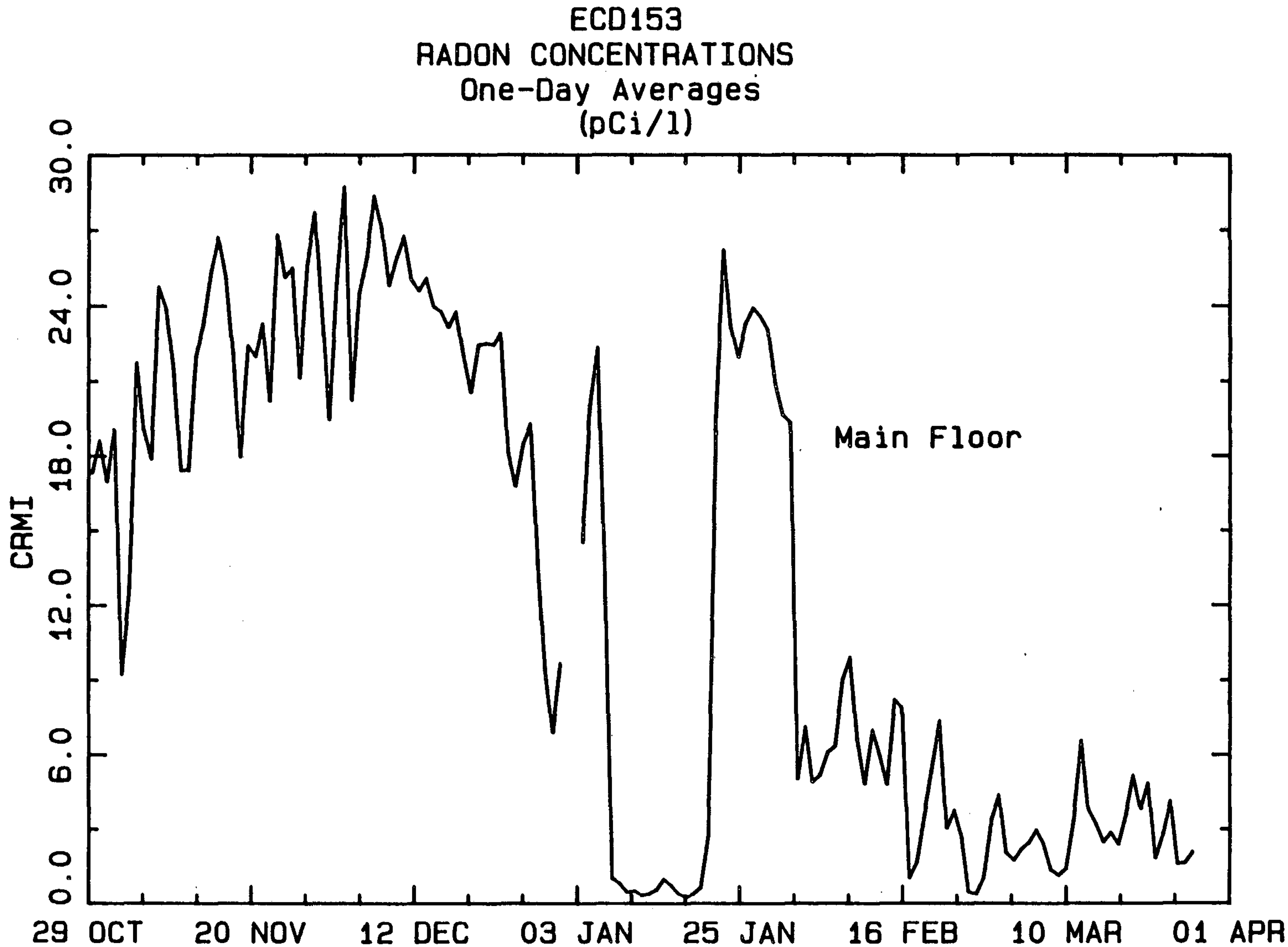
Pressurized basement with centrifugal fan and enclosure attached to forced air furnace return plenum. No backdraft damper. (Installation not according to written specs.)

2/21/86 Centrifugal fan and enclosure attachment to forced air furnace return air plenum. Fan speed maximum flow 202 L/s. ΔP ~ +1.5 Pa	2.3	262.0

MITIGATION E

Modified basement pressurization system. Relocated centrifugal fan and enclosure attachment to forced air furnace return air plenum. Installed permanent, adjustable backdraft damper in forced air furnace supply plenum.

3/11/86 Fan speed at maximum flow = 202 L/s. ΔP ~ +2.5 Pa supply plenum	3.6	201.0
3/20/86 Final modification of centrifugal basement pressurization fan. (Modified to meet original specs.) Speed set to maximum flow = 214 L/s ΔP ~ +2.5 Pa	2.4	119.0



ECD153: 29-OCT-1985 TO 01-APR-1986

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE	27.6	-	1133.0
MITIGATION A			
Ventilated fireplace block wall.			
12/5/85 Fireplace block ventilation fan off. System damper closed.	29.1	-	48.5
12/7/85 Fireplace ventilation fan on depressurization mode. Flow = 25 L/s ΔP = -57 Pa	22.2	-	408.5
MITIGATION B			
Sealed cracks and holes in substructure. Poured walls and floors.			
12/26/85 Substructure sealed, fireplace block fan on.	20.5	-	274.0
1/7/86 Same as above, but fireplace block fan off.	28.3	-	915.5
MITIGATION C			
Installed subsurface ventilation system. 3 locations in full basement, 1 location in 1/2-depth basement Fireplace system off.			
2/24/86 Subsurface ventilation system in depressurization mode. Fireplace block system off. Full basement:	7.4	-	84.5

	Pipe Location		
	NW	SE	SW
Flow (L/s)	8	12	17
ΔP (Pa)	-371	-291	-296

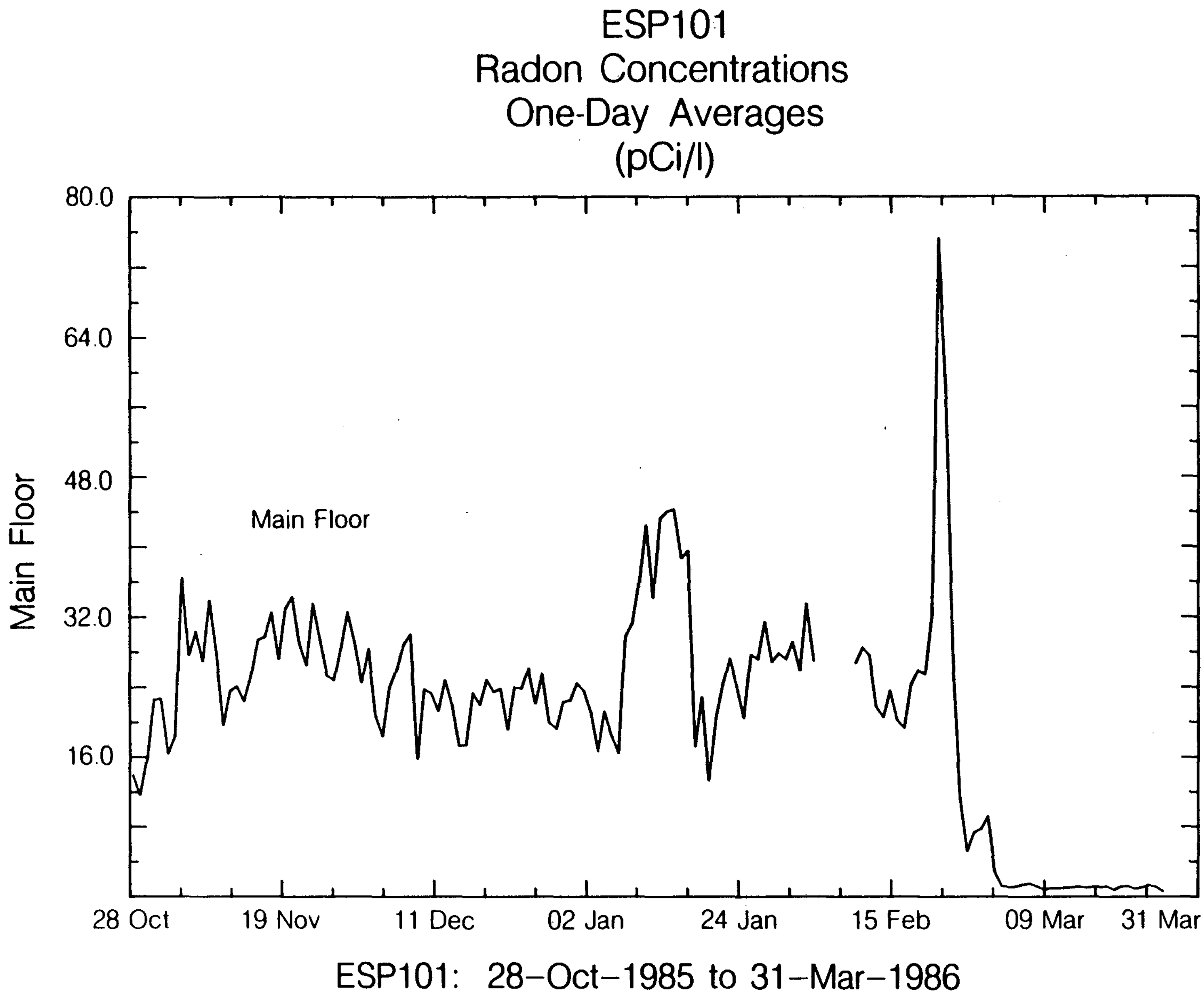
1/2-depth basement:
Flow = 16 L/s
Δ = -456 Pa

MITIGATION D

2/28/86 Subsurface system in pressurization mode. Full basement: NW / SE / SW Flow (L/s) 11 / 17 / 17 ΔP (Pa) +383 / +293 / +260 1/2-depth basement: Flow = 23 L/s Δ = +525 Pa	2.1	-	48.5
3/3/86 Subsurface system in pressurization mode. Full depth basement systems on. Full basement: NW / SE / SW Flow (L/s) 11 / 17 / 17 ΔP (Pa) +383 / +293 / +260 1/2-depth basement system off.	1.3	-	40.5
3/5/86 Subsurface system in pressurization mode. Full depth basement system at reduced ΔP (total flow = 32 L/s, ΔP = 200 Pa): NW / SE / SW Flow (L/s) 7 / 11 / 11 ΔP (Pa) +219 / +150 / +150 1/2-depth basement system off.	1.3	1.7	59.0
3/8/86 Subsurface system in pressurization mode. Full depth basement system at reduced ΔP: Flow = 19 L/s (total) Δ = 101 Pa 1/2 -depth basement system off.	1.1	1.9	105.5

MITIGATION D

3/13/86 Final configuration: Full depth basement system only - pressurization mode. Installed small fan w/dampers open 100%. Flow = 25 L/s (total) ΔP = 175 Pa Removed 1/2-depth basement system.	1.1	2.0	294.0



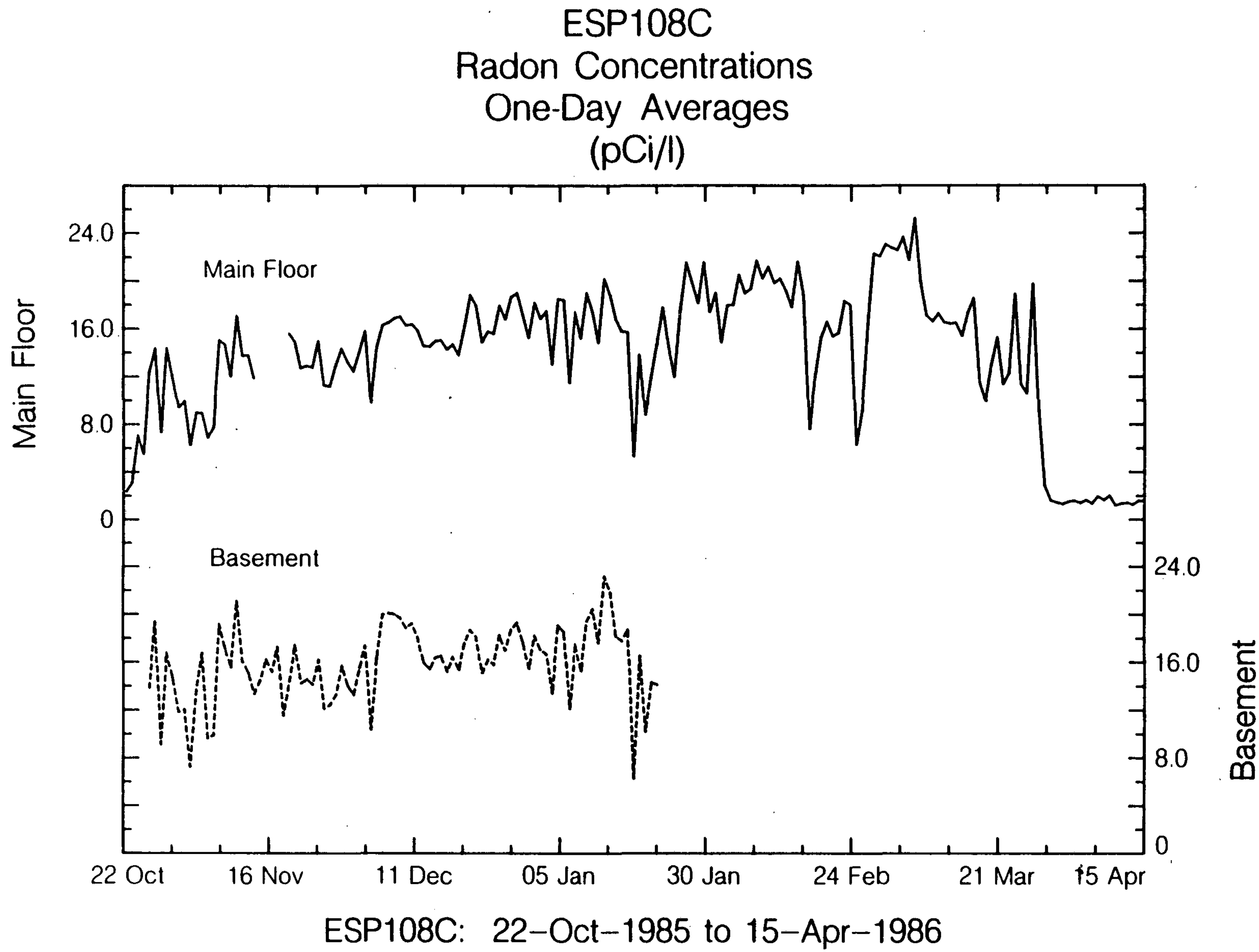
XBL 8711-9353

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE	15.5	16.1	3428.5 CRM-1 1933.0 CRM-2
3/8/86 Floor drain and wall crack sealed.	20.2	-	191.5
MITIGATION A			
3/27/86 Installed subsurface ventilation system in four locations in basement. Sealed floor drain clean out.			
Subsurface ventilation system on pressurization mode.	1.4	1.5	106.0

	Pipe Location			
	Shop	Storage	Office	Closet
Flow (L/s)	17	14	12	12
ΔP (Pa)	+437	+412	+375	+375

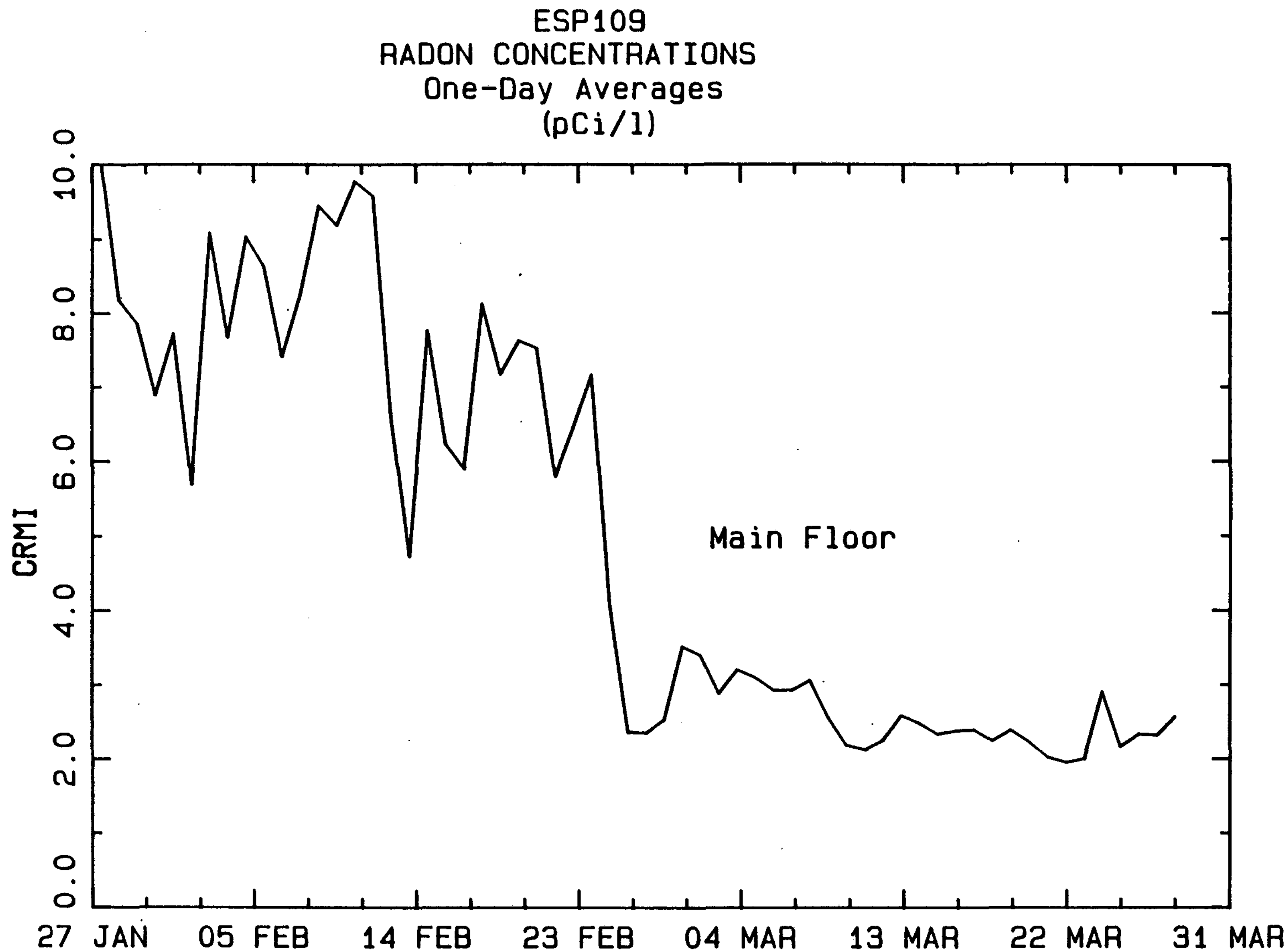
Main Pipe Flow = 57 L/s, ΔP = +537 Pa

CONFIGURATION	CRM-1	CRM-2	HOURS
4/2/86 Same as above in April, 1986.	1.50	1.6	291.5 CRM-1 295.0 CRM-2



XBL 8711-9351

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE	6.9	939.5
MITIGATION A		
Installed air-air heat exchanger.		
2/24/86 Air-air heat exchanger operated at various speeds, unbalanced flows.	2.4	63.0
2/27/86 Air-air heat exchanger operated at "Medium" speed, balanced flows. Supply = 68 L/s Return = 64 L/s	3.3	106.0
3/4/86 Air-air heat exchanger operated at "High" speed, balanced flows. Supply = 112 L/s Return = 108 L/s	2.4	524.5



ESP109: 27-JAN-1986 TO 31-MAR-1986

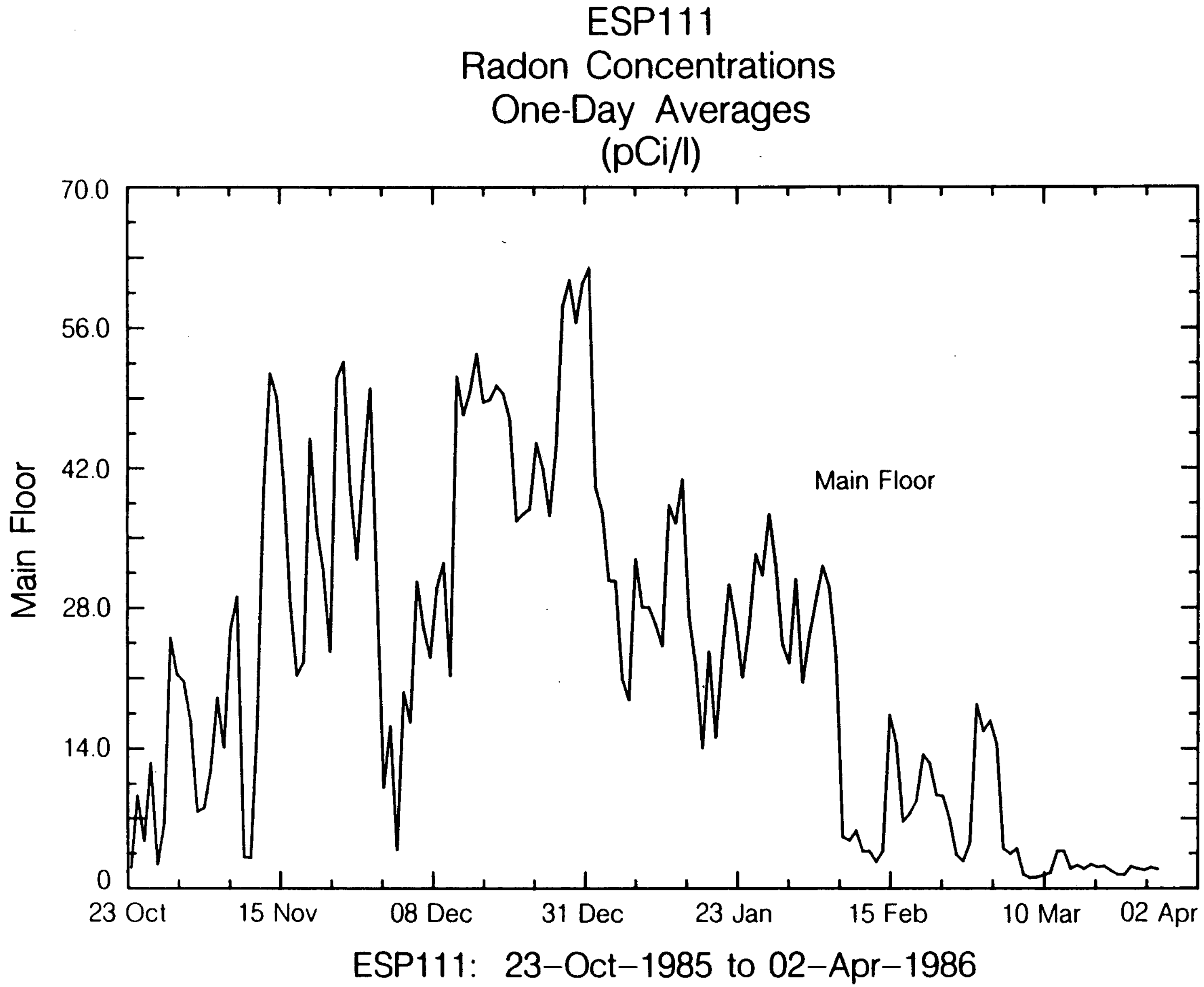
XBL 881-8333

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE	29.6	-	322.0
MITIGATION A			
<u>11/23/85</u> Sealed floor cracks, and pipe penetrations.	28.7	-	401.0
<u>12/10/85</u> Sealed exterior sill plate and windows.	47.9	-	464.5
MITIGATION B			
Installed subsurface ventilation systems. 1 location 1/2-depth basement 1 location full depth basement			
<u>1/9/86</u> Depressurization mode, both systems on. 1/2 depth basement system: Flow = 7 L/s ΔP = -432 Pa Full depth basement system: Flow = 21 L/s ΔP = -419 Pa	33.2	-	115.5
<u>1/14/86</u> Subsurface ventilation systems on depressurization mode. Sealed penetrations between full basement and remainder of house. Systems operating same as previous period.	22.2	-	101.0
<u>1/19/86</u> Full depth basement system off. 1/2-depth basement system on depressurization mode. Flow = 7 L/s (est) ΔP = -425 Pa (est)	25.9	-	88.8
<u>1/23/86</u> 1/2-depth basement system off. Full depth basement system on depressurization mode. Flow = 21 L/s (est) ΔP = -425 Pa (est)	30.6	-	166.5

MITIGATION B (cont'd)			
<u>1/31/86</u>			
Both systems on depressurization mode.			
1/2-depth basement system	27.5	-	143.0
Flow = 7 L/s			
ΔP = -442 Pa			
Full depth basement system:			
Flow = 19 L/s			
ΔP = -412 Pa			
MITIGATION C			
<u>2/6/86</u>			
Subsurface ventilation systems	4.2	-	159.0
on pressurization mode. Both systems on.			
1/2-depth basement system:			
Flow = 9 L/s			
ΔP = +600 Pa			
Full depth basement system:			
Flow = 24 L/s			
ΔP = +562 Pa			
<u>2/13/86</u>			
Full depth basement system off	16.4	-	45.5
1/2-depth basement system on pressurization mode.			
Flow = 9 L/s (est)			
ΔP = +600 Pa (est)			
<u>2/15/86</u>			
1/2-depth basement system off.	8.3	10.3	225.5 CRM-1
Full depth basement system on			138.0 CRM-2
pressurization mode.			
Flow = 27 L/s			
ΔP = +537 Pa			
MITIGATION D			
Install exterior subsurface ventilation system at 2 locations on N/W 1/2-depth basement exterior wall.			
<u>2/27/86</u>			
Exterior subsurface ventilation			
system on depressurization mode.	19.2	28.7	36.5
Full depth basement system on depressurization mode.			
Flow = 19 L/s (est)			
ΔP = -412 Pa (est)			
1/2-depth basement system on depressurization mode.			
Flow = 7 L/s (est)			
ΔP = -442 Pa (est)			

MITIGATION D (cont'd)

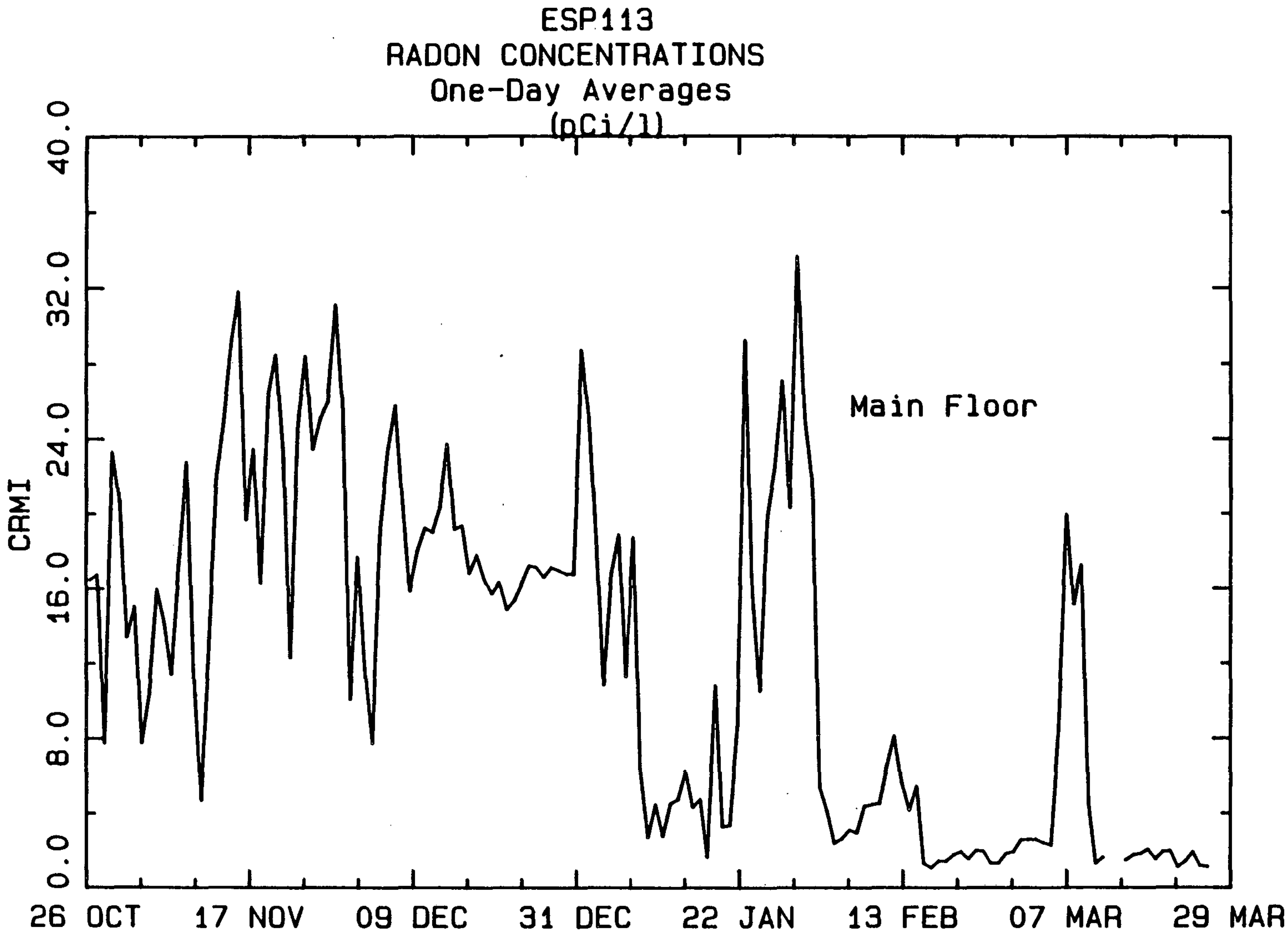
3/2/86 Exterior subsurface ventilation system on depressurization mode. Full depth basement system on pressurization mode. ΔP = +487 Pa (est) 1/2-depth basement system on pressurization mode.	4.1	6.2	60.0
3/5/86 Exterior subsurface system on pressurization mode. ΔP = +505 Pa (est) Full depth basement system on pressurization mode. ΔP = +487 Pa (est) 1/2-depth basement system on pressurization mode.	1.3	2.5	40.5
3/8/86 Exterior subsurface ventilation on pressurization mode. ΔP = +505 Pa Full depth basement system on pressurization mode. ΔP = +487 Pa 1/2-depth basement system off.	1.4	2.0	52.5
3/10/86 Exterior subsurface ventilation on pressurization mode. Reduced ΔP: ΔP +245 Pa Full depth basement system on pressurization. Reduced ΔP: ΔP = +250 Pa Flow = 17 L/s	4.1	6.0	38.5
3/12/86 Removed 1/2-depth basement system. Exterior subsurface ventilation system on pressurization mode. Increased ΔP to = +505 Pa (est) Full depth basement system on pressurization mode. Increased ΔP to Flow = 24 L/s ΔP = +472 Pa	2.0	4.2	272 CRM-1 111 CRM-2



XBL 8711-9347

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE A	19.8	-	635.0
MITIGATION A			
<u>12/6/85</u> Basement baseboard ventilation system installed. Exterior sealed along rim joist. West side ΔP ~ -410 Pa East side ΔP ~ -100 Pa	18.7	-	136.0
<u>12/13/85</u> Modified basement baseboard ventilation system. Flow and pressure distribution changed. West side ΔP ~ -300 Pa, flow = 28 L/s East side ΔP ~ -487 Pa, flow = 12 L/s	17.2	-	503.5
MITIGATION B			
Installed subsurface ventilation system. One location in 1/2-depth basement. Basement baseboard ventilation system permanently off.			
<u>1/8/86</u> Depressurization mode. Full ΔP: Flow = 17 L/s ΔP = -425 Pa (Dryer vent attached to fan exhaust)	4.3	-	168.5
<u>1/16/86</u> Subsurface ventilation system in depressurization mode. Reduced ΔP: Flow = 11 L/s ΔP = -207 Pa	5.0	-	89.5
BASELINE B			
<u>1/21/86</u> Subsurface ventilation system off (Return to baseline)	22.6	-	216.5

MITIGATION B			
<u>1/31/86</u> Subsurface ventilation system on depressurization mode. Full ΔP: ΔP = -442 Pa	3.4	4.4	139.0 CRM-1 51.0 CRM-2
<u>2/9/86</u> Subsurface ventilation system on depressurization mode. ΔP reduced: Flow = 11 L/s ΔP = -210 Pa	6.1	6.0	96.5 CRM-1
MITIGATION C			
<u>2/14/86</u> Subsurface ventilation system on. Fan reversed. Pressurization mode. ΔP = +200 Pa	1.3	1.3	96.5 CRM-1
<u>2/19/86</u> Subsurface ventilation system on. Pressurization mode ΔP reduced: Flow = 8 L/s ΔP = +120 Pa	2.0	-	283
BASELINE C			
<u>3/4/86</u> Subsurface ventilation system off.	14.7	-	83.5
MITIGATION C			
<u>3/8/86</u> Subsurface ventilation system on. Pressurization mode ΔP = +121 Pa	1.8	-	322.5



ESP113: 26-OCT-1985 TO 29-MAR-1986

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE	20.2	836.0
MITIGATION A		
11/21/85 Holes and cracks sealed in basement floor and walls	14.6	403.5
MITIGATION B		
Basement pressurized with forced air furnace fan (fan on manual position). Basement/main floor membrane sealed. (Ducts, penetrations, weather strip door, etc.) Seal fireplace.		
12/10/85 ΔP ~ +4.7 Pa	1.4	35.5
12/12/85 ΔP ~ +2.9 Pa	2.9	158.0
MITIGATION A		
12/19/85 Basement unpressurized - furnace fan auto position. Only holes and cracks sealed.	30.6	472.0
MITIGATION C		
1/10/86 Installed small centrifugal fan using main floor air to pressurize basement. Very noisy. ΔP ≤ +1 Pa Flow = 33 L/s		
MITIGATION A		
1/10/86 Basement unpressurized. Furnace fan returned to auto. Only holes and cracks sealed.	24.0	377.0

MITIGATION D

1/29/86 Installed 10" axial fan into forced air furnace return air plenum to pressurize basement with main level "return" air. Furnace fan on auto position. ΔP = +0.4 Pa Basement fireplace unsealed.	7.1	145.0
2/11/86 10" axial fan operating (same as above). Installed clean furnace filter, sealed additional basement/main floor penetrations, sealed main floor fireplace and around woodstove insert. Δ P ~ -1.0 Pa	7.3	202.0

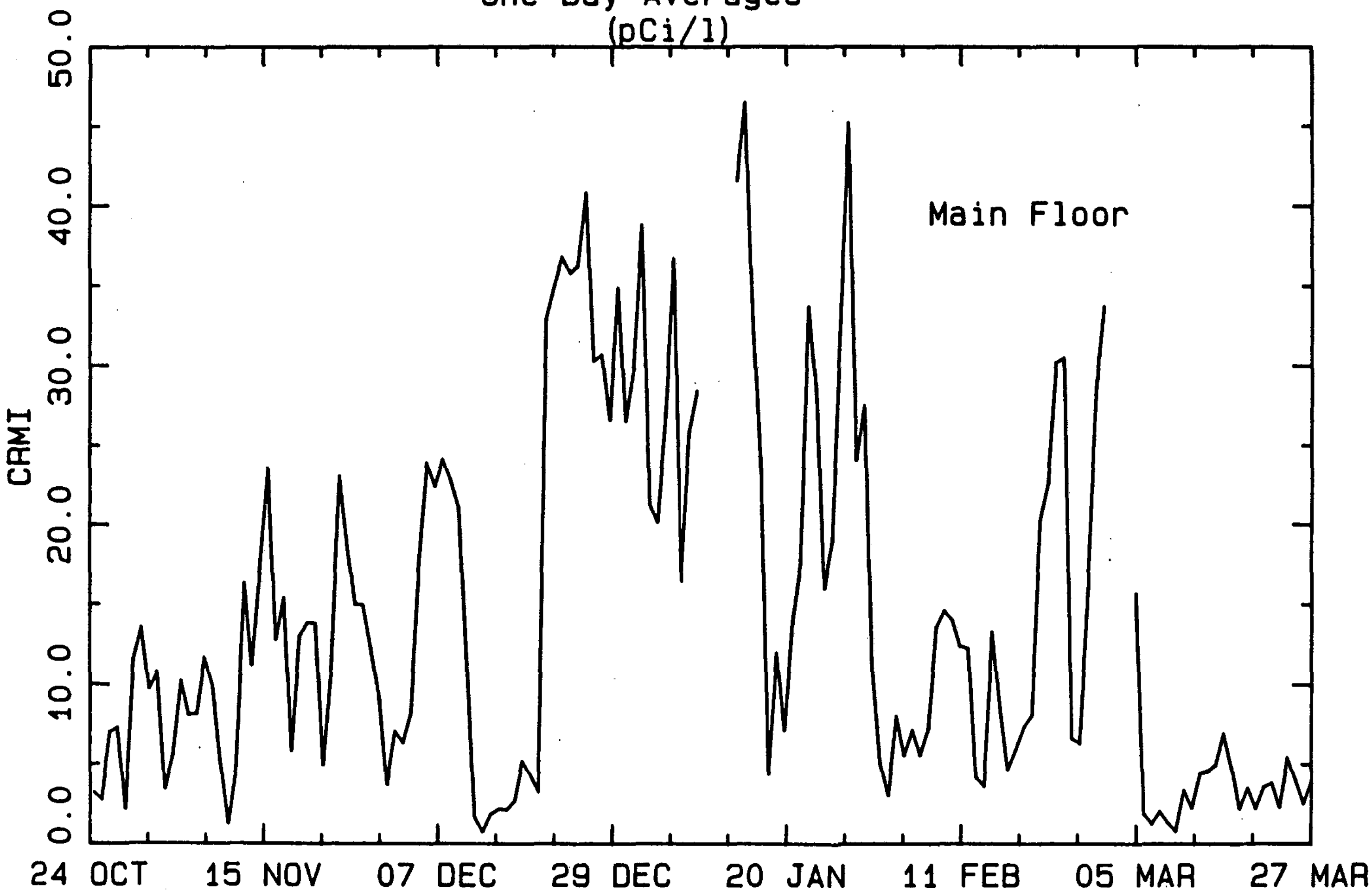
MITIGATION A

2/20/86 Basement unpressurized - furnace fan in auto position. Only holes and cracks sealed.	21.2	184.0

MITIGATION E

3/4/86 Installed centrifugal fan to pressurize basement. Attached to forced air furnace return air plenum. No backdraft damper in forced air furnace supply air plenum. ΔP ~ +3.1 Pa	1.5	59.0
3/7/86 Centrifugal fan operating. Backdraft damper installed in forced air supply plenum. Flow = 229 L/s, ΔP ~ +1.5 Pa to +1.8 Pa.	3.5	442.0

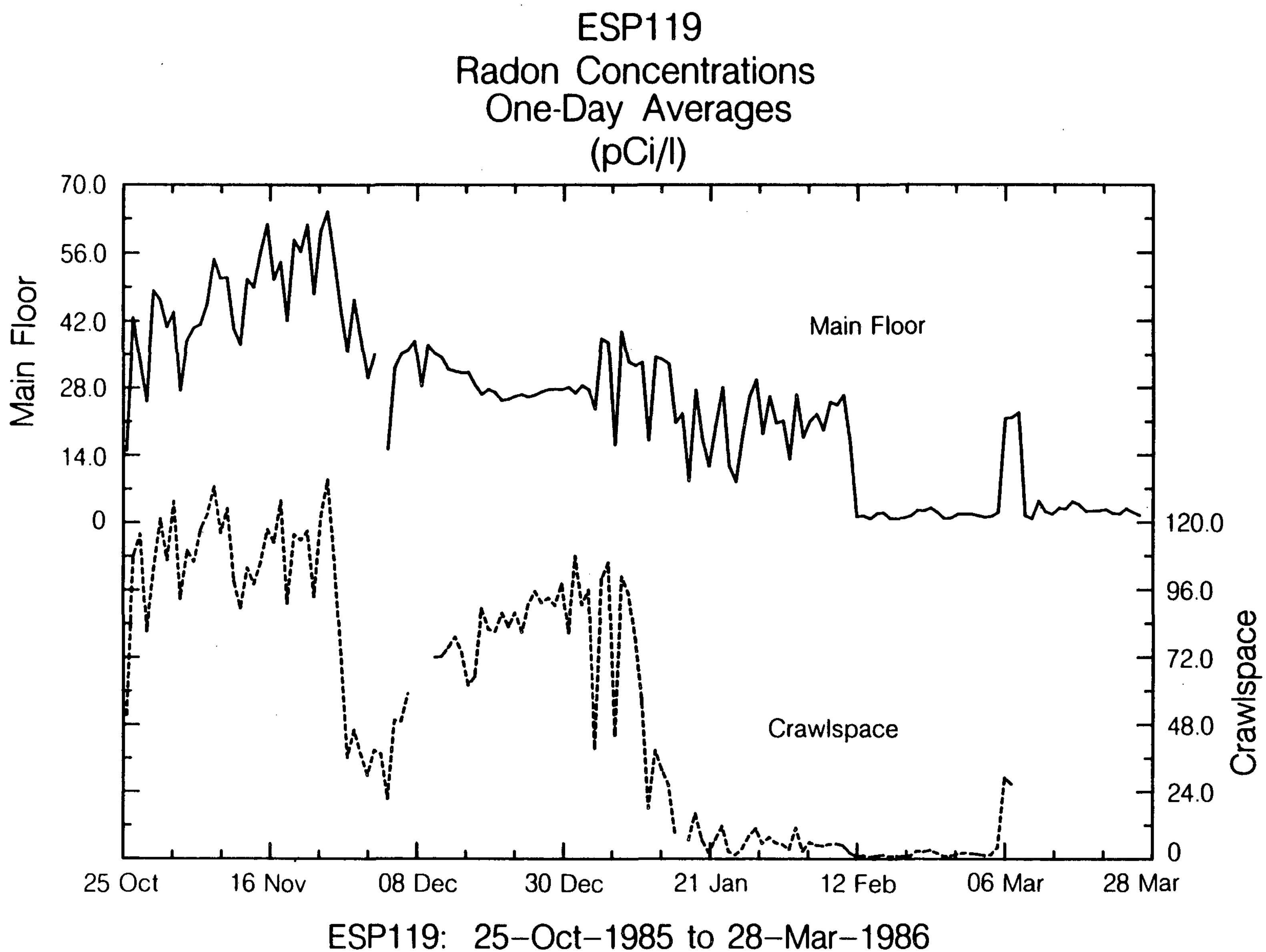
ESP116
RADON CONCENTRATIONS
One-Day Averages
(pCi/l)



ESP116: 24-OCT-1985 TO 27-MAR-1986

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (CRAWLSPACE)	HOURS
BASELINE A	49.4	111.4	586.0
MITIGATION A			
<u>11/26/85</u> Crawlspace floor sealed to top of crawl-space walls. Small crawlspace "vent holes" variously opened and closed.	34.0	62.5	407.5 CRM-1 300.0 CRM-2
MITIGATION B			
<u>12/19/85</u> Sealed walls and floor between crawlspace and house. "Vent holes" closed.	28.8	87.4	515.0
MITIGATION C			
<u>1/14/86</u> Insulated main level/crawlspace membrane and kneewall to 1/2-depth basement, wrap ducts and water pipes with insulation. Install additional crawlspace vents.	20.0	6.2	562.0 CRM-1 464.0 CRM-2
MITIGATION D			
Installed exterior subsurface ventilation system in three locations on west 1/2-depth basement foundation wall.			
<u>2/6/86</u> Passive condition. No fan.	24.9	4.6	85.0
<u>2/10/86</u> Exterior subsurface pipes manifolded together. Fan attached and operating. Depressurization mode. ΔP = -387 Pa.	1.2	0.7	192.0
<u>2/19/86</u> Exterior subsurface system operated at reduced ΔP. Depressurization mode ΔP = -188 Pa.	1.4	1.5 (basement)	304.0

BASELINE B			
3/4/86 Exterior subsurface system turned off. Return to "Baseline"	21.2	28.0 (basement)	34.0
MITIGATION E			
Modify exterior subsurface ventilation system.			
3/7/86 Permanent configuration of system pipes. Temporary centrifugal fan and mounting. Depressurization mode ΔP = -190 Pa Flow = 13 L/s	2.3	-	302.0
3/20/87 Installed permanent small centrifugal fan. Removed damper. Final system configuration depressurization mode ΔP = -192 Pa Flow = 14 L/s	1.75	-	112.0



XBL 8711-9348

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	CRM-2 Rn MEAN-pCi/L (BASEMENT)	HOURS
BASELINE A	106.1	125.9	375.0
MITIGATION A (BASELINE B)			
Installed subsurface ventilation system in four locations in basement. Sealed existing hole in basement floor to install one of the subsurface ventilation pipes.			
12/5/86 Subsurface ventilation system off. Dampers closed. Basement floor hole sealed only.	122.0	139.0	160.0
MITIGATION B			
12/13/85 Subsurface ventilation system fans (3) on; dampers open 100%-depressurization mode.	8.2	12.5	172.5

	Pipe Location			
	N/W	N/E	S/E	S/W
Flow (L/s)	24	17	24	38
ΔP (Pa)	-422	-350	-380	-330

BASELINE B			
12/20/85 Subsurface ventilation system off. Dampers closed.	141.0	168.0	168.5
MITIGATION B (MODIFIED)			
12/30/85 Subsurface ventilation fans on. Dampers open 100%-depressurization mode. Exhaust vented out to yard.	5.2	8.4	160.5
MITIGATION C			
1/6/86 Sealed additional basement floor and wall holes and cracks. Subsurface ventilation system on 100%-depressurization mode. Dampers open 100%.	4.8	8.4	162.0

MITIGATION C (cont'd)

<u>1/15/86</u> N/W Subsurface ventilation system on Damper open 100%-depressurization mode. N/E, S/W, S/E systems off, dampers open. N/W Flow = 22 L/s N/W ΔP = -395 Pa	44.2	64.2	185.5

MITIGATION D

<u>1/28/86</u> Sealed between basement and front porch. S/W, N/W systems off; dampers open. N/E, S/E systems on, dampers open 100%-depressurization mode.	21.5	29.8	81.0

	N/E	S/E
Flow (L/s)	16	21
ΔP (Pa)	-300	-325

MITIGATION E

Installed temporary seals over penetrations in basement/main level membrane. Installed basement pressurization fan. All subsurface ventilation fans on 100%-depressurization mode, dampers open 100%.

<u>1/31/86</u> All subsurface ventilation systems on depressurization mode, dampers open 100%. Basement pressurization fan off.	3.4	12.3	180.5

	N/W	N/E	S/E	S/W
Flow (L/s)	24	17	23	38
ΔP (Pa)	-425	-337	-387	-325

MITIGATION F

<u>2/18/86</u> Basement pressurization fan on "medium". Basement/main floor membrane sealed (temporary). All subsurface ventilation systems off (dampers open). Pressurization fan flow = 152 L/s Basement pressure ΔP ~ +1.5 Pa	14.2	28.0	62.5
<u>2/21/86</u> Basement pressurization fan on "maximum". Fan flow = 161 L/s, ΔP ~ +1.8 Pa	3.3	4.2	207.5

MITIGATION G

<u>3/2/86</u> All subsurface ventilation systems on, dampers open 100%-pressurization mode. Basement pressurization fan off.	1.9	2.1	35.0

MITIGATION H

<u>3/5/86</u> Basement pressurization system on. Permanent sealing (House Doctor) of the main floor/basement membrane and basement windows and doors. Subsurface ventilation systems off. Pre sealing ELA = 524.5 cm^2 Post sealing ELA = 423.9 cm^2 19%	0.87	0.85	96.0

MITIGATION G (Modified)

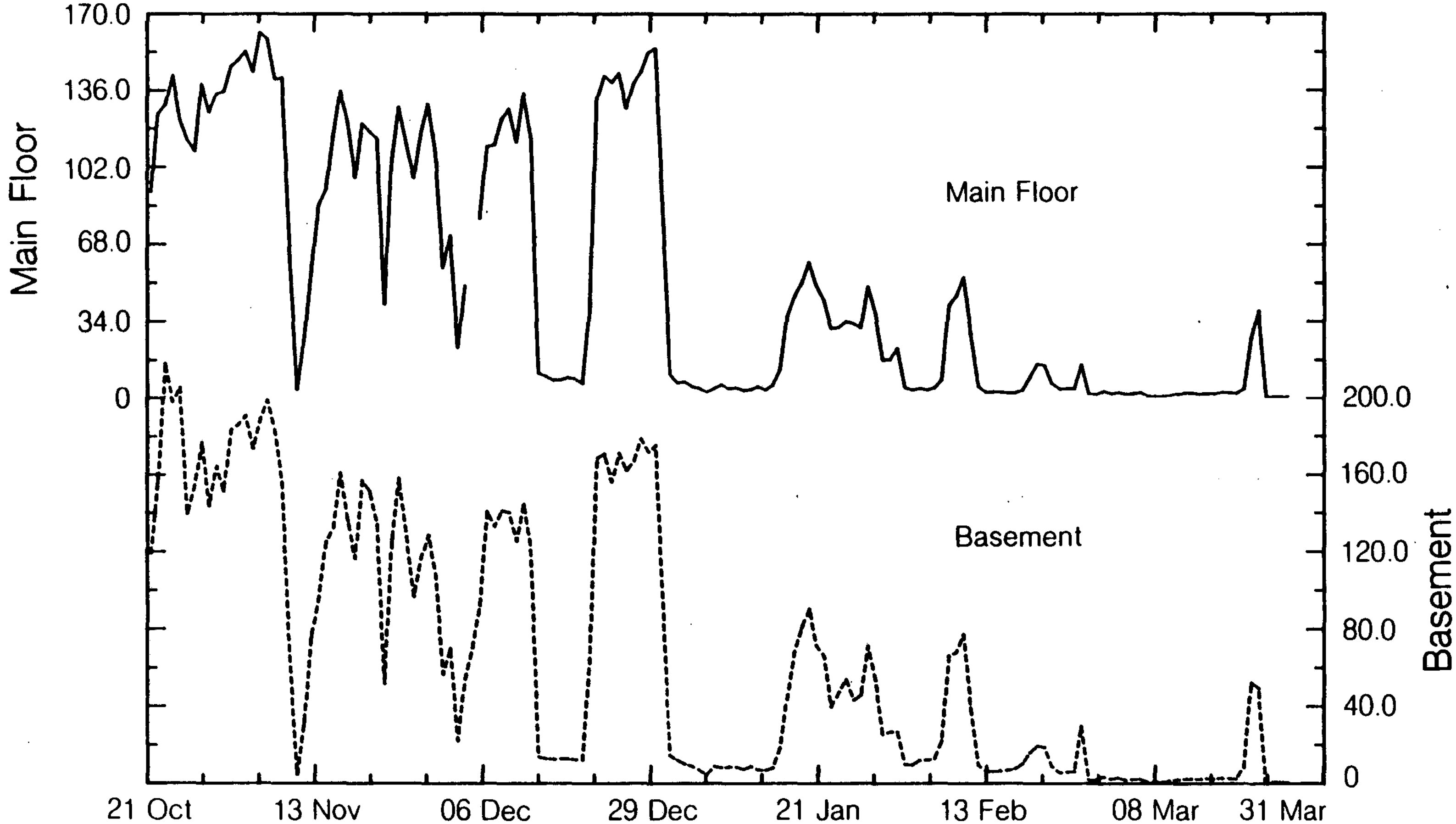
<u>3/9/86</u> N/W, S/E, N/E, subsurface ventilation systems on, pressurization-mode dampers open 100%. S/W subsurface ventilation system remained off. Basement pressurization fan off.	2.24	2.39	43.5
<u>3/11/86</u> N/W subsurface ventilation system off. S/E, N/E, S/W subsurface ventilation systems remained on in pressurization mode. Dampers open 100% except N/W system dampers closed. Basement pressurization fan off.	2.30	2.68	165.5

	N/W	N/E	S/E	S/W
Flow (L/s)	Off	18	23	54
ΔP (Pa)	Off	+275	+272	+320

BASELINE C			
3/19/86 All systems off. (Return to Baseline).	40.3	65.6	34.0
MITIGATION H			
3/21/86 Basement pressurization fan on. Basement pressurized ~ +4.0 Pa. Subsurface systems off.	0.77	0.73	82.0
MITIGATION I			
3/25/86 N/E, S/E, S/W, subsurface ventilation systems on pressurization mode. Dampers open 100% N/W Subsurface ventilation system removed. Basement pressurization fan off.	-	-	-

	N/E	S/E	S/W
Flow (L/s)	16	21	48
ΔP (Pa)	+250	+228	+237
Final ΔP (Pa)	+375	+375	?

ESP120
Radon Concentrations
One-Day Averages
(pCi/1)

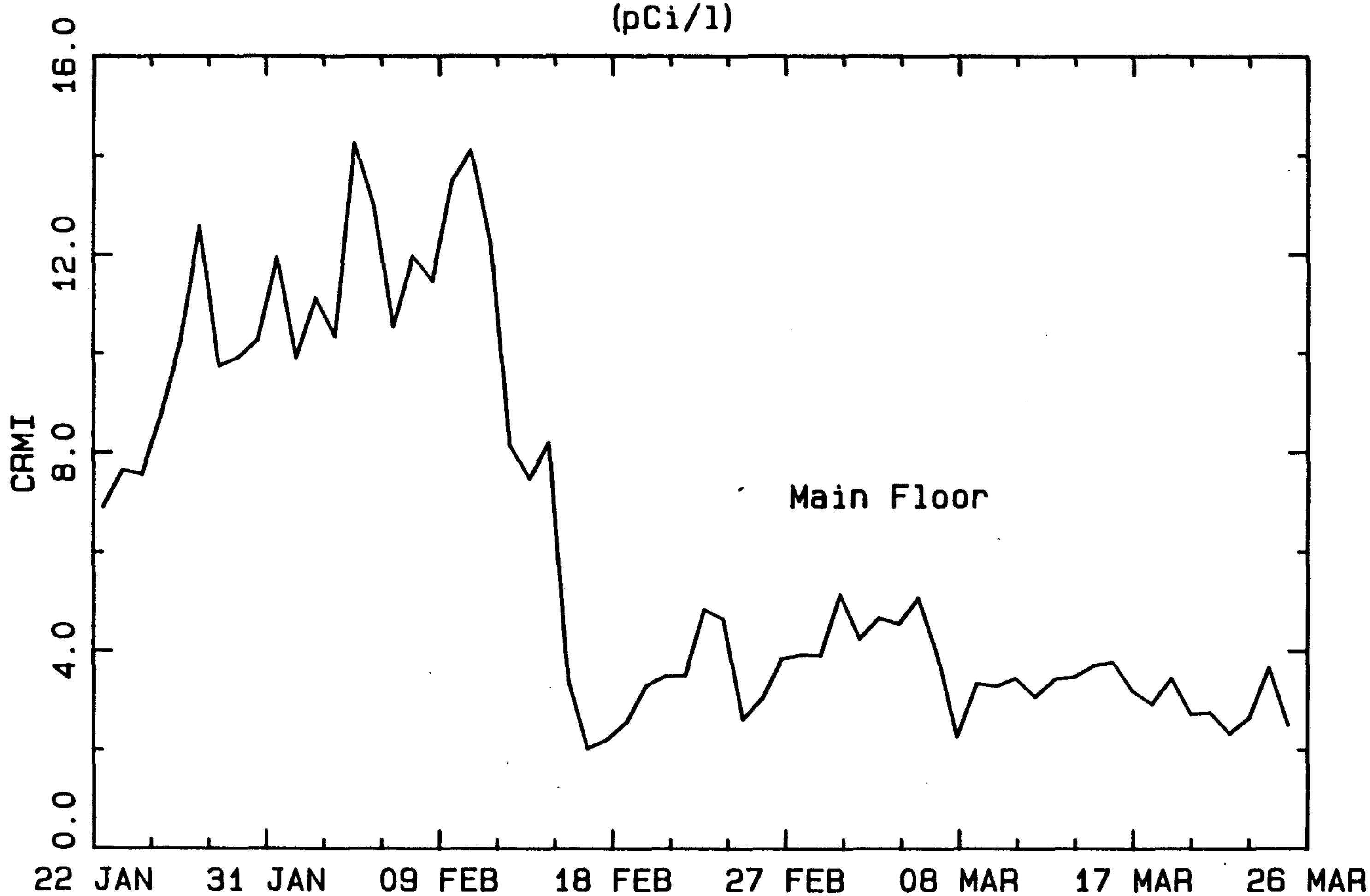


ESP120: 21–Oct–1985 to 31–Mar–1986

XBL 8711-9346

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE	11.2	542.5
MITIGATION A		
Installed air-air heat exchanger in 1/2-depth basement.		
<u>2/15/86</u> Air-air heat exchanger operating. Fan speed set to "maximum". Supply = 72 L/s Return = 59 L/s	2.9	141.0
<u>2/21/86</u> Air-air heat exchanger operating. Fan speed set at "medium". Supply = 44 L/s Return = 56 L/s	4.2	194.5
<u>3/1/86</u> Air-air heat exchanger operating. Balanced supplies to south bedrooms. Fan speed set at "medium". Supply = 44 L/s Return = 56 L/s	5.0	59.5
<u>3/4/86</u> Air-air heat exchanger operating. Fan speed set to "maximum". Supply = 65 L/s Return = 88 L/s	4.1	61.0
<u>3/7/86</u> Air-air heat exchanger operating. Fan speed set to "maximum". System balanced. Supply = 81 L/s Return = 85 L/s	3.5	324.0
<u>3/21/86</u> Air-air heat exchanger operating. Fan speed set to "maximum". Removed coarse fiber filters, installed cotton filters. Supply = 83 L/s Return = 85 L/s	2.9	77.5

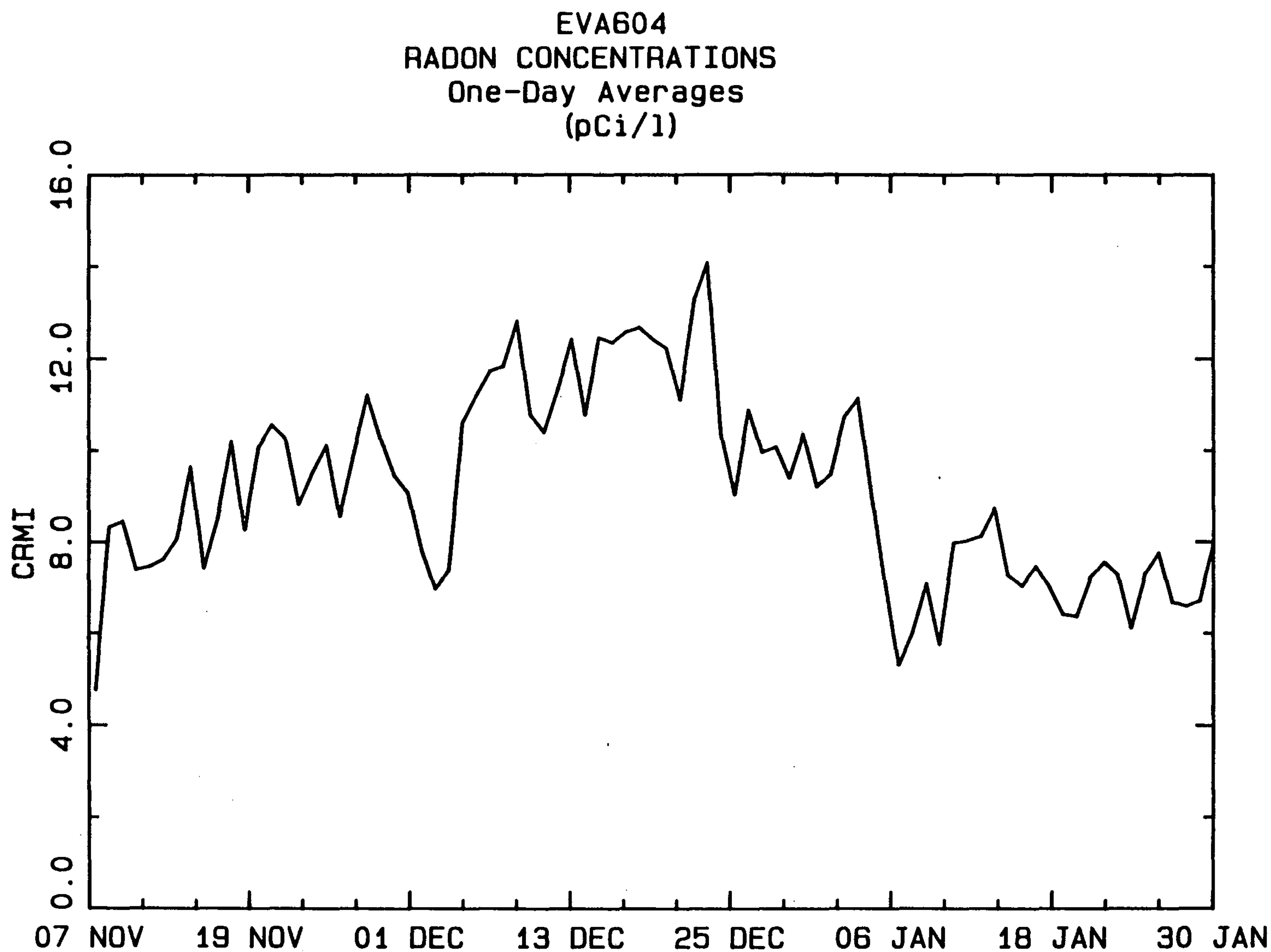
ESP121
RADON CONCENTRATIONS
One-Day Averages
(pCi/l)



ESP121: 22-JAN-1986 TO 26-MAR-1986

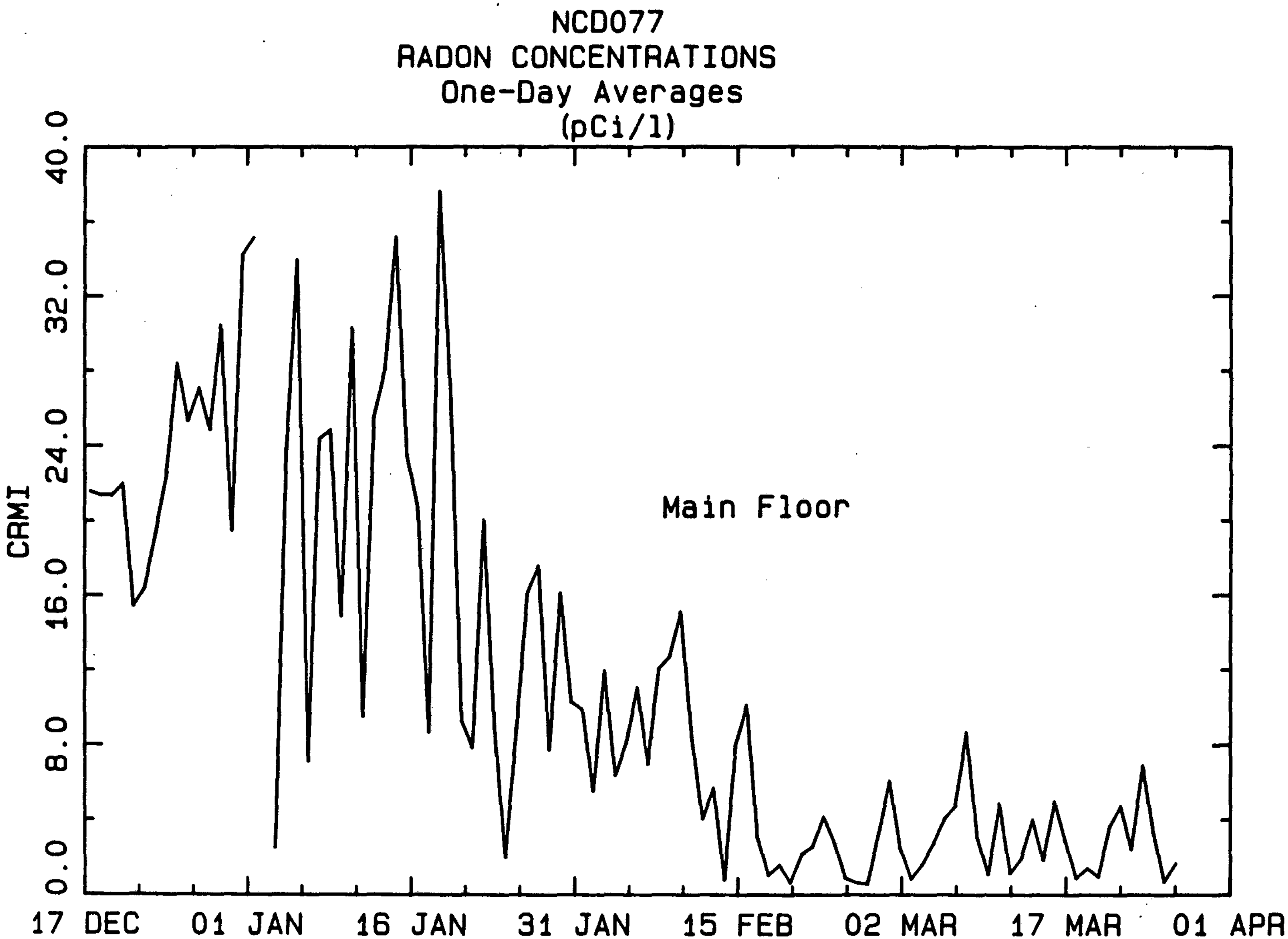
CRM-1

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE	10.4	1637.0
MITIGATION A		
1/4/86 Seal cracks in slab floor: cold joint in living room slab floor and exposed slab/footing joint along perimeter (indoor) of living room.	7.2	482.5



EVA604: 07-NOV-1985 TO 30-JAN-1986

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE	23.3	761.0
MITIGATION A		
1/21/86 Ventilate crawlspace and seal the crawlspace/ basement and crawlspace/main floor membrane.	10.8	480.0
MITIGATION B		
2/10/86 Pressurized basement using 10" axial fan mounted on forced air furnace return air plenum drawing main level return air. Seal penetrations between basement/main floor membrane. Additional sealing of membrane between crawlspace/basement and crawlspace/ main floor. Fan speed set to maximum. ΔP ~ +2 Pa	3.7	216.5
MITIGATION C		
2/21/86 Pressurized basement with centrifugal fan attached to forced air furnace return air plenum using main level return air. Remove 10" axial fan. Fan speed set to "maximum". ΔP ~ 2.7 Pa	1.9	115.0
2/26/86 Same as above, but, basement pressurization fan speed set to "1/2" Flow = 141 L/s and ΔP ~ +2 Pa	2.9	130.0
MITIGATION D		
3/10/86 Modified basement pressurization system. Relocated fan. Installed backdraft dampers in furnace supply air plenum. Fan on fan speed set to "1/2". Flow = 138 L/s and ΔP ~ +1.6 Pa to +2.1 Pa	2.9	286.5



NCD077: 17-DEC-1985 TO 01-APR-1986

CONFIGURATION	CRM-1 Rn MEAN-pCi/L (MAIN LEVEL)	HOURS
BASELINE A	26.3	842.5
Existing air-air heat exchanger operated continuously. Fan speed set to high. Configuration (1) Supply Registers: Open Into Crawlspace Open Into Atrium Return Registers: Open Into Kitchen Open Into Atrium Open Into Master Bathroom Open Into Guest Bathroom (Forced air furnace duct detached from supply register in kitchen. Register "open" to crawlspace.)		
MITIGATION A		
<u>1/22/86</u> Modified air-air heat exchanger configuration (2). Rerouted existing crawlspace supply to two locations in basement. Added a return register in the crawlspace. Fan remained on high, continuous operation. Supply Registers: Open to two Basement Locations (70%) Open to Atrium (30%) Return Registers: Open to Crawlspace (43%) Open to Atrium (22%) Open to Master Bathroom, Open to Guest Bathroom, Open to Kitchen: 35% Connected forced air supply duct to kitchen supply register.	11.2	327.0
MITIGATION B		
<u>2/5/86</u> Modified air-air heat exchanger configuration (3) Increased supply to basement and decreased supply to atrium. Increased return from crawl and decreased return from other areas Fan remained on high, continuous operation. Supply Registers: Open to 2 Basement Locations (93%) Open to Atrium 7%	7.8	340.5

MITIGATION B (cont'd)

Return Registers:
Open to Crawlspace 83%
Open to Atrium 9%
Open to Master Bedroom)
Open to Guest Bedroom) 8%
Open to Kitchen)

MITIGATION C

<u>2/25/86</u>

Modified air-air heat exchanger configuration (4)	6.9	72.5

All air-air heat exchanger supply now directed to main level.
Added air-air heat exchanger supply air to two locations at main level.
Return not modified.
Disconnected both basement supply registers.
Fan remained on high, continuous operation.
Supply Registers:
Open to Atrium 7%
Open to West Bedroom) 93%
Open to Kitchen)
Return Registers:
Open to Crawlspace 83%
Open to Atrium 9%
Open to Master Bedroom)
Open to Guest Bedroom) 8%
Open to Kitcken)

MITIGATION D

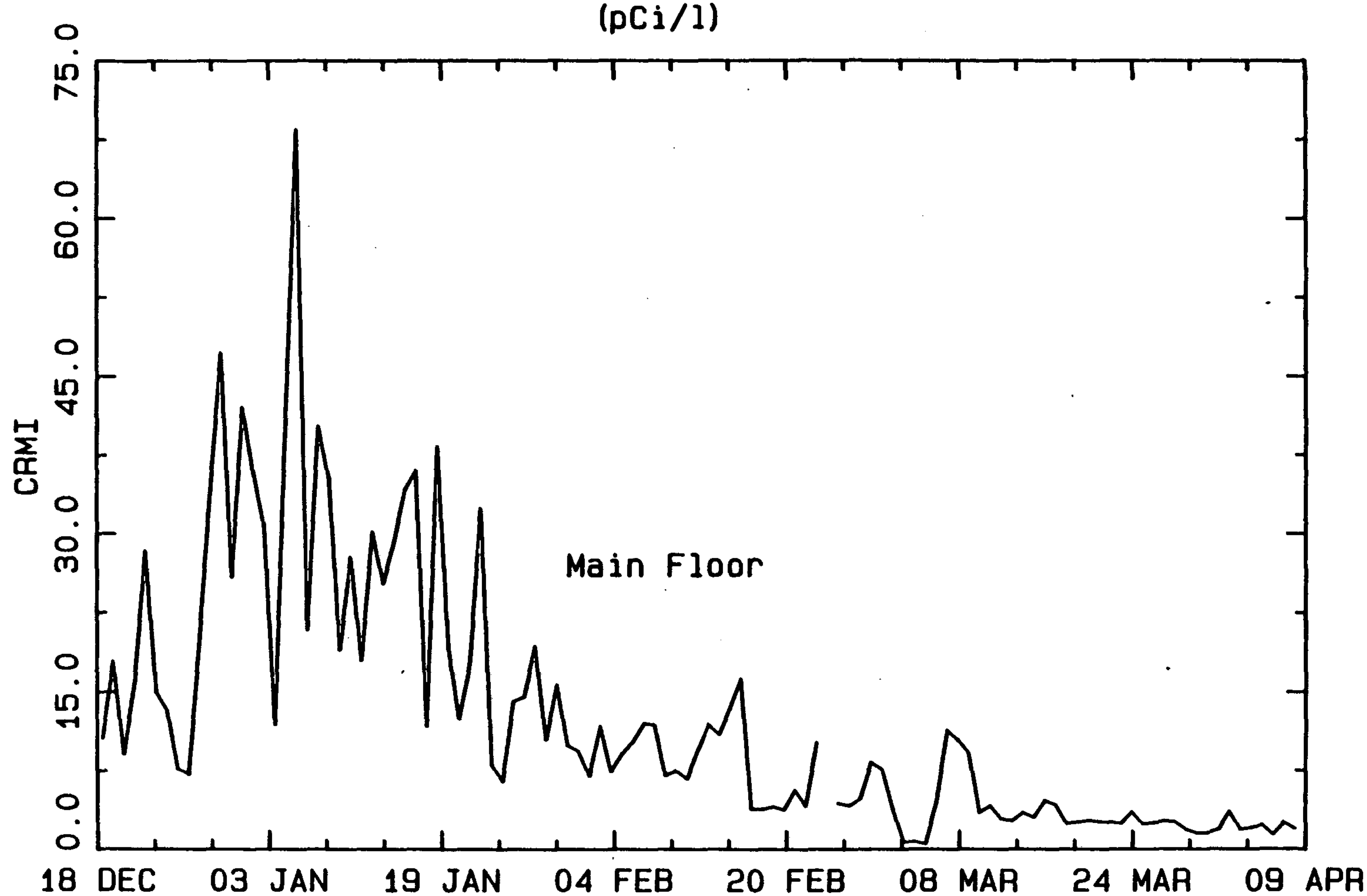
<u>3/1/86</u>

Pressurized basement with forced air furnace fan.	0.7	65.5

ΔP ~ +9Pa
Switched furnace fan to manual on position for continuous operation.
Applied temporary seals to penetrations between basement/crawlspace and basement/main level.
Air-air heat exchanger returned to configuration(3)
Fan on high, continuous operation.
Supply Registers:
Open to 2 Basement Locations 93%
Open to Atrium 7%
Return Registers:
Open to Crawlspace 83%
Open to Atrium 9%
Open to Master Bathroom)
Open to Guest Bathroom) 8%
Open to Kitchen)

BASELINE B		
3/4/86 Forced air furnace fan returned to auto mode, but still pressurizing. Air-air heat exchanger off.	8.7	22.0
MITIGATION E		
3/6/86 Installed 10" axial fan: connected to forced air furnace return plenum. Basement pressurized with main level return air. Air-air heat exchanger was off.	10.8	48.0
MITIGATION F		
3/8/86 Basement pressurized with main level return air using a 10" axial fan mounted on forced air furnace return air plenum. Forced air furnace set to automatic. Backdraft dampers not installed in furnace supply plenum. Pressurization fan flow = 208 L/s Air-air heat exchanger on continuously set to high speed (Config. 4).	3.8	59.0
MITIGATION G		
3/11/86 Removed axial pressurization fan, installed centrifugal pressurization fan. Fan attached to forced air return plenum. Basement pressurized with main level return air. Installed backdraft dampers in forced air furnace supply plenum. Sealed penetrations between basement/main level and the basement/ crawlspace (permanently). Pressurization fan operating continuously. Forced air furnace set to automatic mode. Air-air heat exchanger set to high speed, continuous operation (configuration 4).	2.7	440.0

NSP204
RADON CONCENTRATIONS
One-Day Averages
(pCi/l)



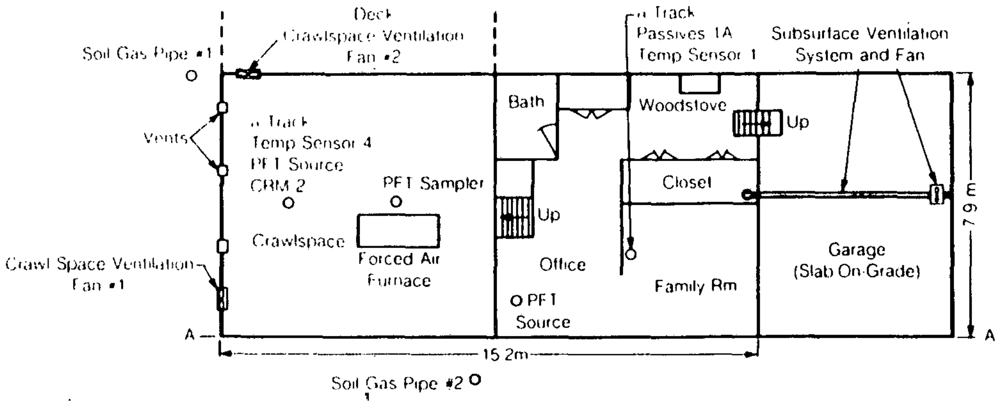
NSP204: 18-DEC-1985 TO 09-APR-1986

APPENDIX D

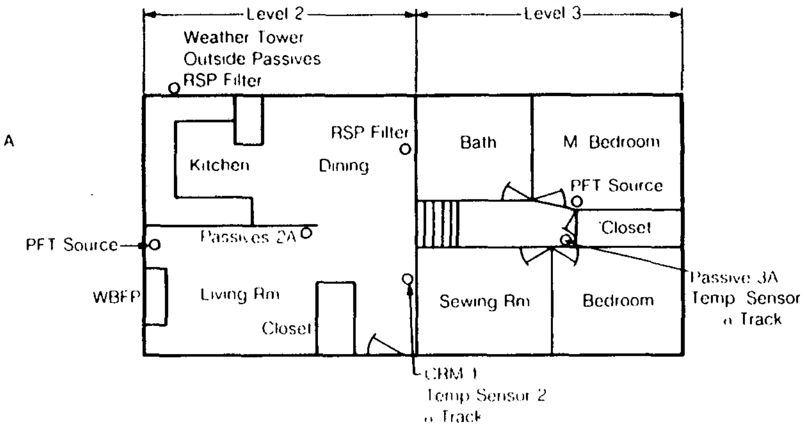
HOUSE FLOOR PLANS

Figures D-1 through D-15 are detailed plans and elevations for each house in this project. Positions of the various monitoring locations are identified as follows: "Passives" refer to the passive samplers for formaldehyde (HCHO), water vapor (H_2O), and in some cases includes the perfluorocarbon tracer (PFT) ventilation measurement sampler ("PFT Sampler"). "PFT Source" are locations of the PFT ventilation measurement sources that permeate tracer into the living spaces, crawlspaces and unoccupied basements. Frequently, a maximum-minimum thermometer was placed nearby to estimate temperatures for correcting tracer permeation rates from the tracer sources. "RSP Filter" refers to measurement of respirable suspended particles (RSP) smaller than three μm that were collected on filters for subsequent gravimetric analysis. Flow through the filter was maintained at 1.7 LPM by a remote pump and control system. Selected filters were also analyzed for polycyclic aromatic hydrocarbons (PAH). "CRM" identifies the sampling port location of the continuous radon monitor (CRM) described in Appendix A. The instrument was frequently located remote and connected to the sample point by polyethylene tubing. Signals from the CRM were sent via cable to the data logger (not shown). "Temp. Sensor" indicates location of the continuously monitored temperature sensors. "α-Track" denotes the placement of the long-term follow-up alpha track detectors. The relative positions of the weather towers that supported the windspeed, wind direction, and outdoor temperature sensors; and the soil pipe probes (designated by "Soil Gas Pipe") are also shown. "WBFP" identifies wood burning fireplaces.

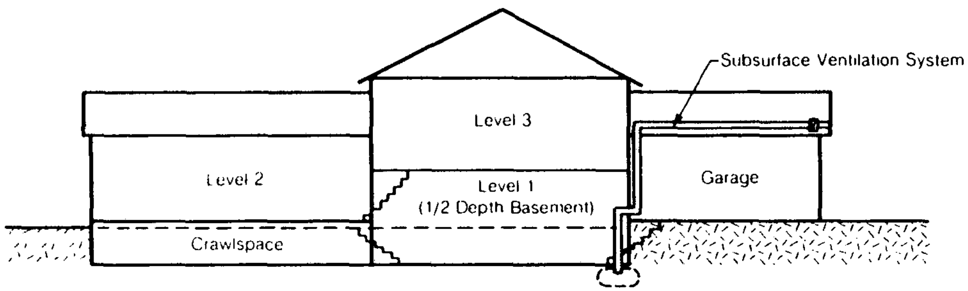
The figures also detail the various mitigation systems installed. Pipe, ducts, fans, sub-slab sumps, air-to-air heat exchanges (AAHX), and house doctored areas are identified. Systems or parts of systems that were eventually removed are indicated on the figures. Substructure-soil cracks and holes that were sealed are not shown.



Level 1 Crawlspace and Half-Depth Basement



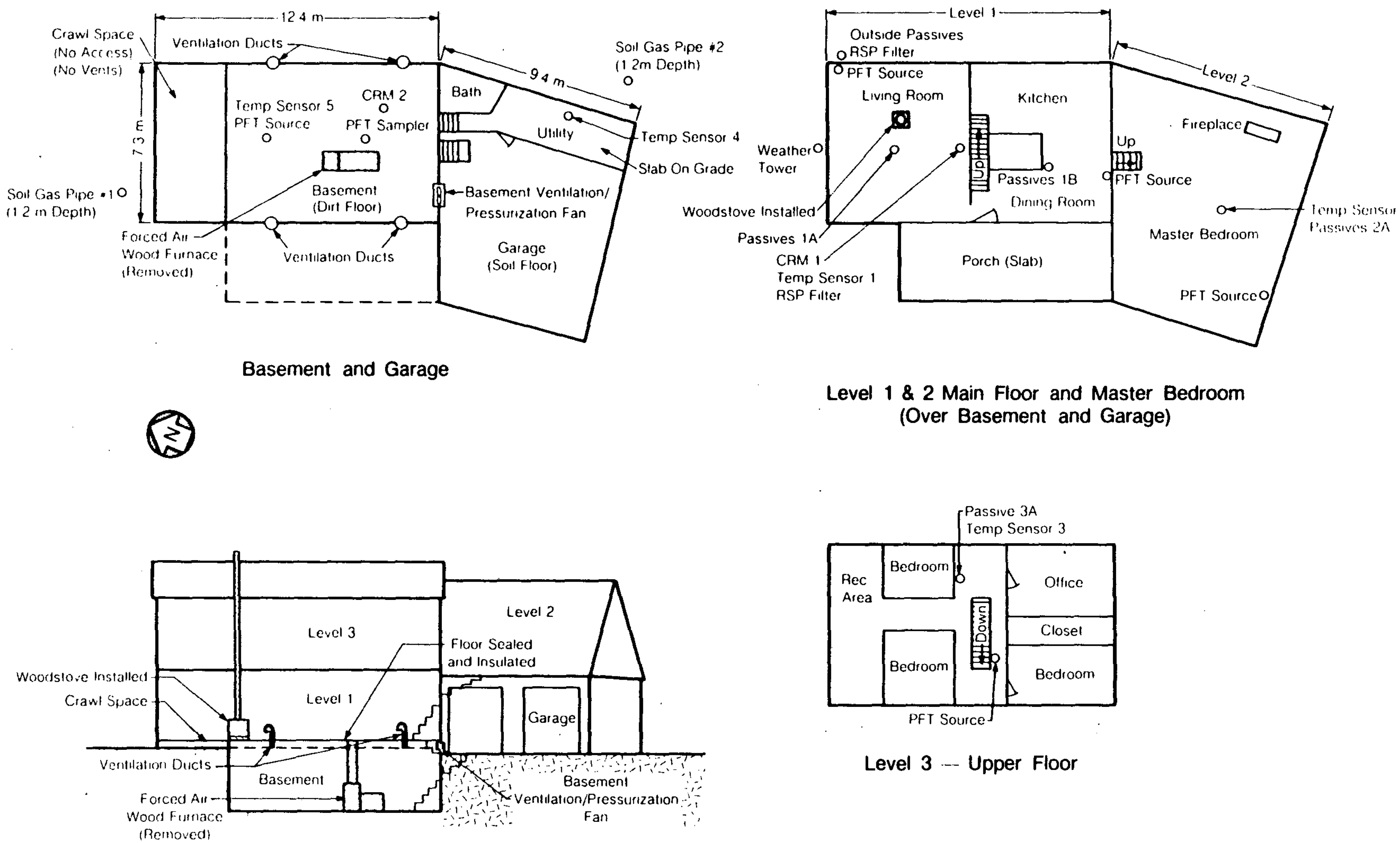
Level 2&3 Main Floor and Upper Floor (Above Crawlspace and 1/2-Depth Basement)



Elevation (A-A)

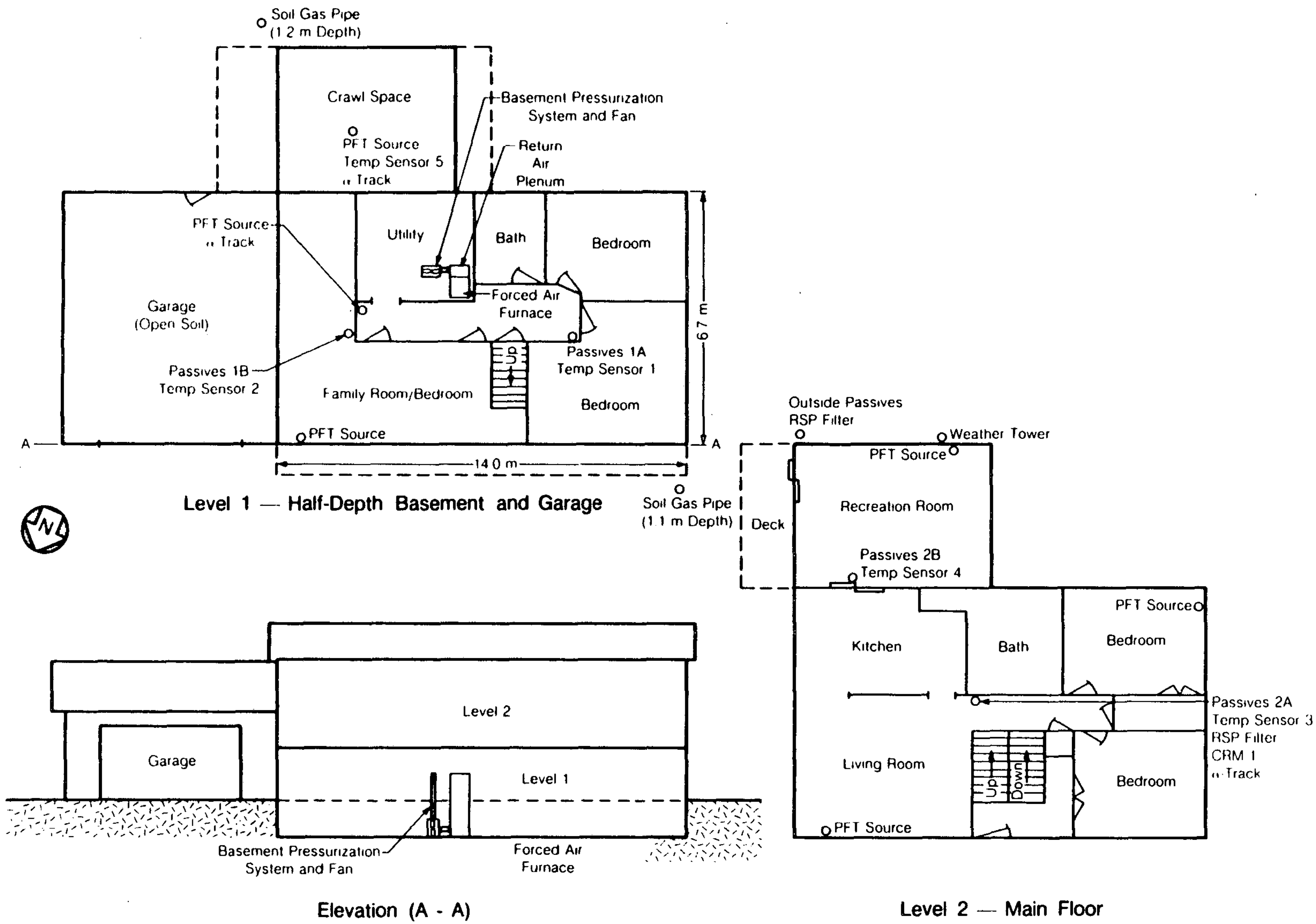
ECD 026C Floor Plan
(Not To Scale)

XBL 8710 10395



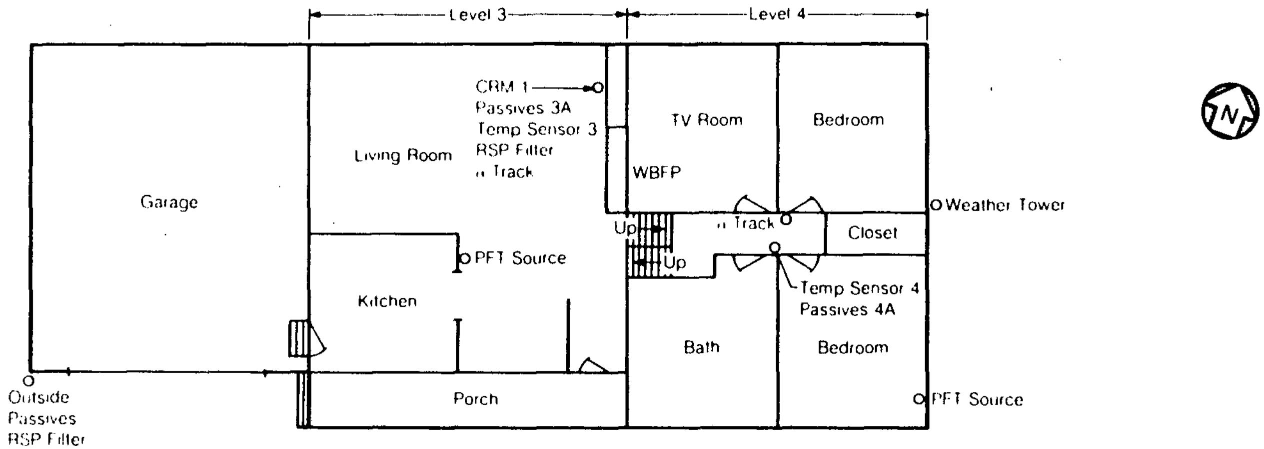
ECD 027 Floor Plan
(Not To Scale)

XBL 8710-10397

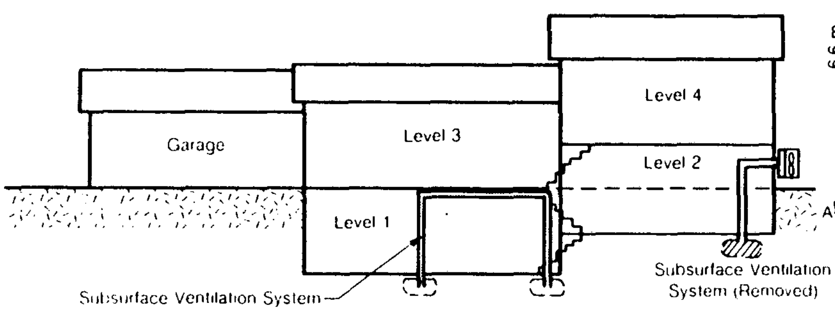


ECD 153 Floor Plan
(Not To Scale)

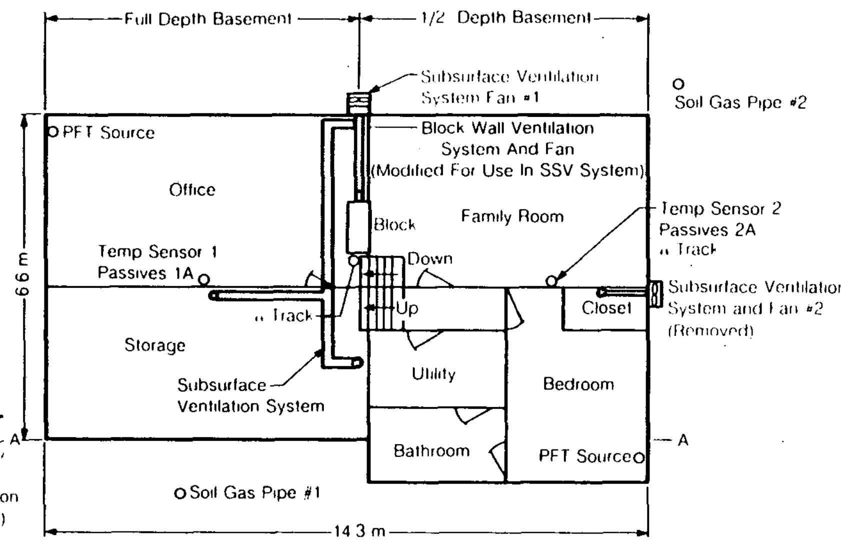
XBL 8710-10396



Level 3&4 — Main And Upper Floors



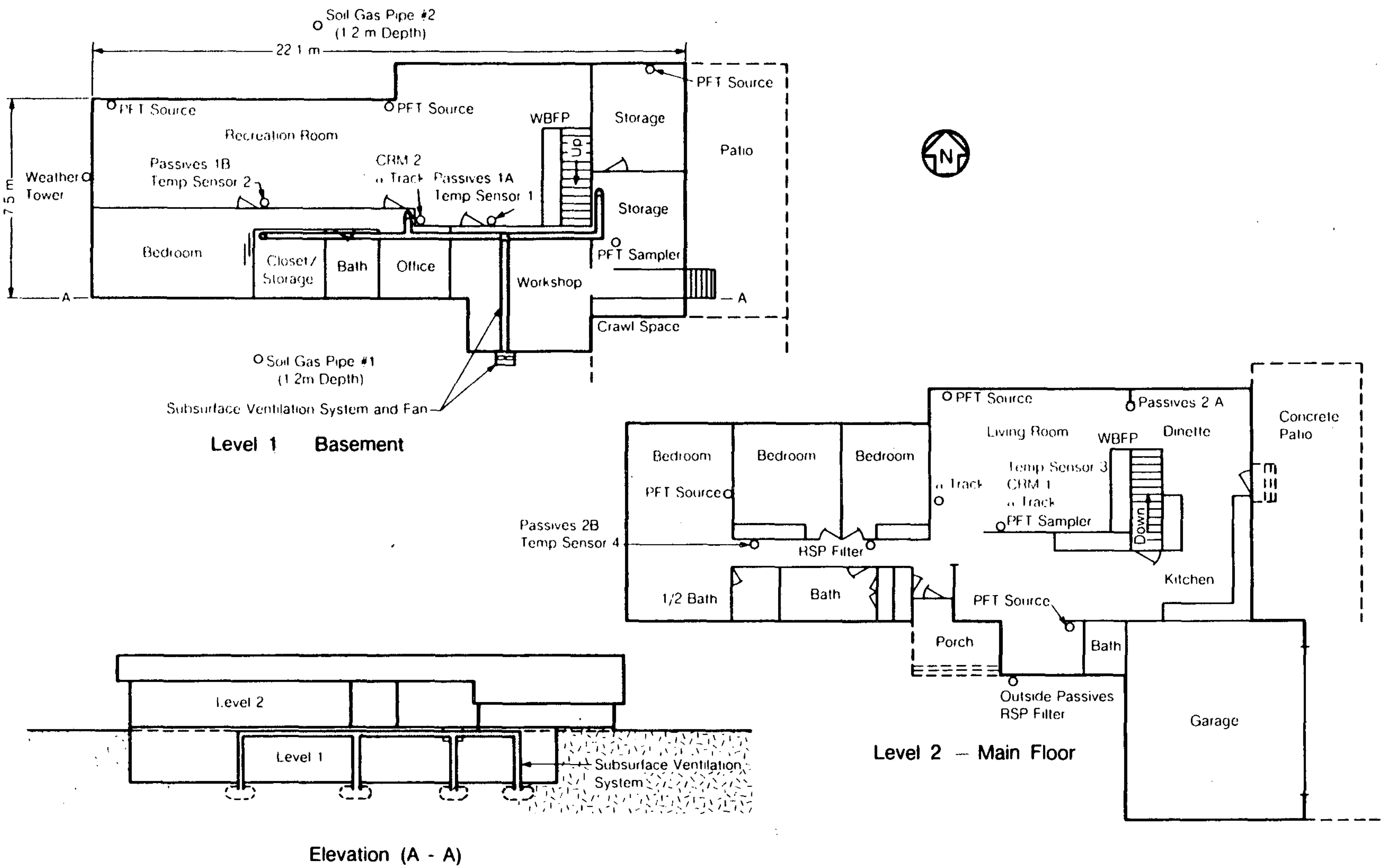
Elevation (A - A)



Level 1&2 — Full And Half-Depth Basement

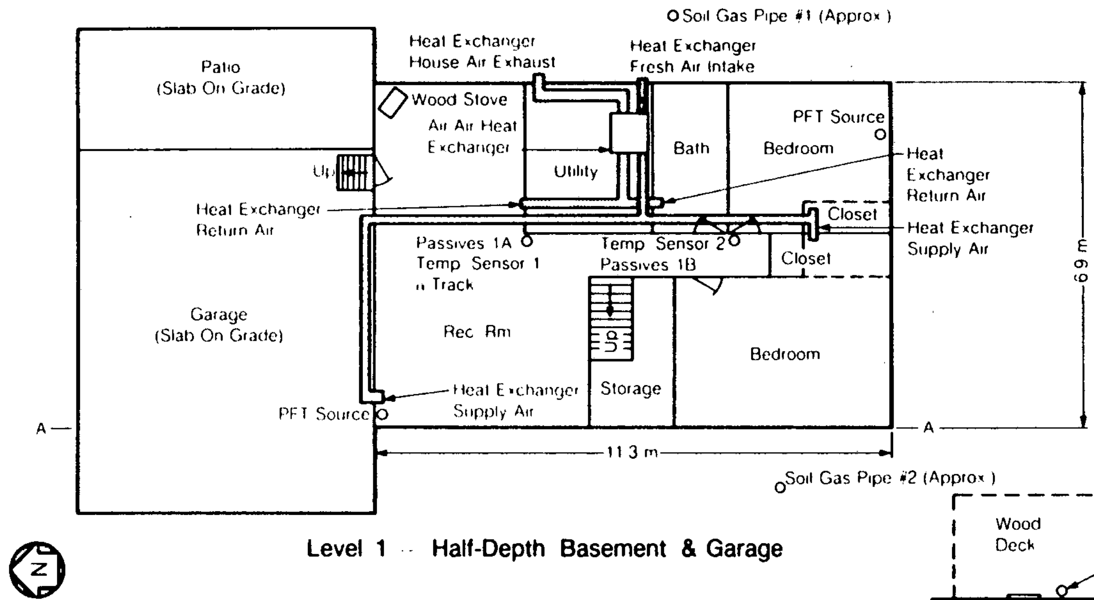
ESP 101 Floor Plan
(Not To Scale)

XBL 8710-10403

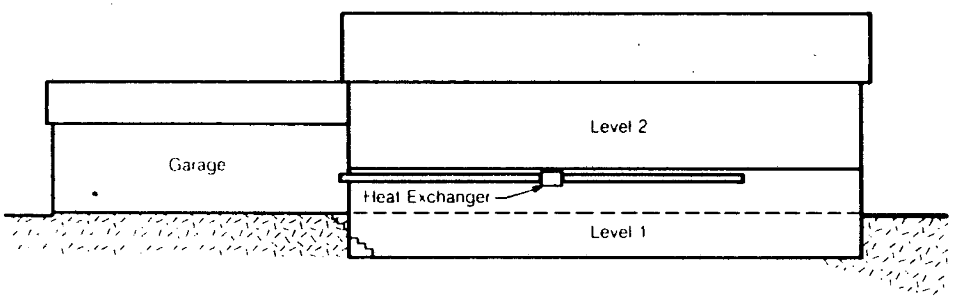


ESP 108C Floor Plan
(Not To Scale)

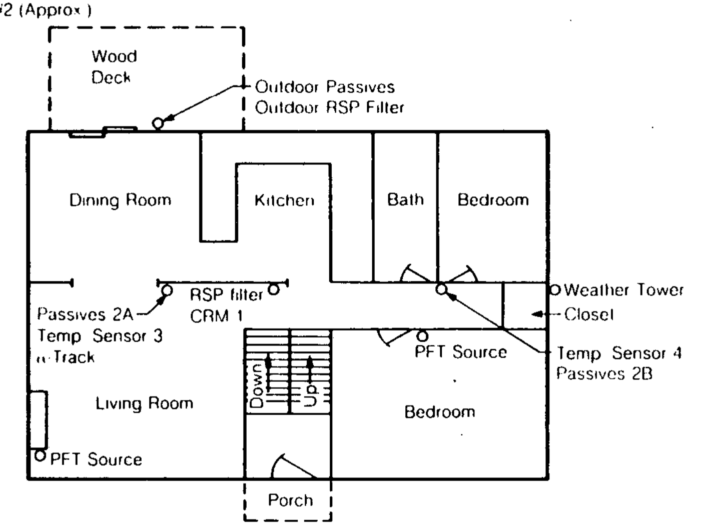
XBL 8710-10391



Level 1 -- Half-Depth Basement & Garage

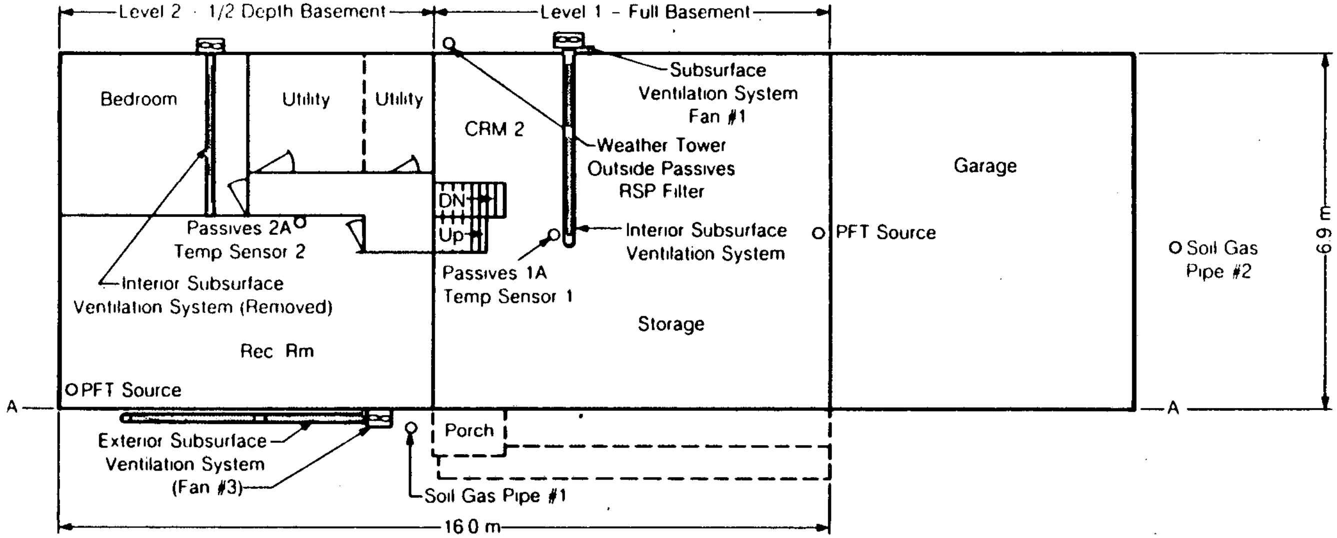


Elevation (A-A)

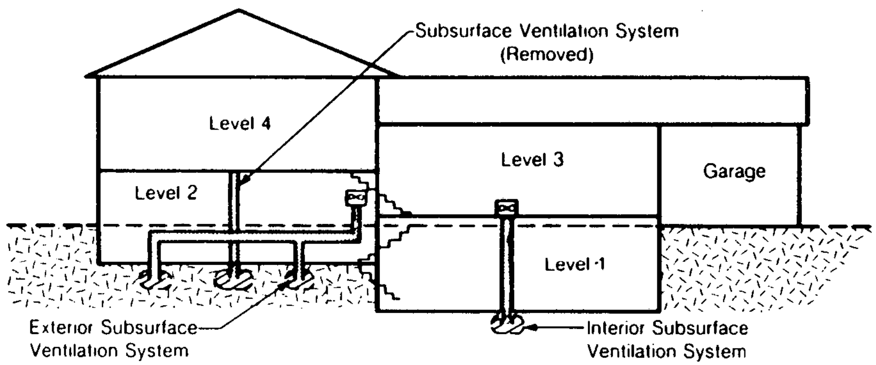


Level 2 Main Floor

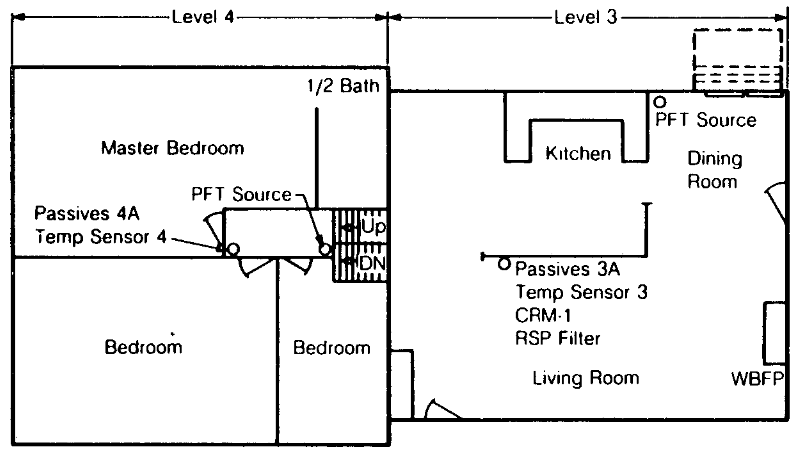
ESP109 Floor Plan
(Not to Scale)



Level 1&2 – Half-Depth Basement and Full Basement



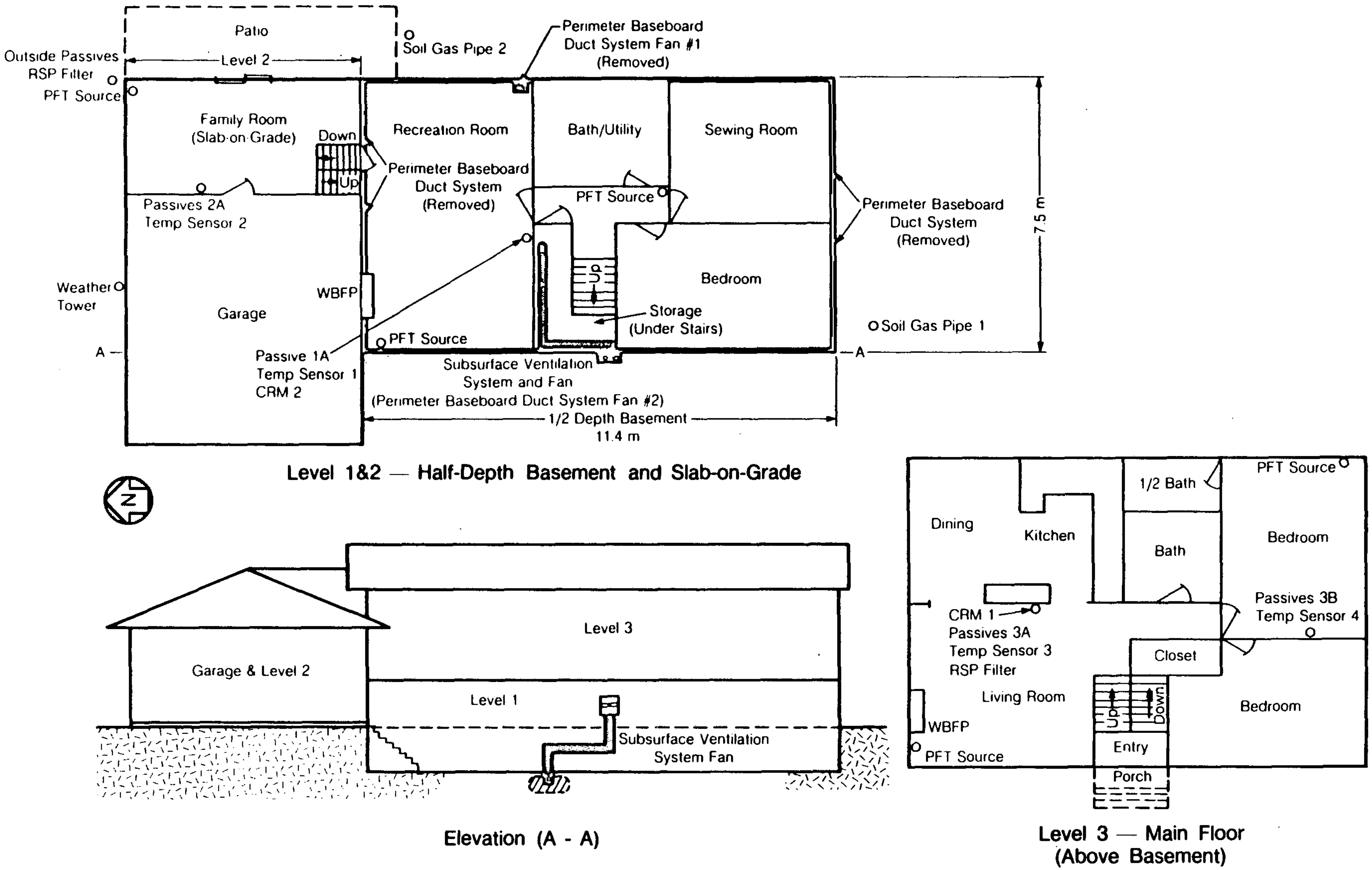
Elevation (A-A)



Level 3&4 – Main Floor and Upper Floor

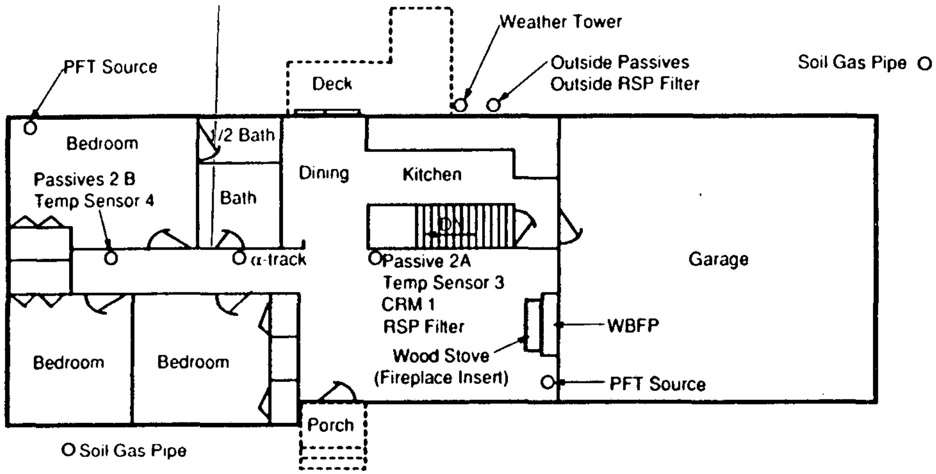
<u>ESP 111 Floor Plan</u>
(Not to Scale)

XBL 8710-10400

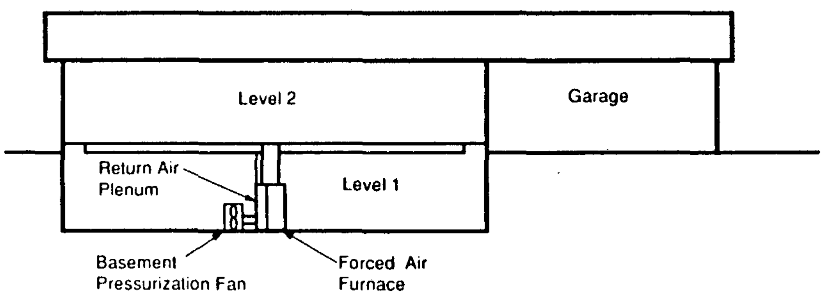


ESP 113 Floor Plan
(Not To Scale)

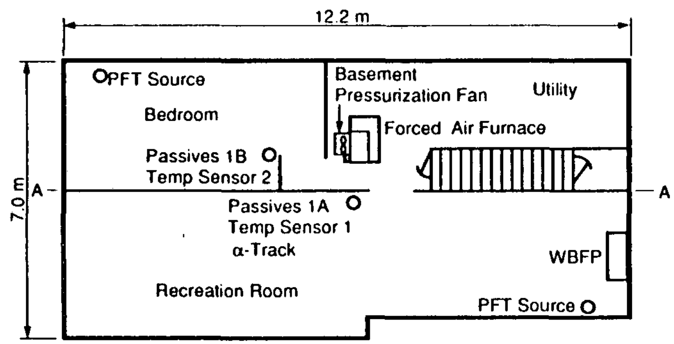
XBL 8710-10398



Level 2-Main Floor



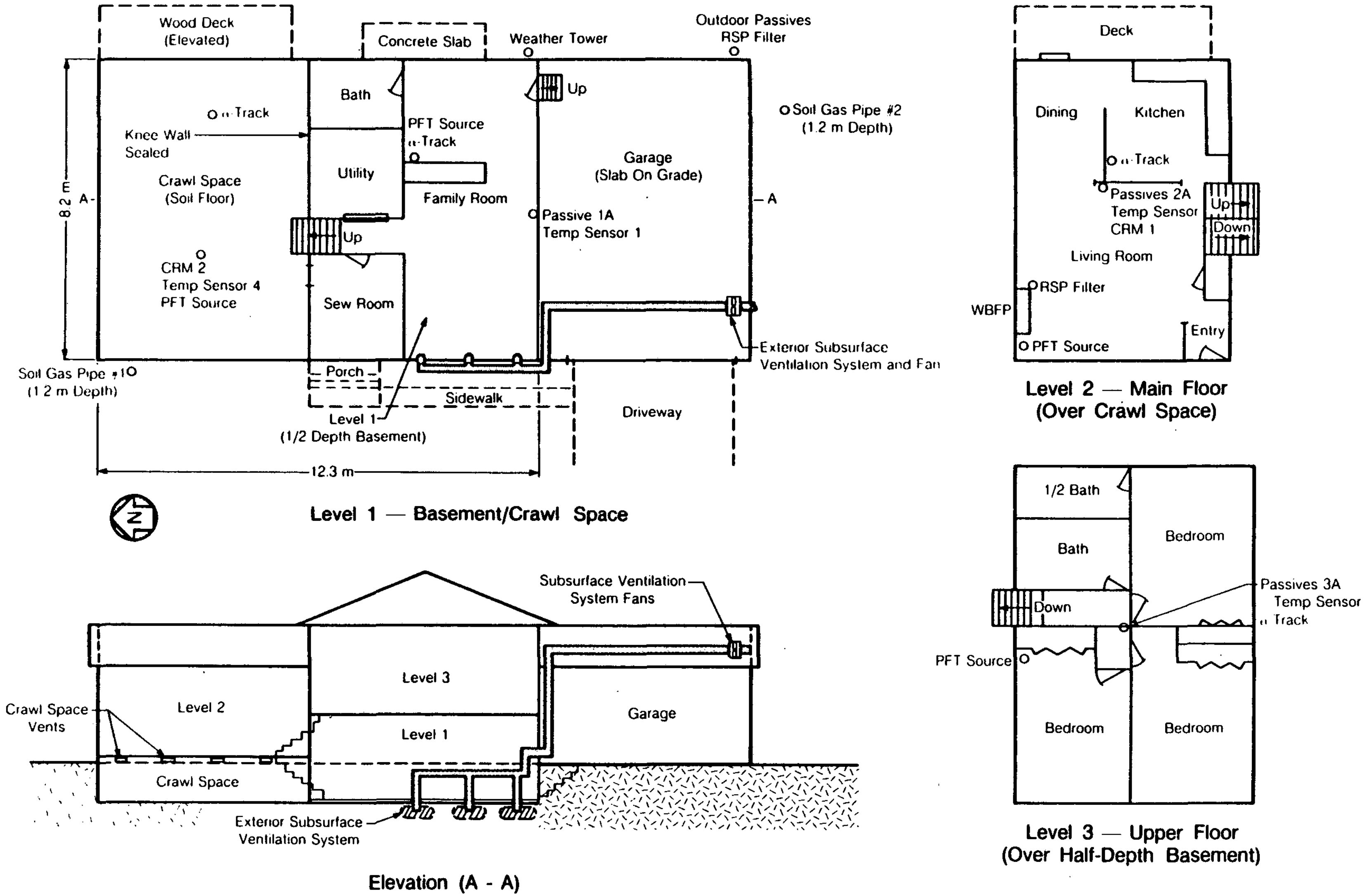
Elevation (A-A)



Level 1-Basement

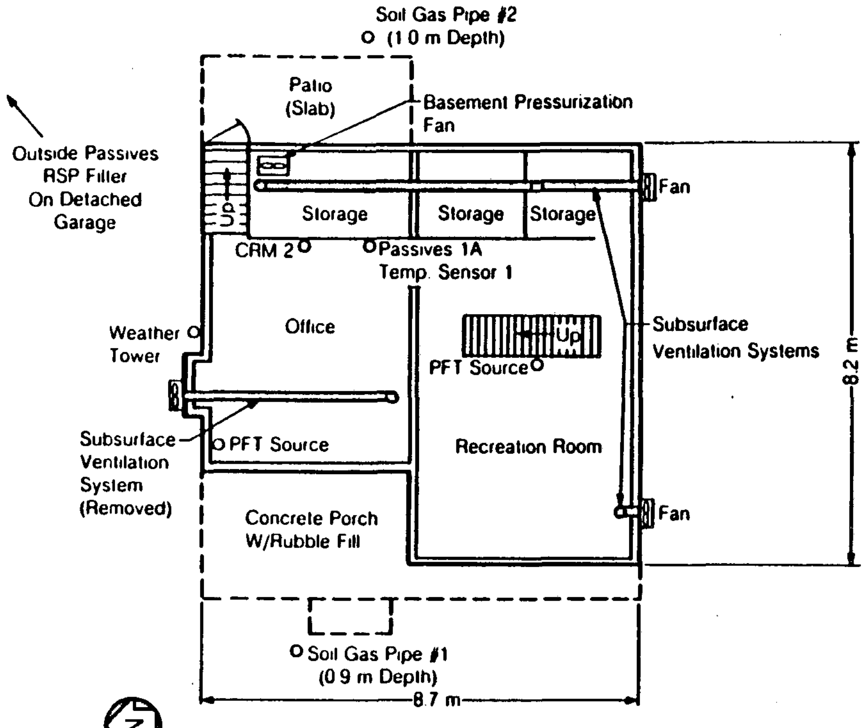
<u>ESP 116 Floor Plan</u>
(Not to scale)

XBL 8710-10389

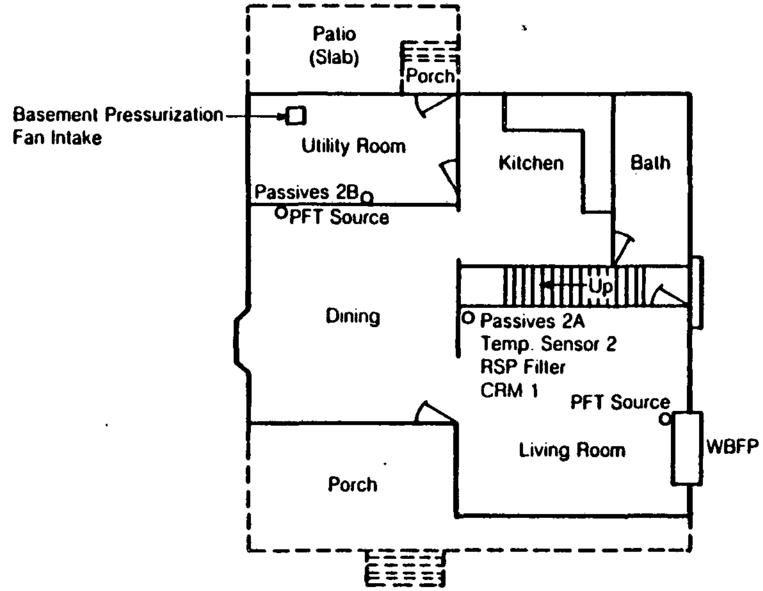


ESP 119 Floor Plan
(Not To Scale)

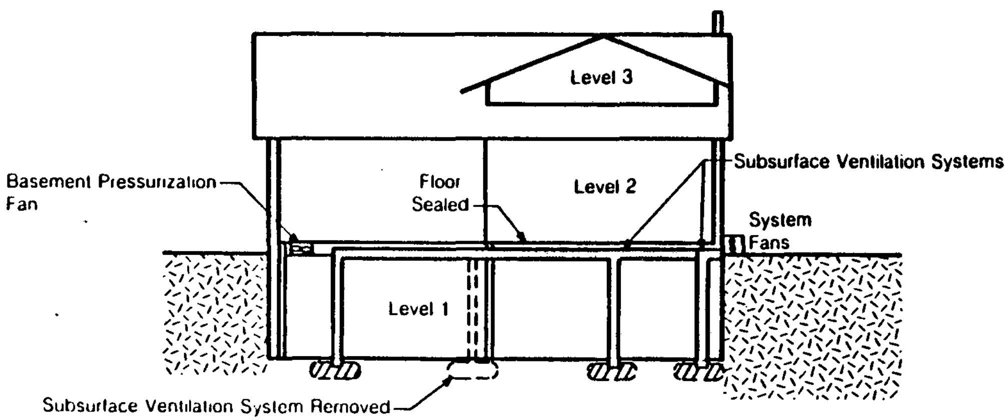
XBL 8710-10399



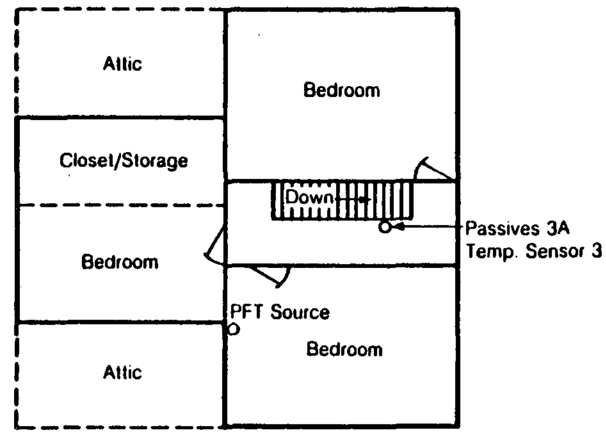
Level 1 — Basement



Level 2 — Main Floor



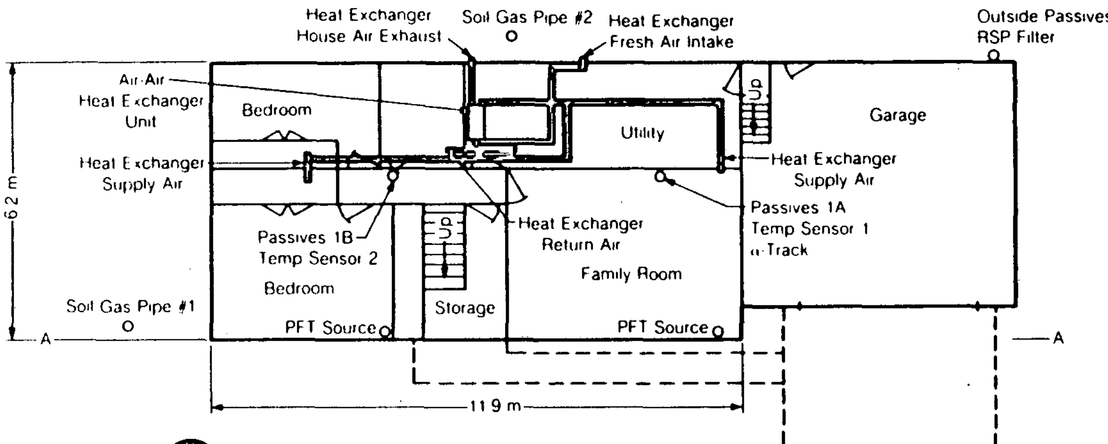
Elevation (West Face)



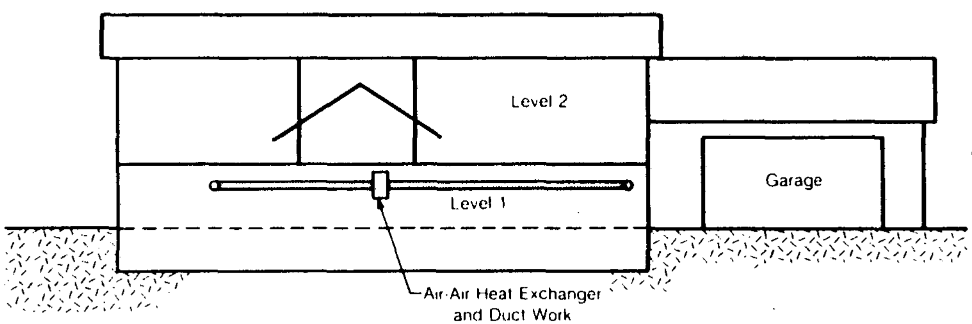
Level 3 — Upper Floor

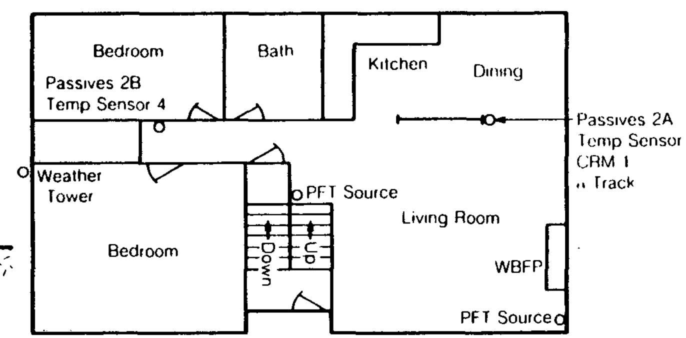
ESP 120 Floor Plan
(Not To Scale)

XBL 8710-10401



Half-Depth
Level 1 -- Basement & Garage



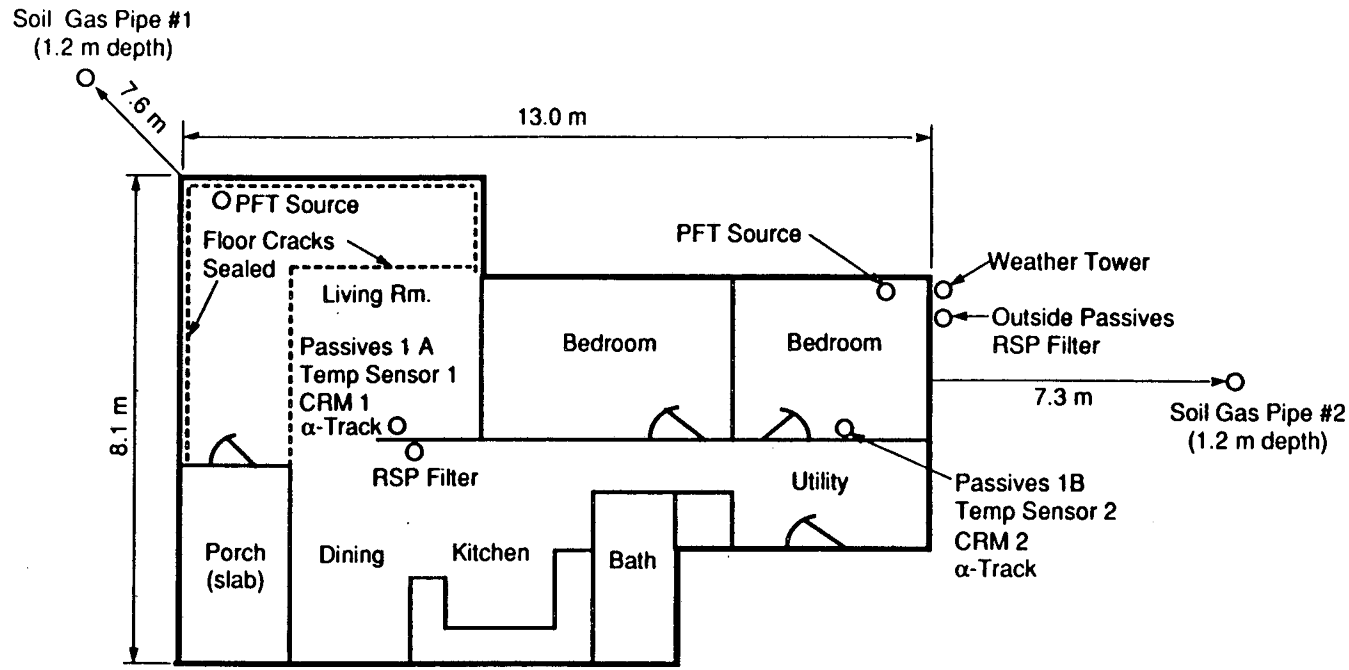


Elevation (A - A) — East Face

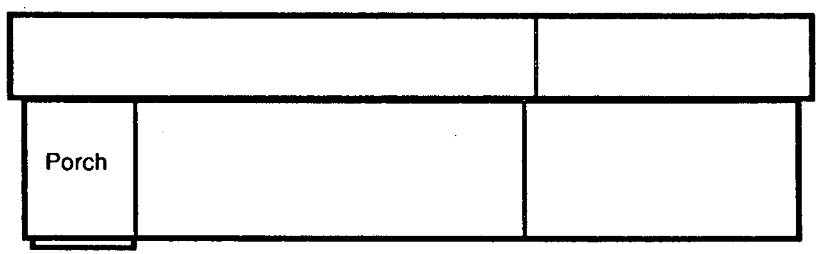
Level 2 – Main Floor

<u>ESP 121 Floor Plan</u>
(Not To Scale)

XBL 8710-10402



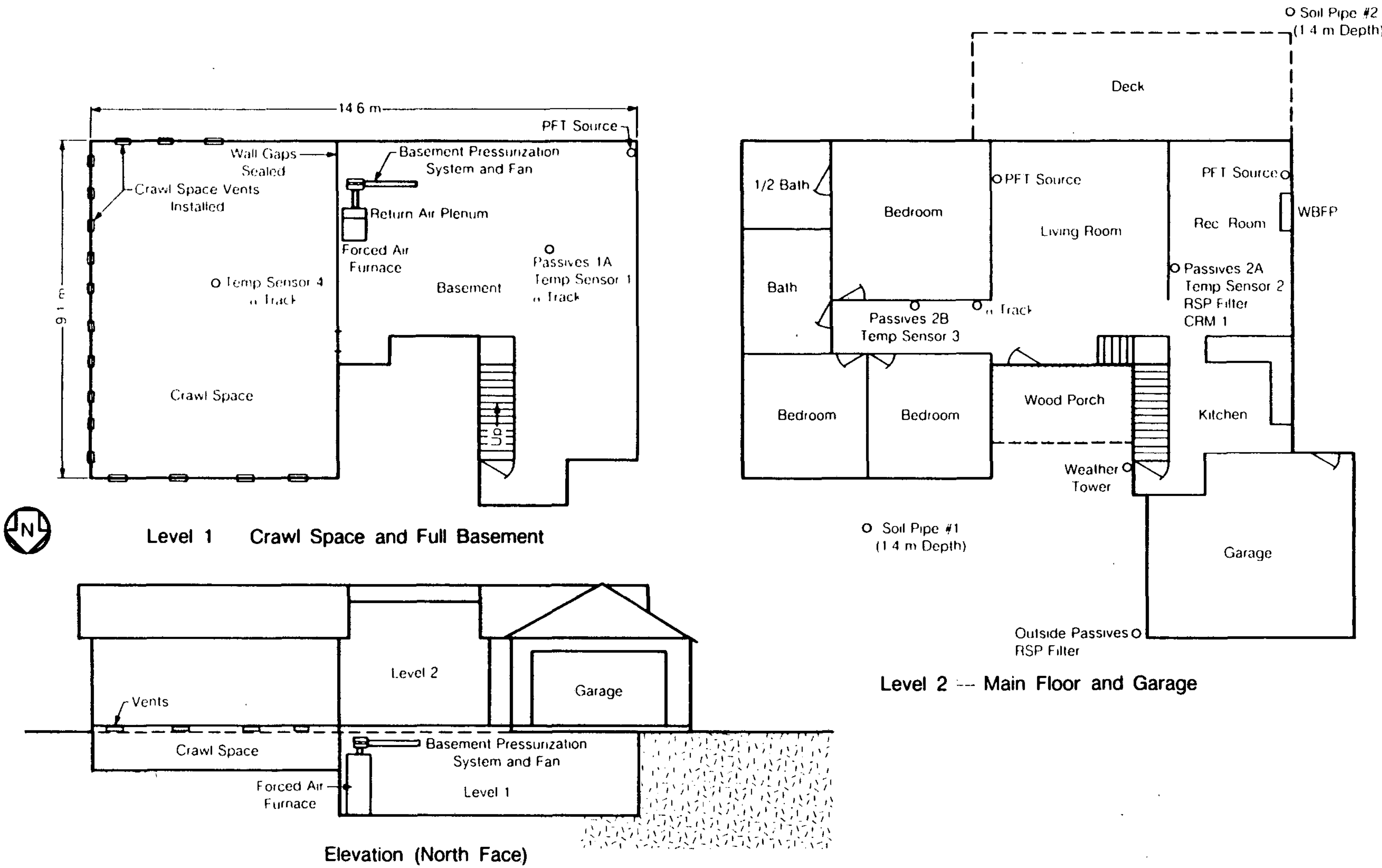
Level 1-Slab-On-Grade



Elevation (east face)

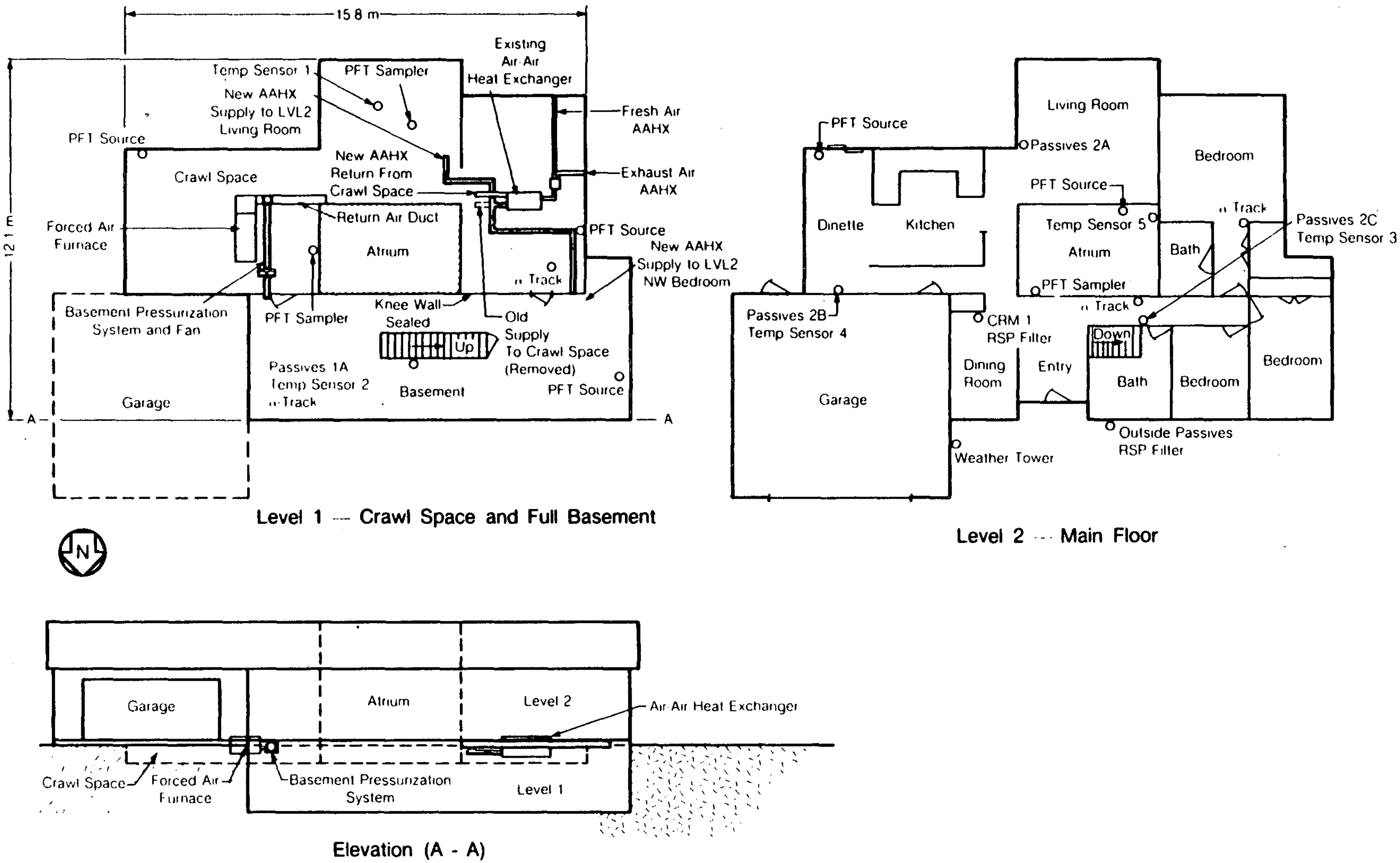
EVA 604 Floor Plan
(Not to scale.)

XBL 8710-10388



<u>NCD 077 Floor Plan</u>
(Not To Scale)

XBL 8710-10390



NSP 204 Floor Plan
(Not To Scale)

XBL 8710-10392

APPENDIX E

SUMMARY POLLUTANT AND VENTILATION DATA

Appendix E (Table E-1) summarizes the measured pollutant and ventilation data for all test periods in each house. The test periods generally spanned seven to ten days during the recommended exposure for the pollutant passive samplers. All data is an average for that period. Additional continuously recorded data for wind, temperature, pressures, and radon that does not have concurrent ventilation and pollutant passive sampler data is not included here. It is summarized in Appendix C and in Figures 23, 24, 29, 33, 41 and 43 in Volume 1.

The test periods are briefly described - for more detail see Appendix C. Pre-mitigation periods in the Control Houses are identified by a number code. Indoor formaldehyde (HCHO) and water vapor (H_2O) concentrations are the arithmetic average of all sites in the building. Indoor HCHO levels never exceeded the frequently recommended guideline of 100 PPB. Outdoor HCHO levels frequently were below the 11 PPB detection limit. In those cases, a mid-point concentration of 5.5 PPB is substituted. Water vapor concentrations are a humidity ratio in units of grams of water per kilogram of dry air, as measured by the passive sampler. To determine the relative humidity requires knowledge of the dry bulb air temperature. For reference, at 21°C, a water vapor concentration of 6.5 g/kg corresponds to a relative humidity of 42%; at -5°C, 2.0 g/kg corresponds to 80% relative humidity. RSP concentrations, μg (particles) per m^3 (air), were often higher outdoors where fireplaces and woodburning stoves are popular. Concentrations occasionally exceeded the National Ambient Air Quality Standard (NAAQS) of 75 $\mu g/m^3$ per year for total suspended particles, but the 24-hour ceiling of 260 $\mu g/m^3$ for PM_{10} (particles smaller than 10 μm in diameter) was never exceeded. The annual ceiling of 50 $\mu g/m^3$ for PM_{10} was more often violated. Indoor concentrations of RSP were generally low, but were significantly affected by the presence of tobacco smoking (ECD153, ESP121, EVA604) and slightly influenced by outdoor air concentrations and the presence of an indoor woodburning appliance. At some houses with tobacco smoking, all standards were exceeded.

Whole house ventilation rates including all occupied zones were determined with the PFT technique. Where it was possible, the PFT data was used to estimate the quantity of outside air infiltrating directly into a substructure. In those substructures where mechanical systems provided considerable additional ventilation air flow from other house zones, the total ventilation is shown in parentheses. These data show the dramatic effect of basement overpressurization, in particular, inhibiting infiltrating air while boosting total substructure ventilation.

The last two columns are the specific leakage area (SLA) data as determined by blower door depressurization. Units are in leakage area (cm^2) normalized by floor area (m^2), so that houses can be compared. For basements and crawlspaces, the floor area is for the substructure only. Reductions in these numbers are due to sealing for either basement overpressurization or crawlspace isolation.

APPENDIX E

TABLE E-1 SUMMARY DATA FOR 7 TO 10-DAY TEST PERIODS

HOUSE ID	TEST PERIOD DESCRIPTION	RADON (pCi/L) MAIN FLOOR	BSMT	CRAWL	OTHER POLLUTANTS HCHO(PPB) IN	OUT*	H2O (g/kg) IN	OUT	RSP (ug/m3) IN	OUT	PFT VENTILATION (ACH) WHOLE HOUSE	BSMT INFILT.+	CRAWL INFILT.	SLA** (cm2/m2) WHOLE HOUSE	BSMT/ CRAWL
ECD 026C	CONTROL #1	14.9	-	20.2	53	5.5	5.86	4.25	16.1	26.1	0.59	-	1.35	3.60	
	#2	17.2	-	19.5	48	21.0	4.36	2.77	27.4	86.7	ND	-	ND	-	
	#3	17.9	-	19.5	33	5.5	4.20	1.78	19.9	71.6	0.52	-	1.38	-	
	#4	19.6	-	19.8	29	11.0	3.45	1.51	9.2	32.3	0.57	-	1.13	-	
	#5	14.4	-	12.8	41	18.0	4.99	3.54	26.3	80.5	0.41	-	1.03	-	
	#6	19.2	-	18.2	43	25.0	4.34	2.04	48.1	175.2	0.42	-	1.40	3.95	
	#7	18.6	-	19.3	53	18.0	4.49	2.86	25.1	83.0	0.15	-	0.39	-	
	#8	17.5	-	24.2	43	12.0	5.32	3.71	23.6	58.6	0.50	-	1.37	4.52	
	#9	15.7	-	18.9	57	5.5	5.56	4.05	21.8	38.7	ND	-	ND	-	
	#10	15.7	-	ND	48	15.0	5.35	3.65	22.1	57.8	0.52	-	1.34	-	
	#11	13.8	-	ND	48	5.5	5.82	4.23	20.7	46.5	0.51	-	1.35	-	
	#12	16.2	-	ND	42	17.0	5.14	2.61	23.2	63.3	0.26	-	1.35	-	
	#13	16.0	-	ND	42	5.5	4.93	2.78	16.5	36.7	0.57	-	1.22	-	
	#14	14.0	-	ND	52	5.5	5.58	4.68	20.2	42.1	0.48	-	0.86	-	
	#15	17.3	-	ND	57	5.5	6.11	4.49	22.3	73.6	0.35	-	1.02	3.53	
	#16	14.3	-	ND	53	5.5	6.34	5.12	16.5	30.8	0.58	-	1.40	-	
	#17	14.5	-	ND	48	5.5	5.70	4.47	14.0	37.1	0.33	-	1.25	-	
	MIT A - VENT CRAWL	7.1	-	ND	ND	ND	ND	ND	ND	ND	ND	-	ND	-	
	MIT B - MIT A + SSV PRESSURE	4.4	-	7.3	50	21.0	5.71	4.42	17.2	34.8	0.55	-	1.27	4.54	
ECD 027	BASELINE	46.2	97.2	-	22	5.5	8.12	6.42	17.9	7.2	1.06	1.82	-	8.13	142.20
	MIT A - SEAL HSE FLR	24.5	307.0	-	23	5.5	4.00	2.74	13.6	9.8	1.17	0.51	-	7.30	12.40
	MIT B - 24 L/s FAN	16.1	194.0	-	25	5.5	3.93	3.08	13.7	8.6	1.16	0.96	-	7.36	-
	- PRESSURE TO > 5 Pa	0.9	1.6	-	25	5.5	5.45	5.16	18.8	11.1	1.16	2.80	-	7.14	-
ECD 153	BASELINE A	23.3	-	-	66	21.0	6.86	2.98	123.7	87.4	0.25	0.21(0.75)	3.87	1.81	-
	MIT A - SEAL CRWL FLR	24.3	-	-	53	5.5	5.75	1.91	114.9	31.3	0.21	0.26(0.72)	1.21	1.95	-
	MIT D - BSMT PRESSURE TO ~ 2.5 Pa	3.3	-	-	78	5.5	7.96	4.38	111.0	17.8	0.16	0.06(0.97)	ND	1.60	5.19
ESP 101	BASELINE	26.9	-	-	48	5.5	5.94	2.69	17.7	22.4	0.16	0.14(2.00)	-	1.96	
	MIT A - VENT. FIREPLACE BLOCK	21.0	-	-	28	16.0	4.62	2.27	28.7	75.7	0.25	0.13(1.49)	-	1.99	
	MIT D - SSV PRESSURIZATION	1.1	2.1	-	36	13.0	6.00	4.80	7.7	10.1	0.34	0.39(1.37)	-	1.79	

APPENDIX E

TABLE E-1 SUMMARY DATA FOR 7 TO 10-DAY TEST PERIODS (CON'T.)

HOUSE ID	TEST PERIOD DESCRIPTION	RADON (pCi/L) MAIN FLOOR	RADON (pCi/L) BSMT	RADON (pCi/L) CRAWL	OTHER POLLUTANTS HCHO(PPB) IN	HCHO(PPB) OUT*	H2O (g/kg) IN	H2O (g/kg) OUT	RSP (ug/m3) IN	RSP (ug/m3) OUT	PFT VENTILATION (ACH) WHOLE HOUSE	BSMT INFILT.+	CRAWL INFILT.	SLA** (cm2/m2) WHOLE HOUSE	SLA** BSMT/ CRAWL
ESP 108C	CONTROL #1	13.0	15.8	-	19	5.5	5.75	3.43	6.0	17.1	0.33	0.47	-	3.08	
	#2	12.6	14.5	-	24	14.0	4.84	2.92	11.3	ND	0.41	0.48	-	-	
	#3	13.2	14.8	-	16	13.0	4.85	1.72	53.4	8.7	0.46	0.74	-	-	
	#4	13.0	14.1	-	22	25.0	5.34	2.00	4.9	31.1	0.45	0.54	-	-	
	#5	16.3	19.1	-	22	11.0	5.57	3.24	9.6	39.4	0.40	0.48	-	-	
	#6	14.4	15.9	-	26	29.0	5.45	2.11	22.5	152.5	0.47	0.79	-	3.18	
	#7	16.9	19.6	-	23	11.0	6.16	3.79	5.0	29.1	0.38	0.36	-	2.94	
	#8	12.6	12.7	-	24	5.5	6.03	4.10	4.7	14.1	0.26	0.50	-	-	
	#9	18.7	ND	-	26	14.0	6.08	4.24	4.6	24.8	0.35	0.54	-	-	
	#10	20.0	ND	-	22	5.5	6.30	3.28	7.1	36.7	0.25	0.34	-	-	
	#11	17.0	ND	-	23	5.5	6.20	3.14	3.4	14.7	0.31	0.46	-	-	
	#12	14.4	ND	-	22	5.5	6.30	4.32	3.5	16.2	0.29	0.29	-	2.98	
	#13	20.3	ND	-	25	5.5	6.46	4.98	8.7	23.3	0.24	0.33	-	-	
	#14	20.2	ND	-	26	5.5	7.04	5.20	7.9	19.6	0.28	0.34	-	-	
	#15	15.4	ND	-	22	5.5	6.62	4.26	15.5	14.4	0.33	0.42	-	-	
	MIT A - SSV PRESSURIZATION	1.6	1.8	-	31	5.5	6.41	4.62	10.5	14.1	0.19	0.28	-	2.96	
ESP 109	BASELINE	8.5	-	-	ND	ND	ND	ND	30.0	32.3	0.31	0.45	-	2.76	
	MIT A - AAHX ON MAX	2.3			ND	ND	ND	ND	12.6	11.7	0.84	1.59	-	3.97	
ESP 111	BASELINE	14.2	-	-	57	5.5	7.12	6.04	7.9	10.0	0.31	0.44(1.01)	-	3.91	
	MIT A - SEAL HOLES	38.5	-	-	53	11.0	4.51	1.45	16.2	45.7	0.41	0.69(2.59)	-	4.60	
	MIT A - SEAL SILL PLATE	48.0	-	-	52	35.0	5.38	2.50	29.2	91.0	0.25	0.53(1.24)	-	3.76	
	MIT D - INT AND EXT SSV PRESSURIZATION	1.9	-	-	54	5.5	6.28	4.99	8.5	10.0	0.46	0.35(0.71)	-	1.82	
ESP 113	BASELINE A	23.4	-	-	13	11.0	5.61	2.71	17.2	34.6	0.04	ND	-	4.63	
	MIT A - BASEBOARD VENTILATION	18.9	-	-	22	5.5	4.25	2.86	17.1	25.0	0.21	0.01	-	3.80	
	MIT C - SSV PRESSURIZATION	1.8	-	-	24	5.5	6.00	4.40	11.6	10.8	0.15	0.19	-	3.54	
	MIT C - SAME AS ABOVE	1.7	-	-	ND	ND	ND	ND	ND	ND	0.19	0.28	-	-	
ESP 116	BASELINE	10.6	-	-	61	5.5	5.51	2.90	17.5	26.2	0.45	0.45(0.70)	-	1.01	-
	MIT A - SEAL HOLES	14.5	-	-	31	12.0	4.19	1.44	26.8	42.3	0.46	0.52(0.83)	-	1.44	7.11
	MIT B - BSMT PRESSURE W/FURNACE FAN	2.9	-	-	50	20.0	4.66	2.12	26.1	97.5	0.31	0(2.53)	-	1.50	6.39
	MIT E - BSMT PRESSURE ~1.5 Pa	4.3	-	-	62	5.5	7.07	4.30	15.2	8.8	0.30	0.05(1.53)	-	1.59	8.58

APPENDIX E

TABLE E-1 SUMMARY DATA FOR 7 TO 10-DAY TEST PERIODS (CON'T.)

HOUSE ID	TEST PERIOD DESCRIPTION	RADON (pCi/L) MAIN FLOOR	RADON BSMT	RADON CRAWL	OTHER POLLUTANTS HCHO(PPB) IN	HCHO(PPB) OUT*	H2O (g/kg) IN	H2O (g/kg) OUT	RSP (ug/m3) IN	RSP (ug/m3) OUT	PFT VENTILATION (ACH) WHOLE HOUSE	BSMT INFILT.+	CRAWL INFILT.	SLA** (cm2/m2) WHOLE HOUSE	BSMT/ CRAWL
ESP 119	BASELINE A	41.2	-	115.0	78	5.5	7.32	5.71	13.3	9.8	0.47	-	0.49	2.07	-
	MIT A - SEAL CRAWL FLOOR	33.0	-	54.6	44	13.0	5.48	3.75	27.6	30.3	0.46	-	0.54	5.54	10.49
	MIT B - SEAL HOUSE FLOOR	32.6	-	84.9	46	17.0	5.24	3.43	10.9	27.4	0.44	-	0.22	4.53	3.13
	MIT C - VENT CRAWL	17.8	-	6.8	61	5.5	5.88	4.36	15.0	11.0	0.42	-	1.21	4.56	-
	MIT E - MIT C + EXT SSV DEPRESS.	2.6	-	-	56	5.5	6.59	4.45	14.4	10.8	0.31	-	1.04	4.77	-
ESP 120	BASELINE A	151.0	187.0	-	26	5.5	8.09	5.48	7.0	6.5	0.20	0.54(0.56)	-	3.11	-
	MIT A - SEAL HOLES	122.0	139.0	-	28	5.5	6.20	3.33	10.3	30.9	0.25	0.69(0.75)	-	2.95	-
	MIT B-SSV DEPRESSURIZATION	4.8	8.4	-	12	5.5	5.24	3.72	42.6	24.8	0.38	0.55(0.66)	-	3.17	8.08
	MIT G - SSV PRESSURIZATION	2.3	2.7	-	19	12.0	7.06	4.39	9.2	11.2	0.26	0.68(0.69)	-	2.58	6.53
	MIT H - BSMT PRESSURE	0.8	0.7	-	30	31.0	6.56	4.52	6.7	7.6	0.31	0.07(2.54)	-	-	-
ESP 121	BASELINE	12.0	-	-	56	5.5	6.56	4.82	83.2	24.4	0.29	0.57	-	2.42	
	MIT A - AAHX ON MAX	3.5	-	-	24	5.5	6.14	4.62	63.7	14.8	0.94	1.95	-	2.01	
EVA 604	BASELINE 1	9.4	-	-	49	5.5	7.98	4.38	426.9	21.4	0.19	-	-	3.23	
	BASELINE 2	12.5	-	-	36	24.0	6.27	2.79	290.2	55.8	0.16	-	-	3.46	
	MIT A - SEAL CRACKS	7.7	-	-	51	15.0	8.06	4.71	365.7	30.7	0.12	-	-	3.26	
NCD 077	BASELINE														
	MIT A - VENT CRAWL	18.3	-	-	38	5.5	5.37	3.12	11.4	33.3	0.46	0.48(1.25)	0.35	3.50	-
	MIT D - BSMT	8.3	-	-	48	5.5	6.62	4.34	17.9	31.5	0.39	0.40(1.27)	3.24	3.99	-
	PRESSURE ~ 2 Pa	2.2	-	-	55	5.5	7.16	4.31	11.4	19.8	0.40	0(2.19)	2.44	2.48	8.82
NSP 204	BASELINE A	35.2	-	-	40	14.0	5.87	3.56	9.6	23.8	0.74	0.26(1.58)	0.48	2.42	
	MIT A - MODIFY AAHX	5.1	-	-	37	5.5	4.67	3.78	8.3	18.5	1.04	1.27(2.47)	0.15	1.60	
	MIT G - BSMT PRESSURIZED	3.3	-	-	ND	ND	ND	ND	ND	ND	1.33	0(6.30)	0.70	-	
	MIT G - SAME AS ABOVE	2.1	-	-	34	21.0	6.59	5.63	22.1	8.5	1.26	0(6.47)	1.45	1.65	

*HCHO LEVELS BELOW THE DETECTION LIMIT OF 11 PPB ARE SUBSTITUTED WITH 5.5 PPB.

+ONLY OUTSIDE AIR INFILTRATION IS CONSIDERED, EXCEPT FOR THOSE ZONES WHERE MECHANICAL SYSTEMS PROVIDE CONSIDERABLE ADDITIONAL VENTILATION. TOTAL VENTILATION IS THEN SHOWN IN PARENTHESES.

**SPECIFIC LEAKAGE AREA (SLA) AS DETERMINED USING BLOWER DOOR DEPRESSURIZATION

ND = NO DATA AVAILABLE

APPENDIX F

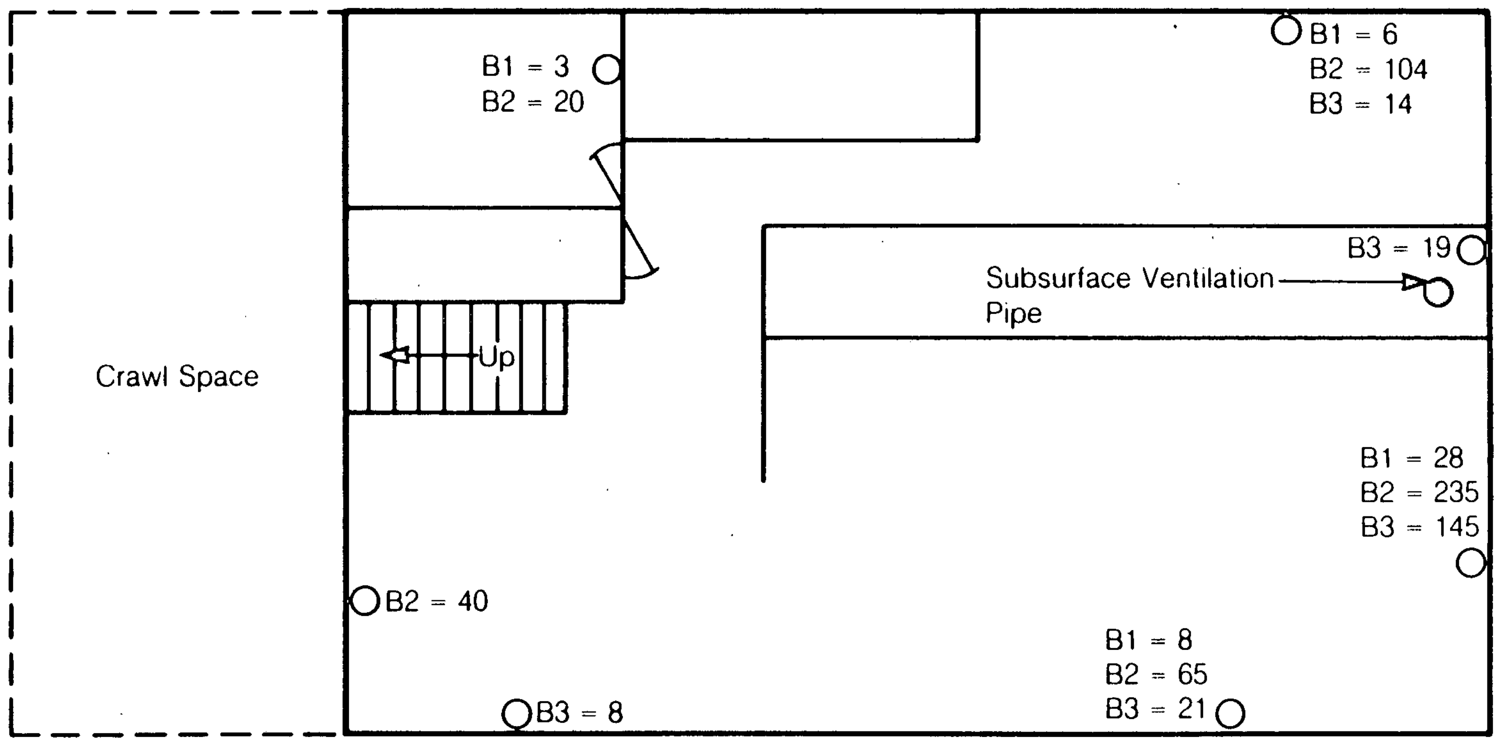
DIAGNOSTIC MAPS OF RADON GRAB SAMPLES

Figures F-1 through F-6 of Appendix F are the diagnostic maps of grab sample concentrations taken at suspected radon entry locations for houses ECD026C, ESP101, ESP108C, ESP111, ESP113, and ESP119. The maps were prepared to guide the selection, design, and placement of mitigation systems, particularly subsurface ventilation (SSV), and to study the effectiveness of the system after installation. At the time of this study, this approach was experimental and preliminary. Samples were generally collected from finished, firred wall cavities through openings around electrical boxes or from substructure floor or wall penetrations.

It was expected that higher concentrations would indicate areas with greater radon entry rates. Mitigation systems were then designed to focus on those locations (See Appendix D). Follow-up measurements of concentrations in both the living spaces and at the previously monitored entry locations were intended to indicate the effectiveness of the system. If follow-up measurements were still high, then additional work was planned. These techniques, while elementary, were a valuable tool for efficiently selecting and performing mitigation.

ECD 026C DIAGNOSTIC MAP OF RADON GRAB SAMPLES

Half-Depth Basement



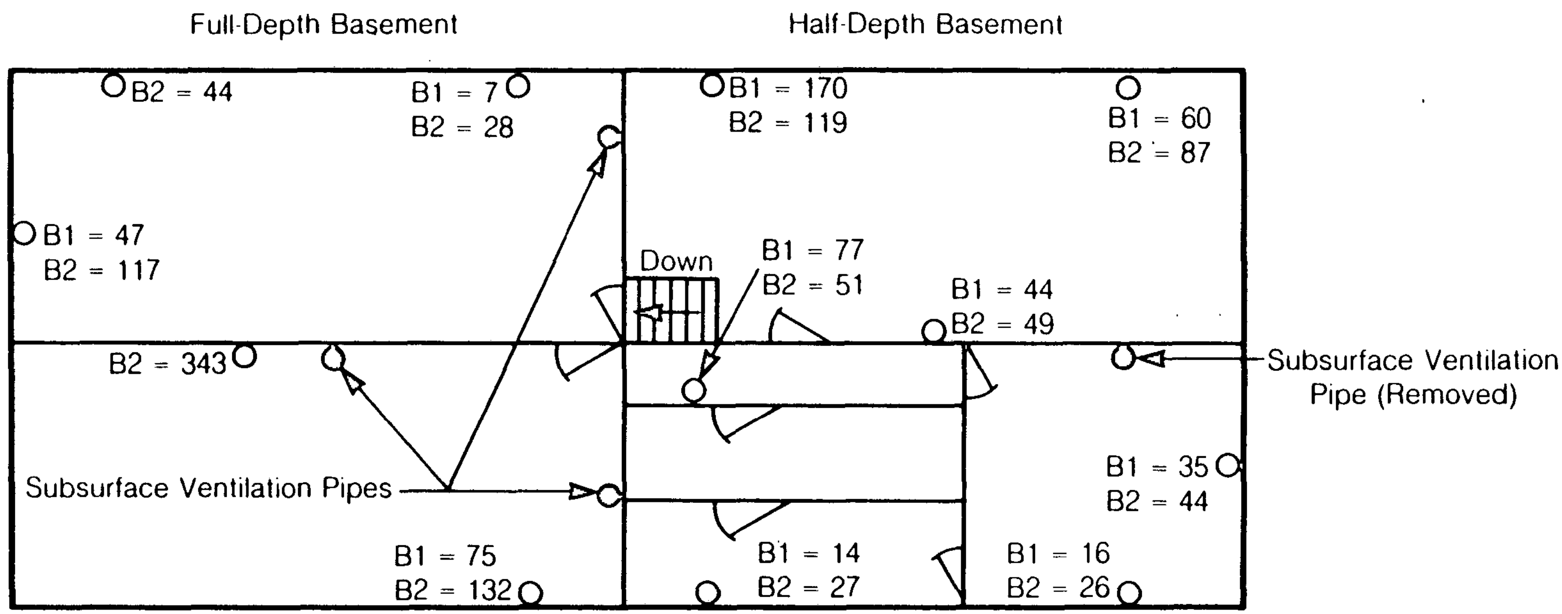
Key To Symbols
(pCi/L)

		Level 2 Room Air (pCi/L)
B1 (2/18/86)	= Baseline, Before Mitigation	3
B2 (3/6/86)	= Baseline, Before Mitigation	27
B3 (3/12/86)	= Baseline, Before Mitigation	9

NOTE: Samples Taken From Finished, Firred Wall Cavities at Electrical Boxes.

XBL 8710-10407

ESP 101 DIAGNOSTIC MAP OF RADON GRAB SAMPLING



Key To Symbols
(pCi/L)

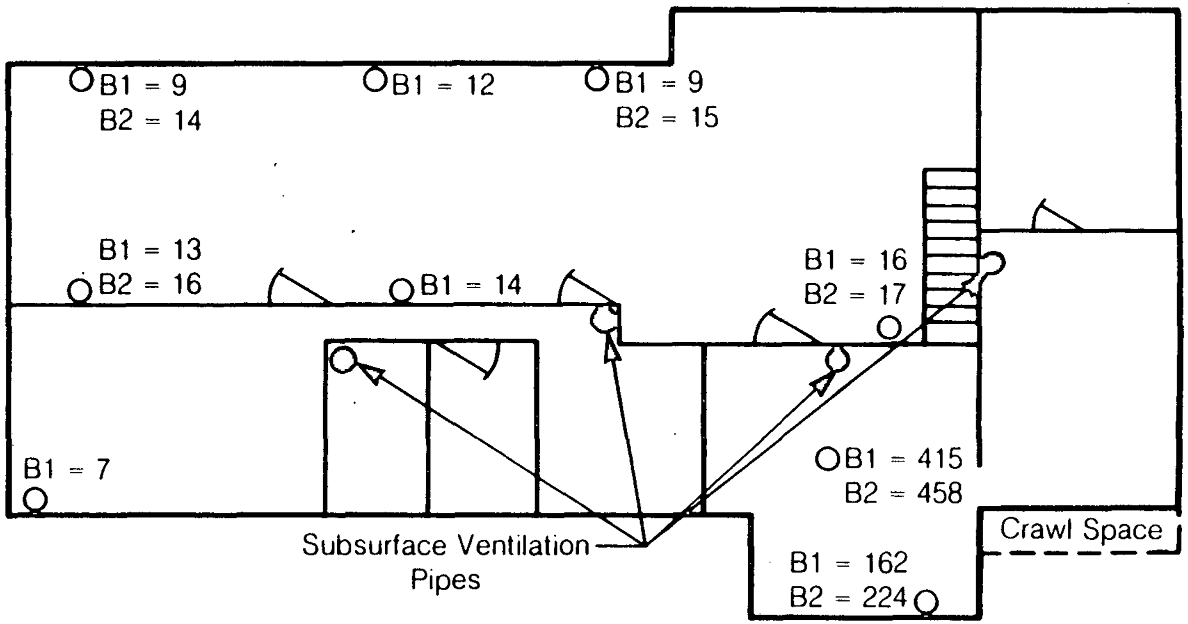
		Level 3 Room Air (pCi/L)
B1 (2/5/86)	= Baseline, Before SSV System Installed	No Data
B2 (2/9/86)	= Baseline, Before SSV System Installed	25

NOTE: Samples Taken From Finished, Firred Wall Cavities at Various Service Penetrations.

XBL 8710-10409

ESP 108C DIAGNOSTIC MAP OF RADON GRAB SAMPLING

Full-Depth Basement



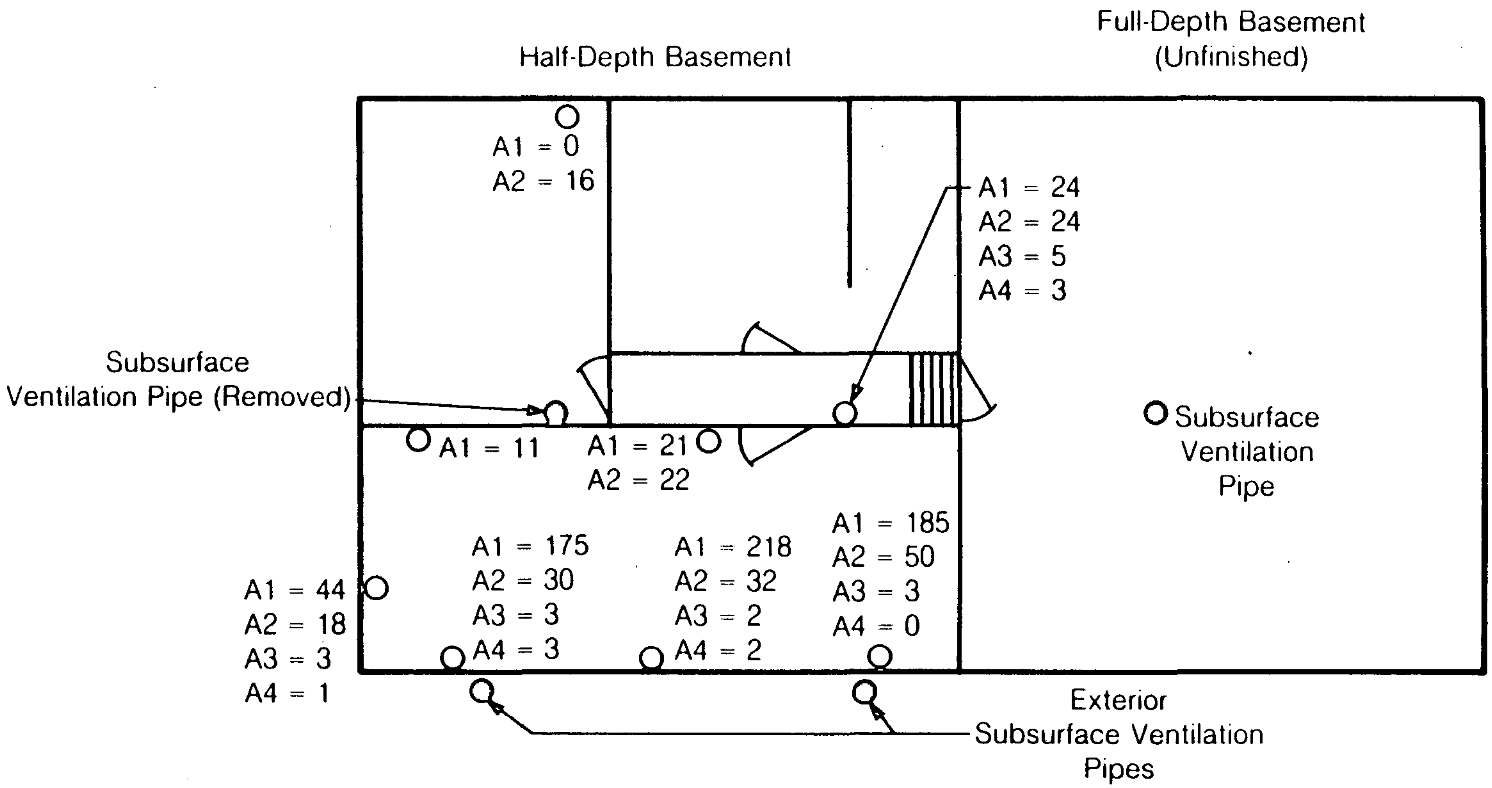
Key To Symbols
(pCi/L)

		Level 2 Room Air (pCi/L)
B1 (2/20/86)	= Baseline, Before SSV System Installed	16
B2 (3/3/86)	= Baseline, Before SSV System Installed	22

NOTE: Samples Taken From Various Service Penetrations.

XBL 8710-10406

ESP 111 DIAGNOSTIC MAP OF RADON GRAB SAMPLING



Key To Symbols
(pCi/L)

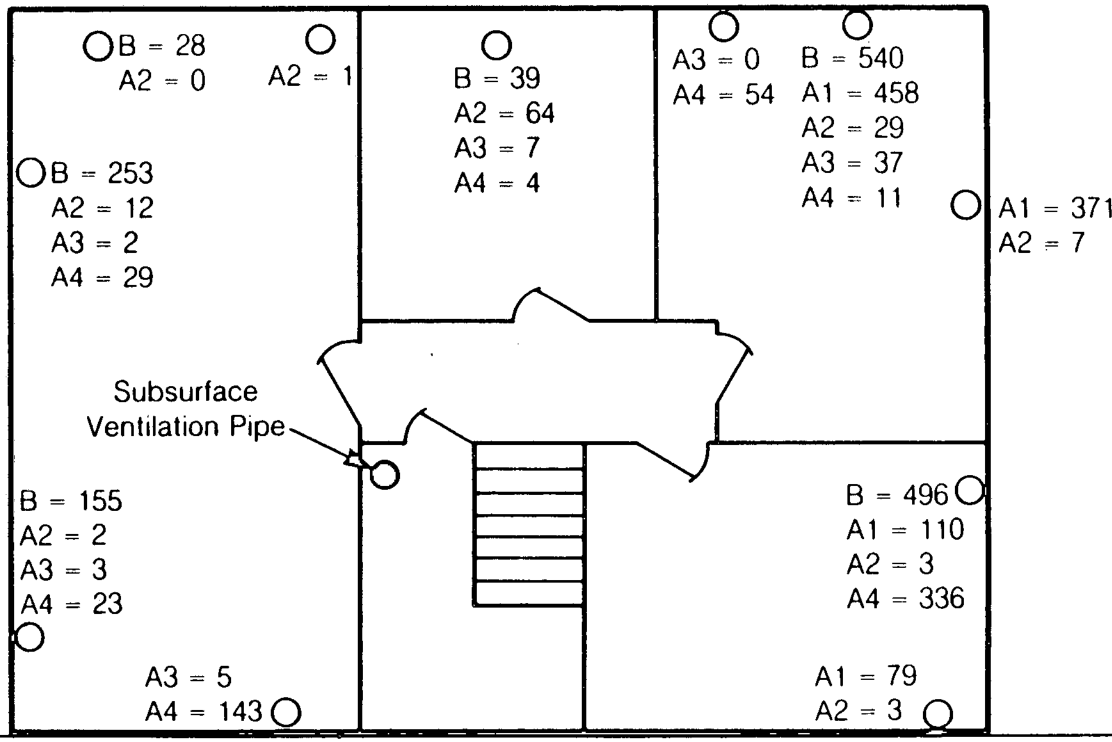
		Level 3 Room Air (pCi/L)
A1 (1/29/86)	= Full-Basement SSV Depressurizing, 1/2-Basement SSV Off	27
A2 (2/3/86)	= Both Full- and 1/2-Basement SSV Depressurizing	33
A3 (2/13/86)	= Both Full- and 1/2-Basement SSV Pressurizing	3
A4 (3/4/86)	= Both Full- and 1/2-Basement SSV Pressurizing, Exterior SSV Depressurizing	5

NOTE: Samples Taken From Finished, Firred Wall Cavities at Electrical Boxes.

XBL 8710-10404

ESP 113 DIAGNOSTIC MAP OF RADON GRAB SAMPLING

Half-Depth Basement



Key to Symbols
(pCi/L)

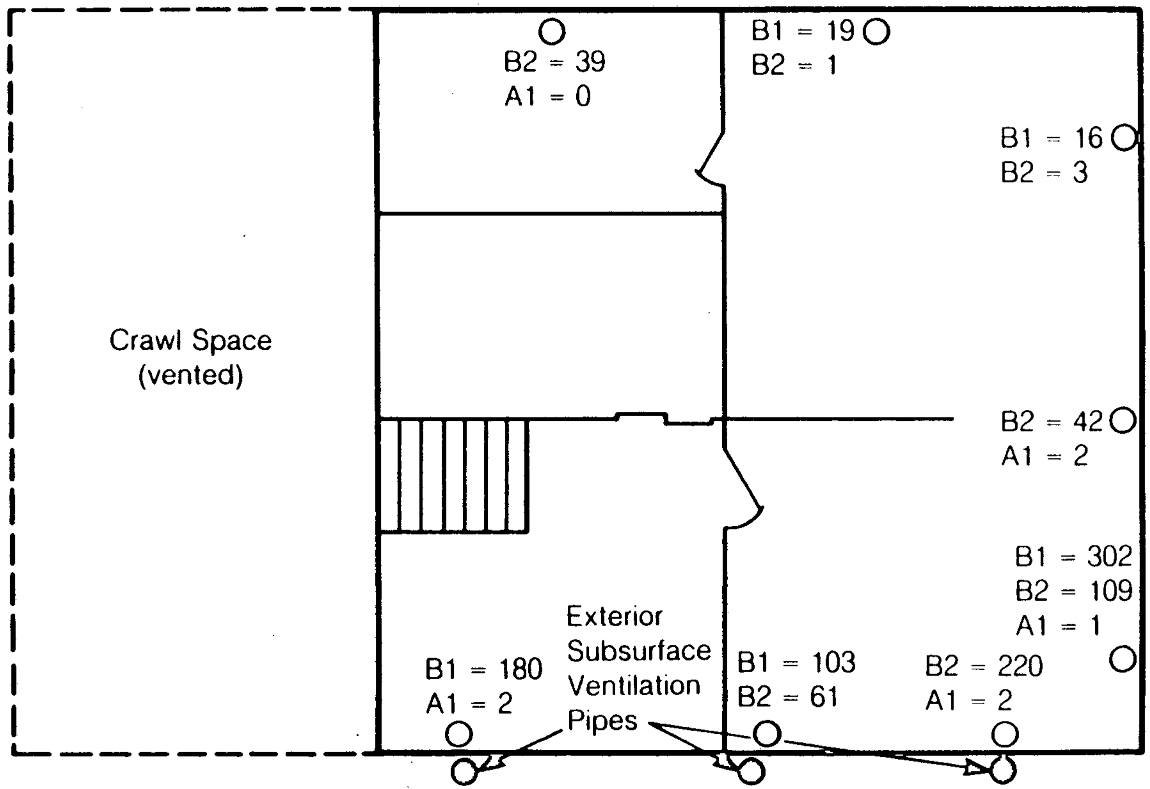
			Level 2 Room Air (pCi/L)
B (1/28/86)	=	Baseline, Mitigation Systems Off	32
A1(12/18/85)	=	Baseboard Duct Ventilation, Initial System	19
A2 (2/2/86)	=	SSV Depressurizing At −425 PA	5 (4-BSMT)
A3 (2/6/86)	=	SSV Depressurizing At −425 PA	3 (2-BSMT)
A4 (2/14/86)	=	SSV Depressurizing At −200 PA	6 (7-BSMT)

NOTE: Samples Taken From Finished, Firred Wall Cavities At Electrical Boxes.

XBL 8710-10408

ESP 119 DIAGNOSTIC MAP OF RADON GRAB SAMPLING

Half-Depth Basement



Key To Symbols
(pCi/L)

		Level 2 Room Air (pCi/L)
B1 (1/28/86)	= Before SSV System Installation, Crawl Space Vented	20
B2 (2/1/86)	= Before SSV System Installation, Crawl Space Vented	8
A1 (2/13/86)	= Exterior SSV Depressurizing At −387 PA	1

NOTE: Samples Taken From Finished, Firred Wall Cavities at Electrical Boxes.

XBL 8710-10405

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