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Spatial Variability in Radon Concentrations at a Large Commercial Facility Southeastern Wisconsin

ITS WORKSHOP – AEHS CONFERENCE

October 22, 2019

Variability of Radon in Sub-Slab Vapor & Indoor Air

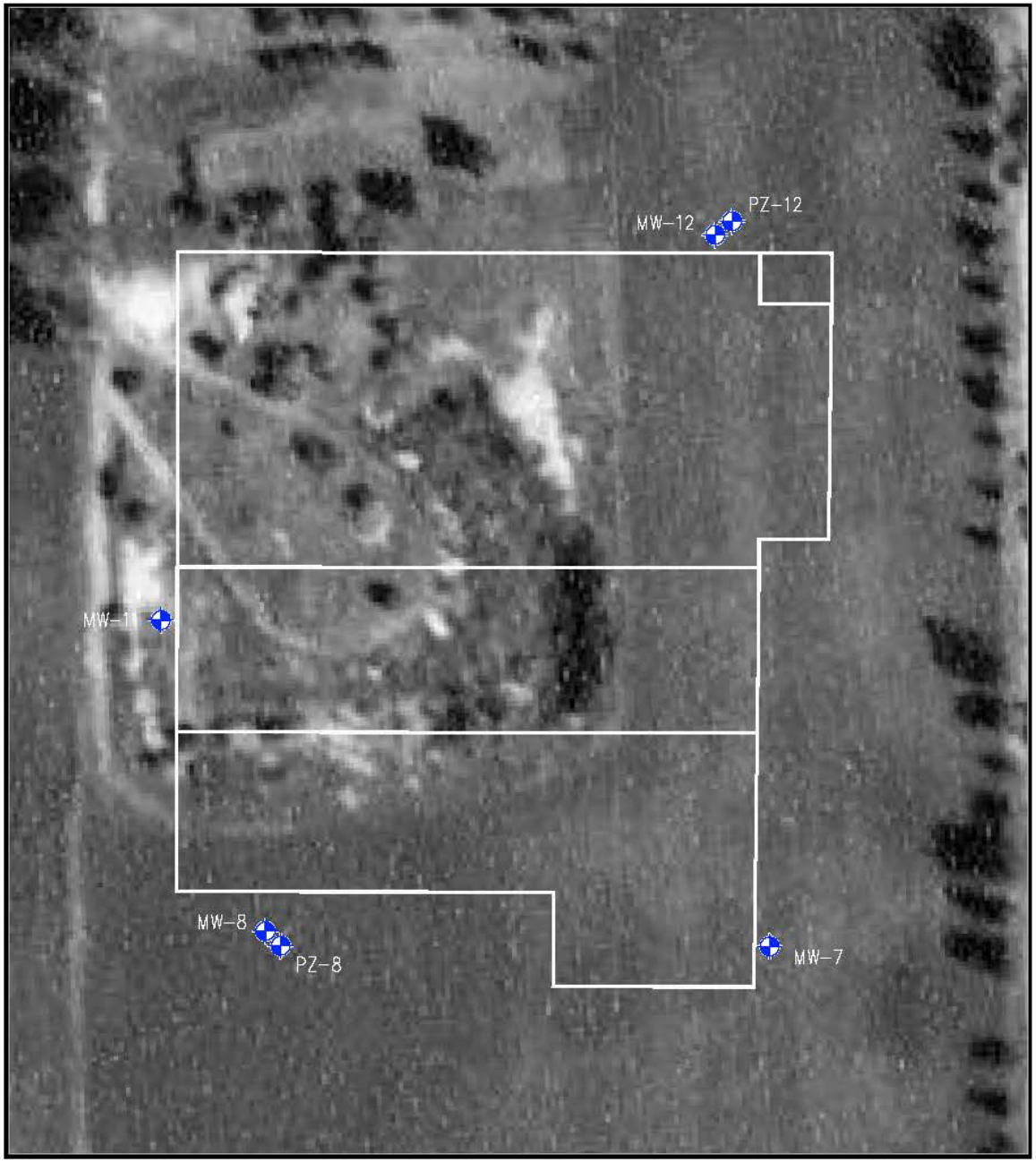
- **How do radon concentrations vary in the sub-slab vapor beneath a large commercial building?**

- **How do radon concentrations vary in indoor air?**

Site Background Information

- **Site is in SE Wisconsin & was undeveloped through 1920s**
- **Quarried for Sand & Gravel - 1930s to early 1960s**
- **Facility (162,000 ft^2) Built in 3 Stages:**
  - Northern Portion in 1960s – 82,500 ft^2
  - Middle Portion in 1970s – 36,000 ft^2
  - Southern Portion in 1980s – 43,500 ft^2

FIGURE 1



1 INCH = APPROX. 100 FT.

AERIAL IMAGERY
EDR, 1963

Site Background Information

- **Sediments mostly sand & gravel with some silty clay layers**

- **Depth to groundwater 20-25 ft bgs**

Site Background Information

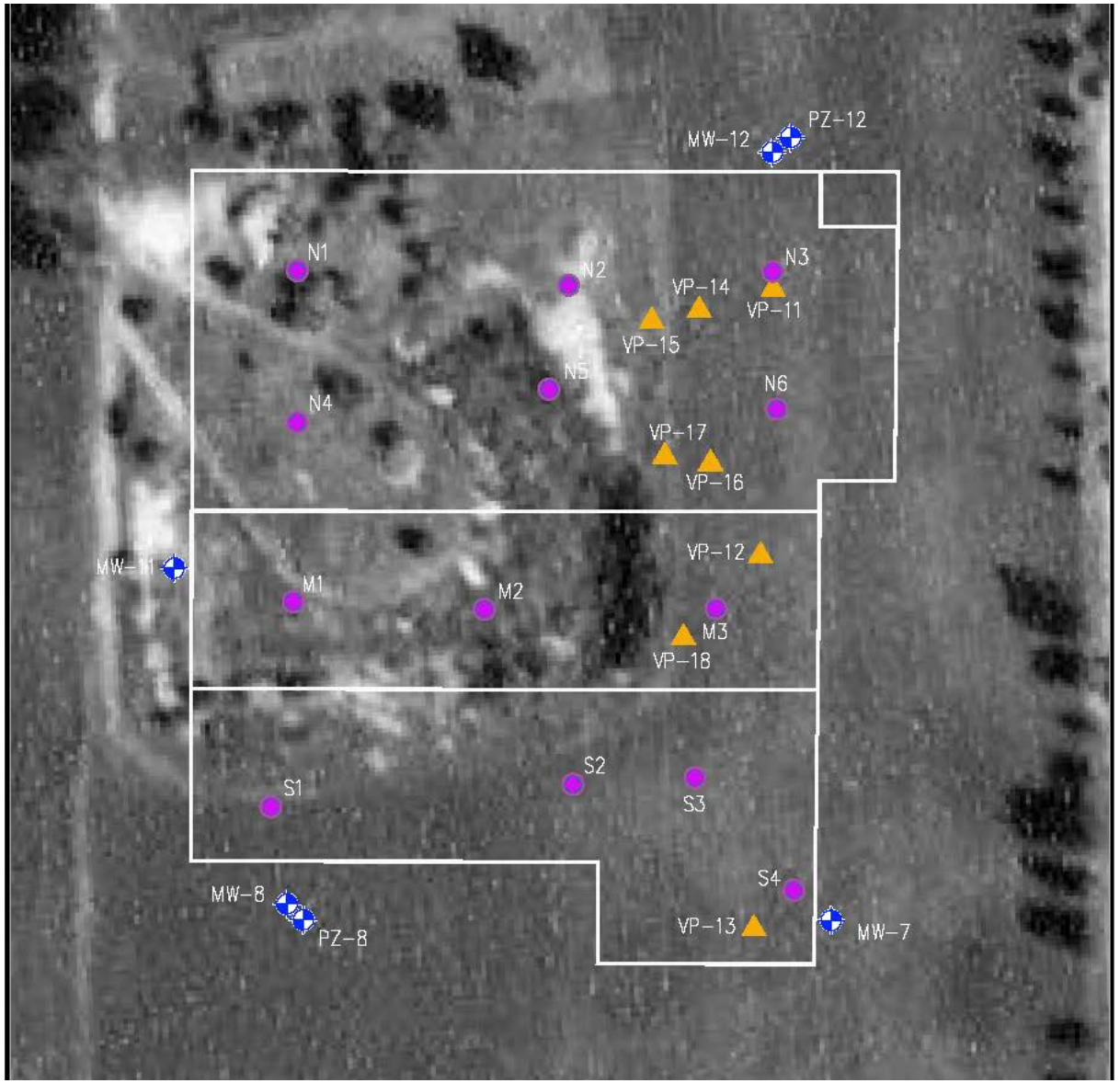
- **Building is slab-on-grade with eastern portion of facility built into hillside (i.e. below grade)**
- **4-ft deep frost walls assumed between each portion of facility**
- **Visual inspection of facility identified numerous seams, stress fractures, and penetration points including beams, drains, bolts for machinery, and piping – However, overall the floor slab was in good condition**

Site Background Information (Cont)

- **No known use of PCE on site**
- **Two sources of PCE in vapor beneath building**
  - Off-Site PCE Groundwater Plume (PCE ≤ 600 ppb upgradient of site/building and ≤ 800 ppb beneath building)
  - On-Site fill material used to level site before development (PCE in soil ≤ 2,200 ppb) first identified in June 2018
- **PCE in vapor beneath building (≤134,000 ug/m^3) measured in Feb 2018**

Site Background Information (Cont)

- **November 2017 & February 2018 –**
  - Vapor intrusion assessment (VIA) conducted by another consultant consisted of collecting 3 indoor air, 1 outdoor air, and 8 sub-slab vapor samples for VOCs analyses only along eastern side of building where elevated concentrations of PCE were measured in groundwater in monitoring wells.
  - **PCE in vapor beneath building (≤134,000 ug/m^3) measured in Feb 2018**
  - **PCE in indoor air 1.7, 7.7 & 7.9 pCI/L**


MW-12
PZ-12
N1
N2
N3
VP-14
VP-11
VP-15
N5
N6
N4
VP-17
VP-16
MW-11
VP-12
M1
M2
M3
VP-18
S2
S1
S3
S4
MW-8
PZ-8
VP-13
MW-7

Site Background Information (Cont)

- **June 2018 –**
  - PCE-impacted fill materials first identified beneath building
  - Source of PCE was backfill used to fill quarry and level site before northern portion of facility was constructed in 1966

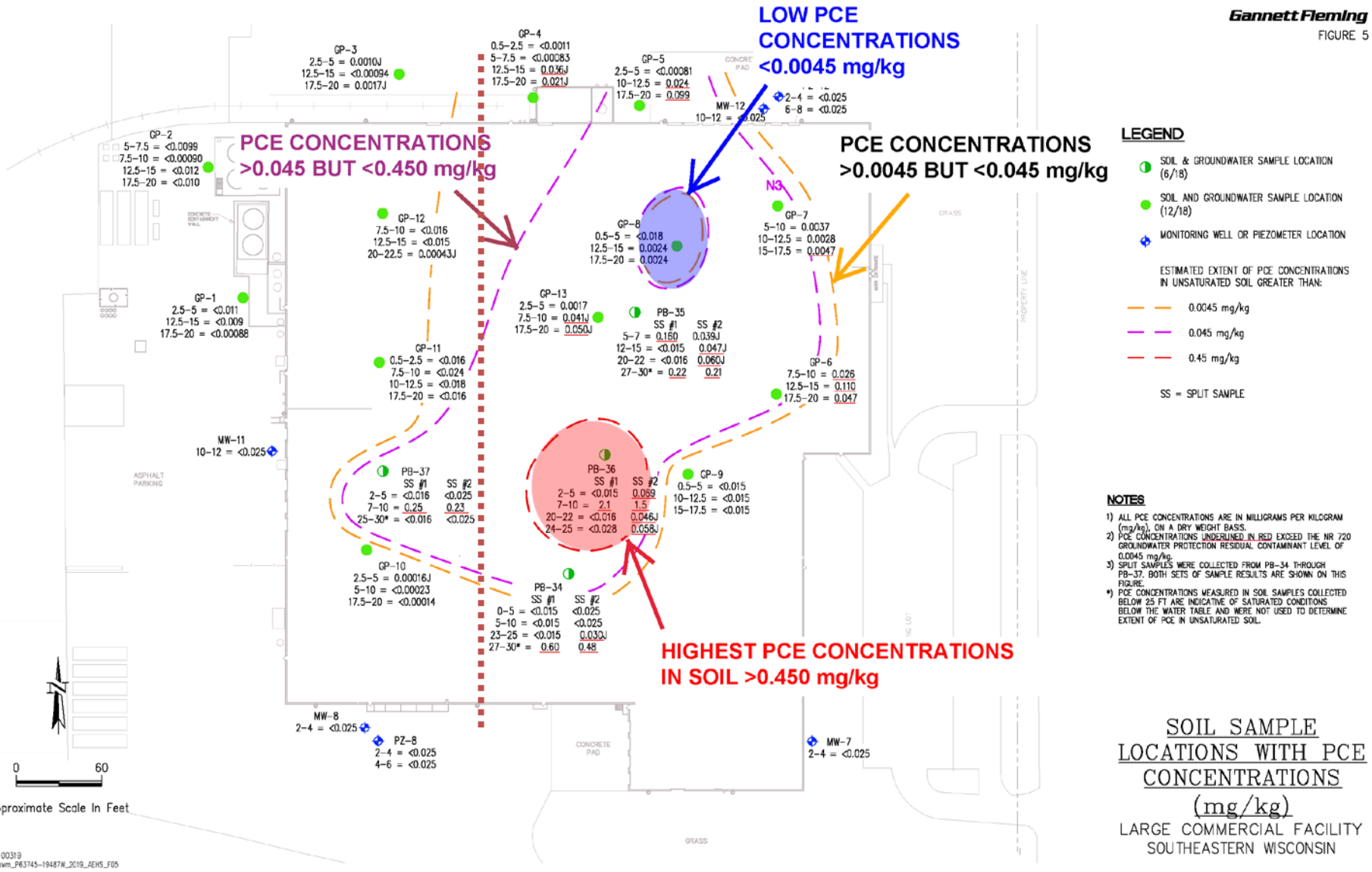


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FIGURE 5

LEGEND

- SOIL & GROUNDWATER SAMPLE LOCATION (6/18)
- SOIL AND GROUNDWATER SAMPLE LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION

ESTIMATED EXTENT OF PCE CONCENTRATIONS IN UNSATURATED SOIL GREATER THAN:

- 0.0045 mg/kg
- 0.045 mg/kg
- 0.45 mg/kg

SS = SPLIT SAMPLE

NOTES

1) ALL PCE CONCENTRATIONS ARE IN MILLIGRAMS PER KILOGRAM (mg/kg), ON A DRY WEIGHT BASIS.
2) PCE CONCENTRATIONS UNDERLINED IN RED EXCEED THE NR 720 GROUNDWATER PROTECTION RESIDUAL CONTAMINANT LEVEL OF 0.0045 mg/kg.
3) SPLIT SAMPLES WERE COLLECTED FROM PB-34 THROUGH PB-37. BOTH SETS OF SAMPLE RESULTS ARE SHOWN ON THIS FIGURE.
*) PCE CONCENTRATIONS MEASURED IN SOIL SAMPLES COLLECTED BELOW 25 FT ARE INDICATIVE OF SATURATED CONDITIONS BELOW THE WATER TABLE AND WERE NOT USED TO DETERMINE EXTENT OF PCE IN UNSATURATED SOIL.

SOIL SAMPLE LOCATIONS WITH PCE CONCENTRATIONS (mg/kg)

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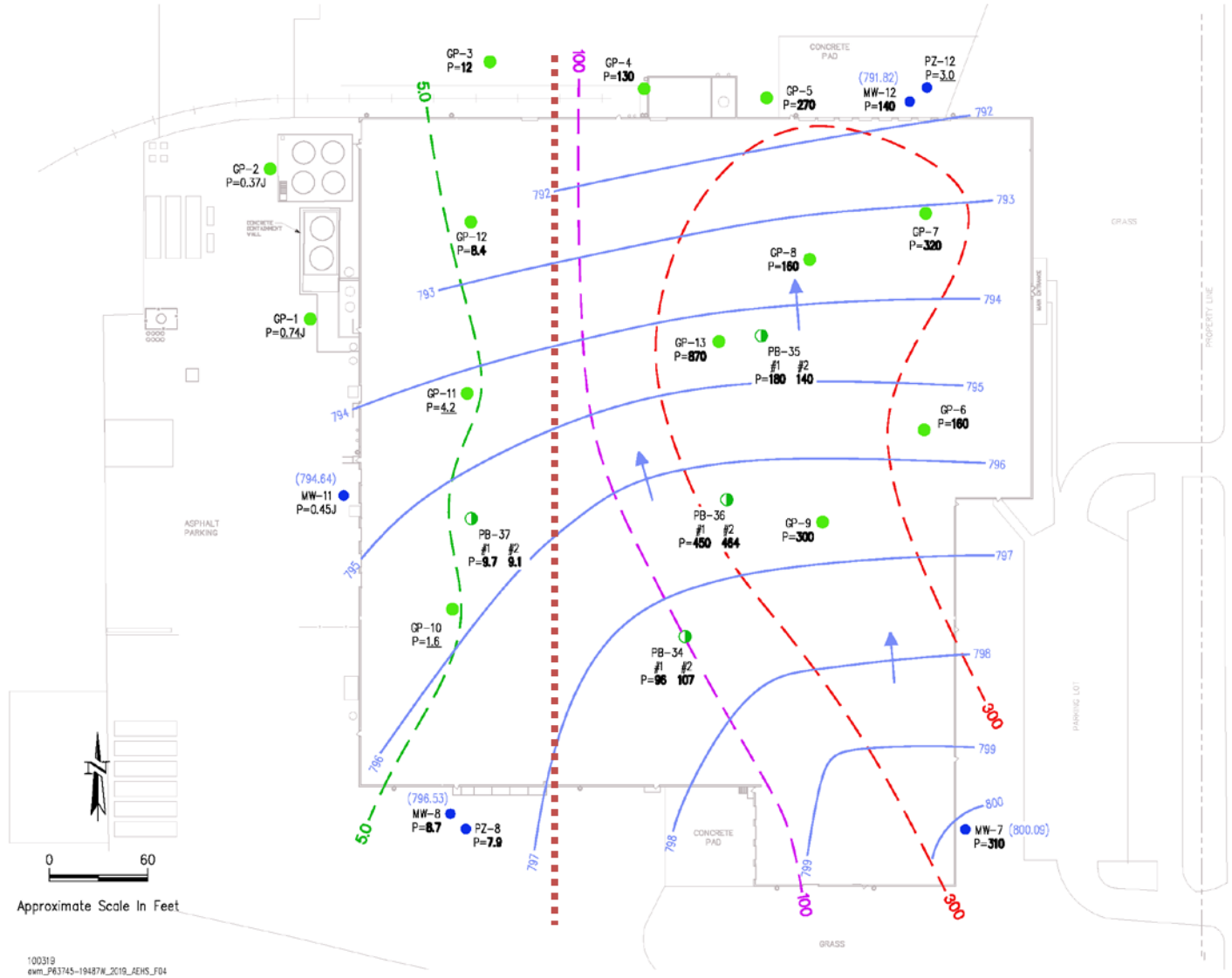
FIGURE 4



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LEGEND

- SOIL & GROUNDWATER SAMPLE LOCATION (6/18)
- SOIL AND GROUNDWATER SAMPLE LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER (12/18)
- GROUNDWATER ELEVATION ISOCONTOUR LINE (FT MSL) & FLOW DIRECTION
- 5.0 — ISOCONCENTRATIONS OF PCE IN GROUNDWATER BASED ON RESULTS OF SAMPLES COLLECTED IN JUNE & DECEMBER 2018
- 100
- 300

NOTES

1) P = PCE-TETRACHLOROETHYLENE
2) CONCENTRATIONS ARE IN MICROGRAMS PER LITER (µg/L), EQUIVALENT TO PARTS PER BILLION (ppb).
3) CONCENTRATIONS GREATER THAN THE NR 140 PREVENTATIVE ACTION LIMIT (PAL) OR ENFORCEMENT STANDARD (ES) ARE UNDERLINED OR IN BOLD, RESPECTIVELY.
4) GROUNDWATER CONTOURS BASED ON ELEVATIONS MEASURED ON 12/13/18.
5) SPLIT SAMPLES WERE COLLECTED FORM PB-34 THROUGH PB-37 IN JUNE 2018, AND BOTH RESULTS ARE SHOWN.

GROUNDWATER SAMPLE LOCATIONS WITH PCE CONCENTRATIONS (µg/L) (JUNE–DEC 2018)

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Background Information (Cont)

- **December 2018**
  - Vapor intrusion assessment included dividing facility into 13 sections: 6 in the northern portion, 3 in the middle portion, and 4 in the southern portion
  - Barometric Pressure, Temperature, & Differential Pressure measured between IA and SSV and IA and outdoor air
  - Radon measured in Indoor Air and Sub-Slab Vapor with RAD7 electronic radon detector and 1-liter grab samples for laboratory analyses

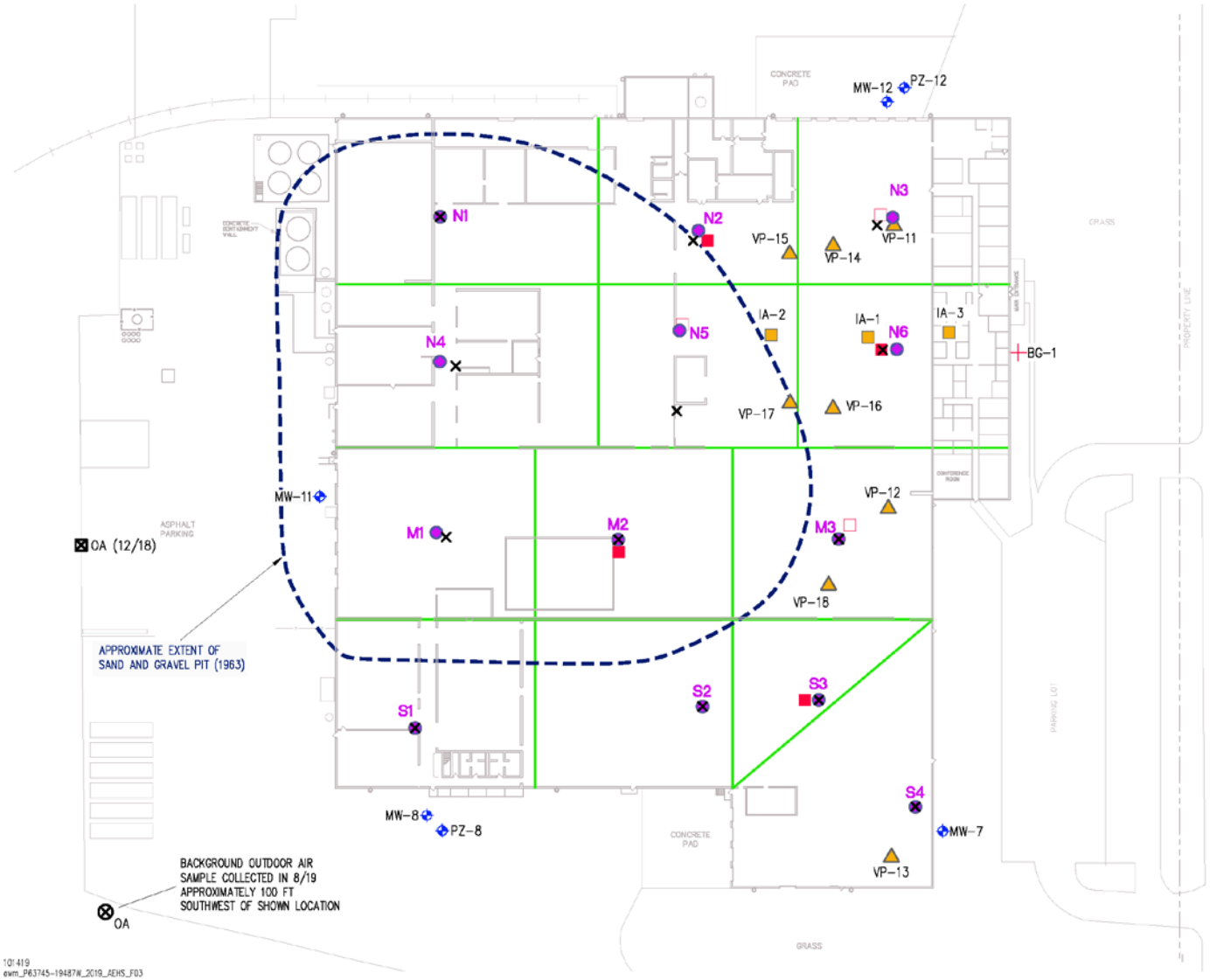

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FIGURE 3

LEGEND

- SUB-SLAB VAPOR SAMPLE LOCATION (11/17 & 2/18)
- BACKGROUND OUTDOOR AIR SAMPLE (2/18)
- OUTDOOR AIR SAMPLE LOCATION (12/18)
- OUTDOOR AIR SAMPLE LOCATION (8/19)
- INDOOR AIR SAMPLE LOCATION (12/18 & 8/19)
- INDOOR AIR SAMPLE LOCATION (8/19)
- INDOOR AIR SAMPLE LOCATION (2/18)
- VAPOR PIN SAMPLE LOCATION (12/18 & 8/19)
- RSSI RADON SENSOR LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY.

INDOOR/OUTDOOR AIR & SUB-SLAB VAPOR SAMPLE LOCATIONS (NOV 2017 – AUG 2019)

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Background Information (Cont)

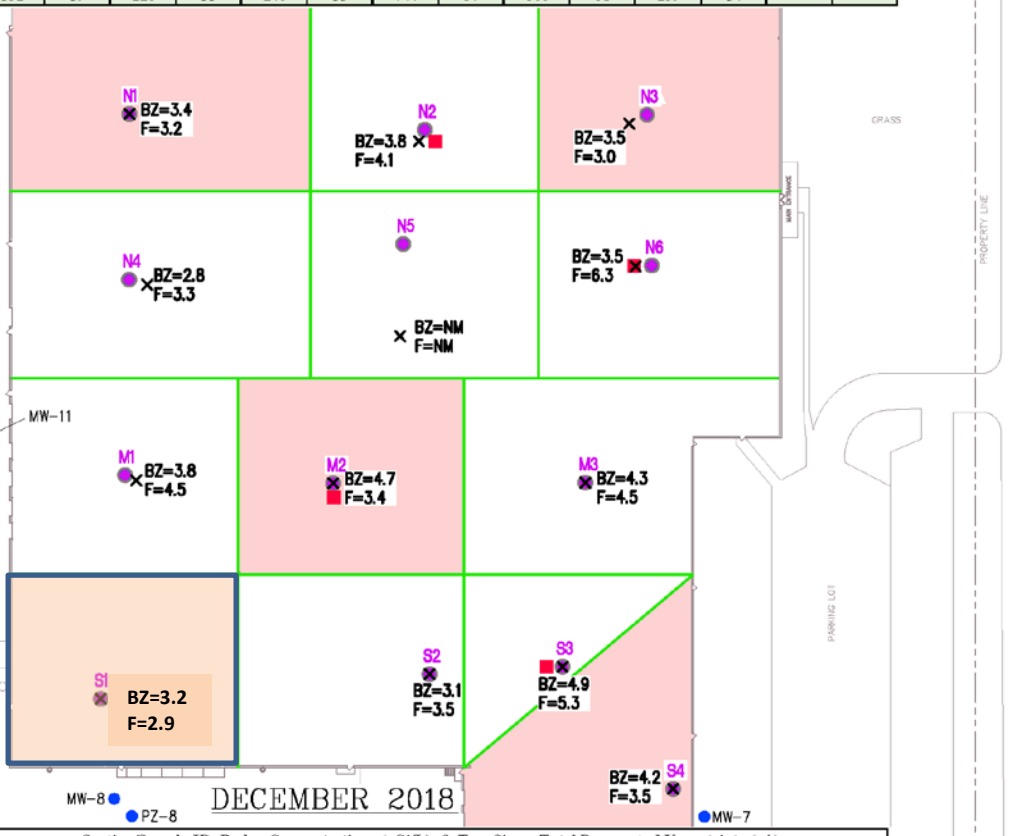
- **December 2018 -**
  - Prior to conducting first round in December 2018, 9-day radon concentrations were measured in the Indoor Air (IA) at floor level and in breathing zone (BZ) in each section using Radiation Safety Services, Inc (RSSI) Alpha-Track radon detector
  - PCE concentrations measured in soil & GW and radon in Alpha-Track detectors were used to determine some of the paired IA and sub-slab vapor sample locations

Sample Location	Lab ID	Section/Sample ID, Radon Concentrations (pCi/L), & Two-Sigma Total Propagated Uncertainty (+/-)													
		N1	TPU	N2	TPU	N3	TPU	N4	TPU	N5	TPU	N6	TPU	OA	TPU
BZ	RSSI	3.4	0.41	3.8	0.46	3.5	0.42	2.8	0.36	--	--	3.5	0.42	3.0	0.33
	ALS	--	--	0.6	1.0	--	--	--	--	0.55	0.53	0.63	0.96	0.2	1.0
	RAD7	--	--	0.97	4.67	--	--	--	--	0.0	3.87	0.97	4.67	0.0	3.87
Floor	RSSI	3.2	0.38	4.1	0.45	3.0	0.39	3.3	0.40	--	--	6.3	0.63	--	--
SSV	ALS	--	--	164	41	--	--	--	--	520	130	172	43	--	--
	RAD7	352	39	226	33	248	33	744	57	588	51	259	34	--	--

- RSSI IA SAMPLES WERE COLLECTED OVER 9-DAY PERIOD & RANGED FROM 2.8-6.4 pCi/L
- IA RADON CONCENTRATIONS MEASURED WITH RSSI SENSORS SHOWED RELATIVELY GOOD MIXING OF AIR BETWEEN BZ & FLOOR
- IA CONCENTRATIONS MEASURED IN "GRAB: SAMPLES ANALYZED BY LAB OR RAD7 SHOWED GOOD CORRELATION & RANGED FROM ND TO 1.6 pCi/L

OA × **BZ=3.0**

- SECTIONS HIGHLIGHTED IN RED HAD HIGHER RADON CONCENTRATIONS IN BZ THAN IN FLOOR SAMLES



DECEMBER 2018

Sample Location	Lab ID	Section/Sample ID, Radon Concentrations (pCi/L), & Two-Sigma Total Propagated Uncertainty (+/-)													
		M1	TPU	M2	TPU	M3	TPU	S1	TPU	S2	TPU	S3	TPU	S4	TPU
BZ	RSSI	3.8	0.46	4.7	0.52	4.3	0.47	3.2	0.38	3.1	0.37	4.9	0.54	4.2	0.46
	ALS	--	--	0.5	1.1	--	--	--	--	--	--	1.6	1.2	--	--
	RAD7	--	--	0.97	4.67	--	--	--	--	--	--	0.97	4.67	--	--
Floor	RSSI	4.5	0.50	3.4	0.41	4.5	0.50	2.9	0.38	3.5	0.42	5.3	0.53	3.5	0.42
SSV	ALS	--	--	285	71	--	--	--	--	--	--	222	55	--	--
	RAD7	536	48	254	34	138	26	253	34	32	14	224	32	257	34

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FIGURE 9.2

LEGEND

- INDOOR AIR SAMPLE (12/18 & 8/19)
- VAPOR PIN SAMPLE LOCATION (12/18 & 8/19)
- × RSSI RADON SENSOR LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY
- Rn – RADON CONCENTRATIONS ARE IN PICO CURIES PER LITER (pCi/L)
- NA = NOT ANALYZED
- VRSL = VAPOR RISK SCREENING LEVEL
- BZ = INDOOR AIR SAMPLE COLLECTED IN BREATHING ZONE
- SSV = SUB-SLB VAPOR SAMPLE
- OA = OUTDOOR AIR SAMPLE IN BREATHING ZONE
- F = INDOOR AIR SAMPLE COLLECTED AT FLOOR LEVEL

0 60

Approximate Scale In Feet

RADON CONCENTRATIONS MEASURED IN INDOOR AIR SAMPLES (DECEMBER 2018)

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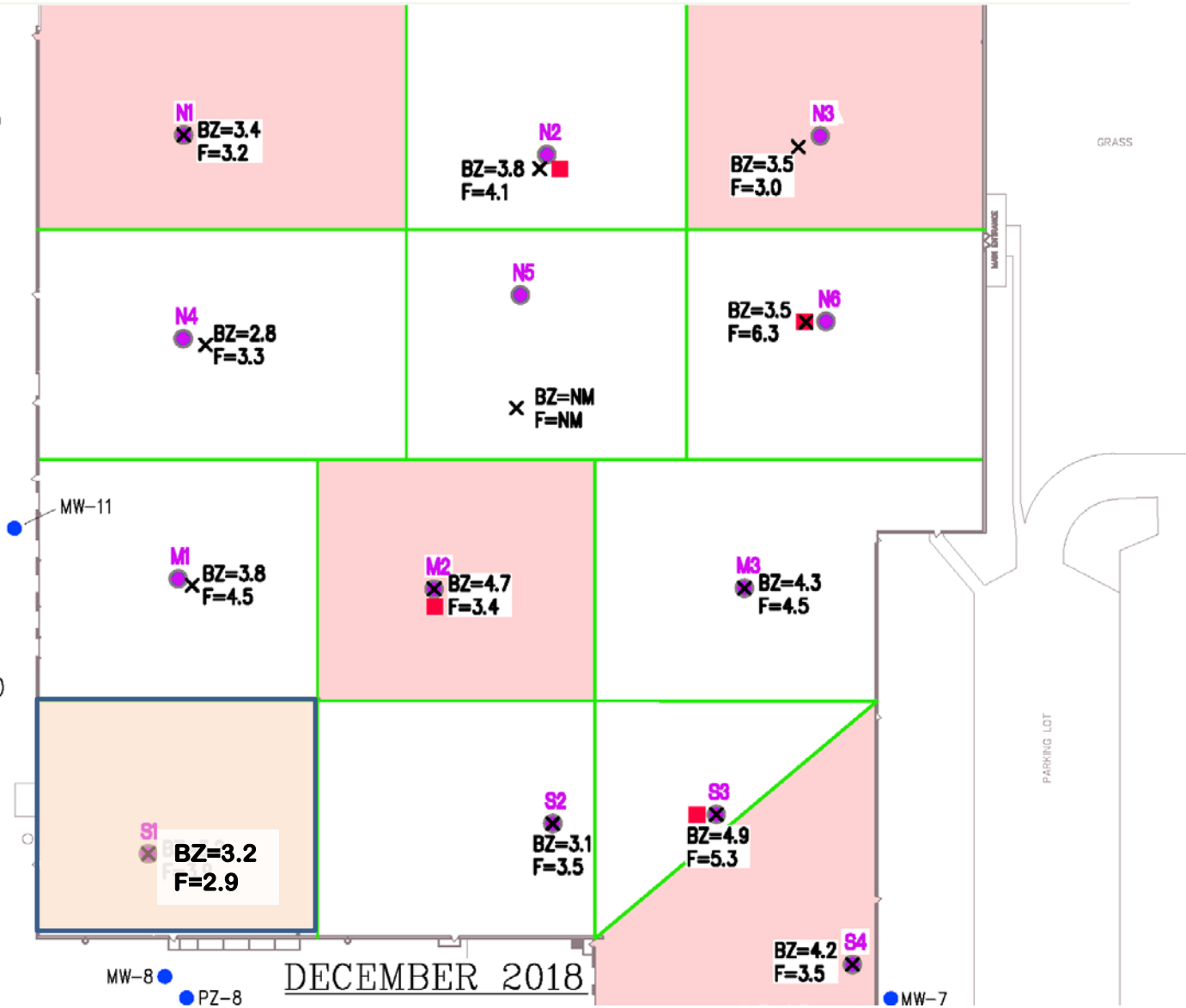
- RSSI IA SAMPLES WERE COLLECTED OVER 9-DAY PERIOD & RANGED FROM 2.8–6.4 pCi/L
- IA RADON CONCENTRATIONS MEASURED WITH RSSI SENSORS SHOWED RELATIVELY GOOD MIXING OF AIR BETWEEN BZ & FLOOR
- IA CONCENTRATIONS MEASURED IN "GRAB: SAMPLES ANALYZED BY LAB OR RAD7 SHOWED GOOD CORRELATION & RANGED FROM ND TO 1.6 pCi/L

OA BZ=3.0

- SECTIONS HIGHLIGHTED IN RED HAD HIGHER RADON CONCENTRATIONS IN BZ THAN IN FLOOR SAMLES



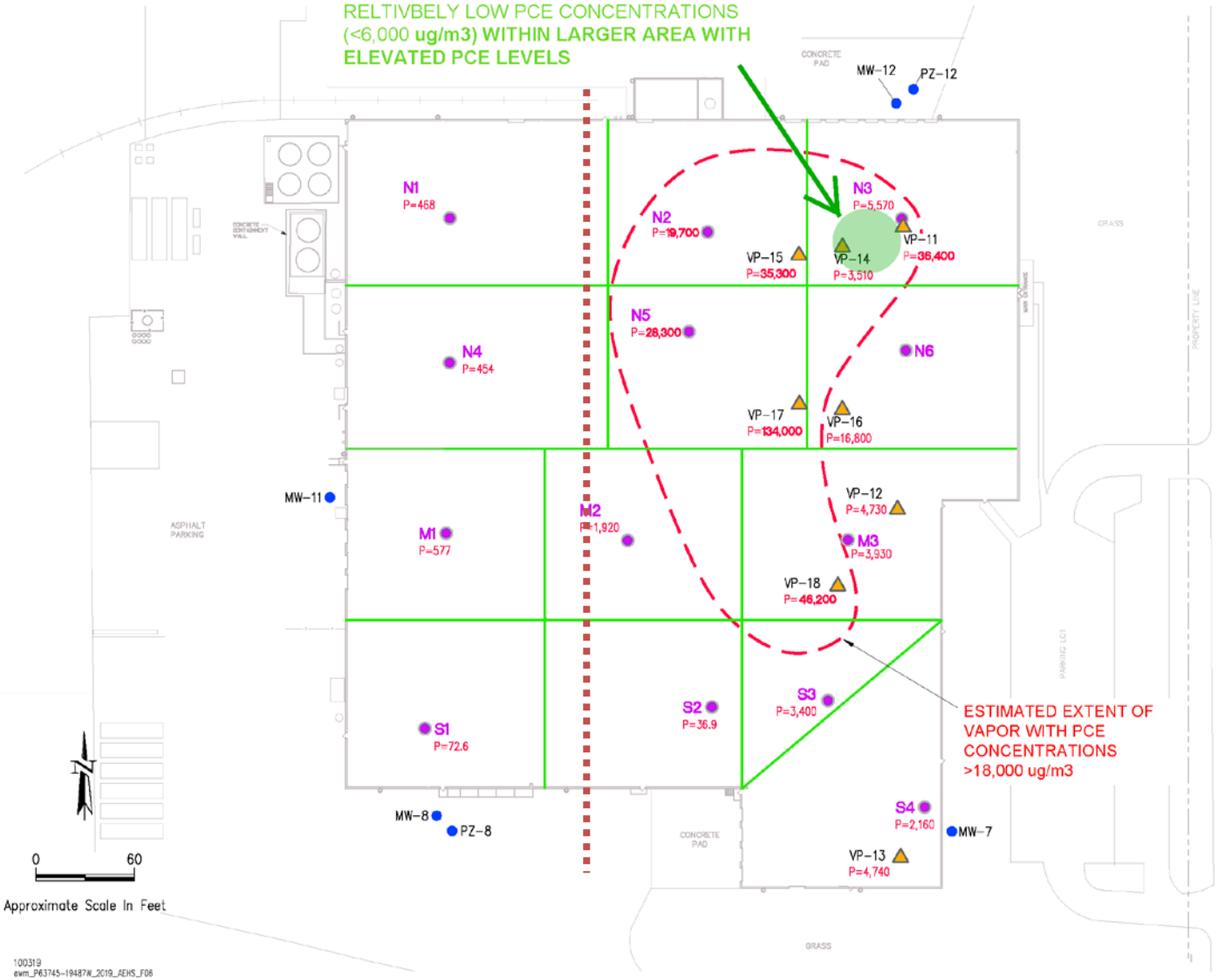


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FIGURE 6

LEGEND

- SUB SLAB VAPOR SAMPLE LOCATION (11/17 & 2/18)
- VAPOR PIN SAMPLE LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 — SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY.
- P – PCE CONCENTRATIONS IN INDOOR AIR VAPOR SAMPLES ARE IN MICROGRAMS PER CUBIC METER ($\mu g/m^3$). CONCENTRATIONS ABOVE THE PCE VRSL OF 18,000 $\mu g/m^3$ ARE IN **BOLD**.
- NA = NOT ANALYZED
- NR = NOT REPORTED
- VRSL = VAPOR RISK SCREENING LEVEL

PCE CONCENTRATIONS MEASURED IN SUB-SLAB VAPOR SAMPLES (NOVEMBER 2017 – DECEMBER 2018)

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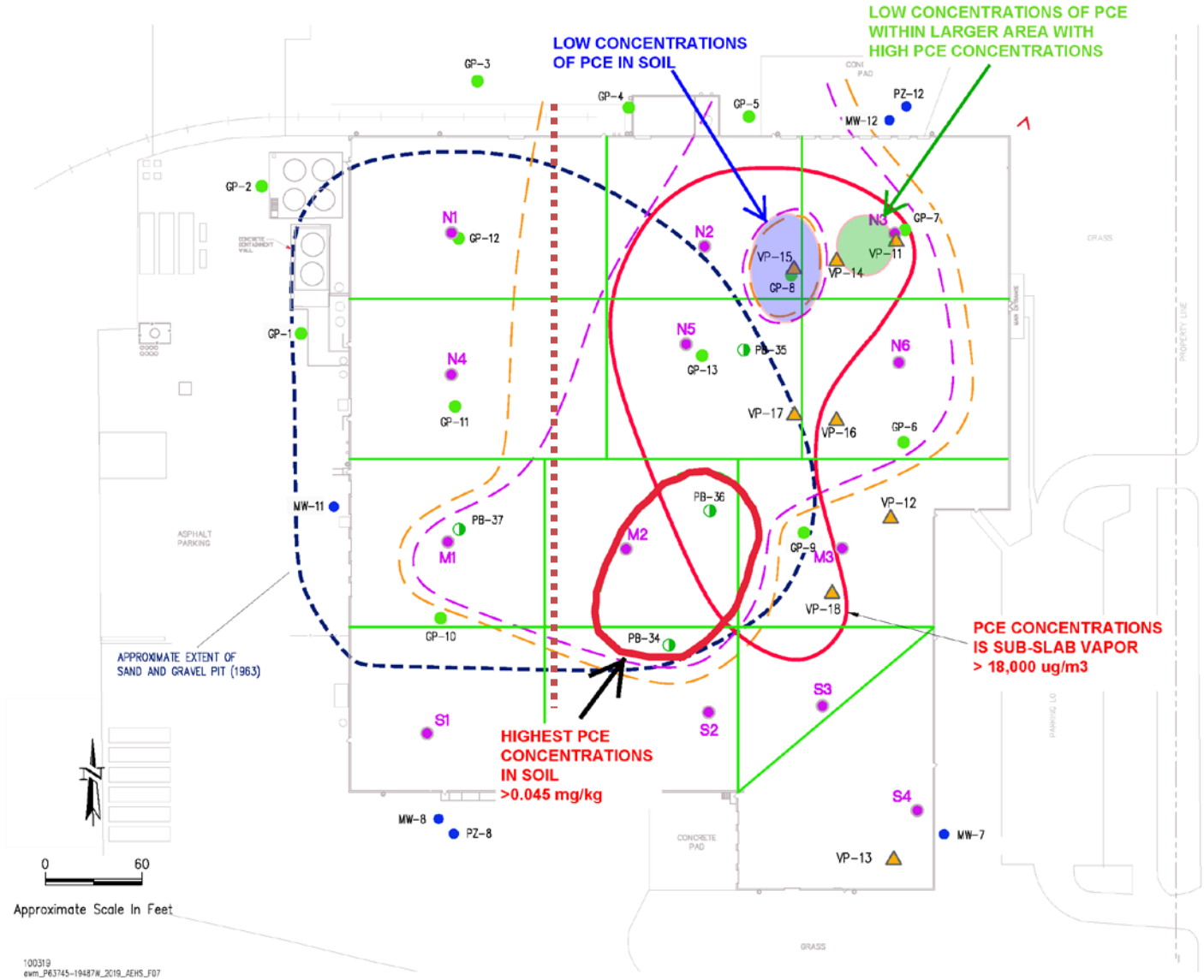

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FIGURE 7

LEGEND

- SUB SLAB VAPOR SAMPLE LOCATION (11/17 & 2/18)
- SOIL & GROUNDWATER SAMPLE LOCATION (6/18)
- VAPOR PIN SAMPLE LOCATION (12/18)
- SOIL AND GROUNDWATER SAMPLE LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY.

ESTIMATED EXTENT OF PCE CONCENTRATIONS IN SOIL GREATER THAN:

- 0.0045 mg/kg
- 0.045 mg/kg
- 0.45 mg/kg

SEE FIGURE 5 FOR ANALYTICAL RESULTS

ESTIMATED EXTENT OF ELEVATED PCE CONCENTRATIONS MEASURED IN SOIL AND VAPOR SAMPLES NOVEMBER 2017 – DECEMBER 2018

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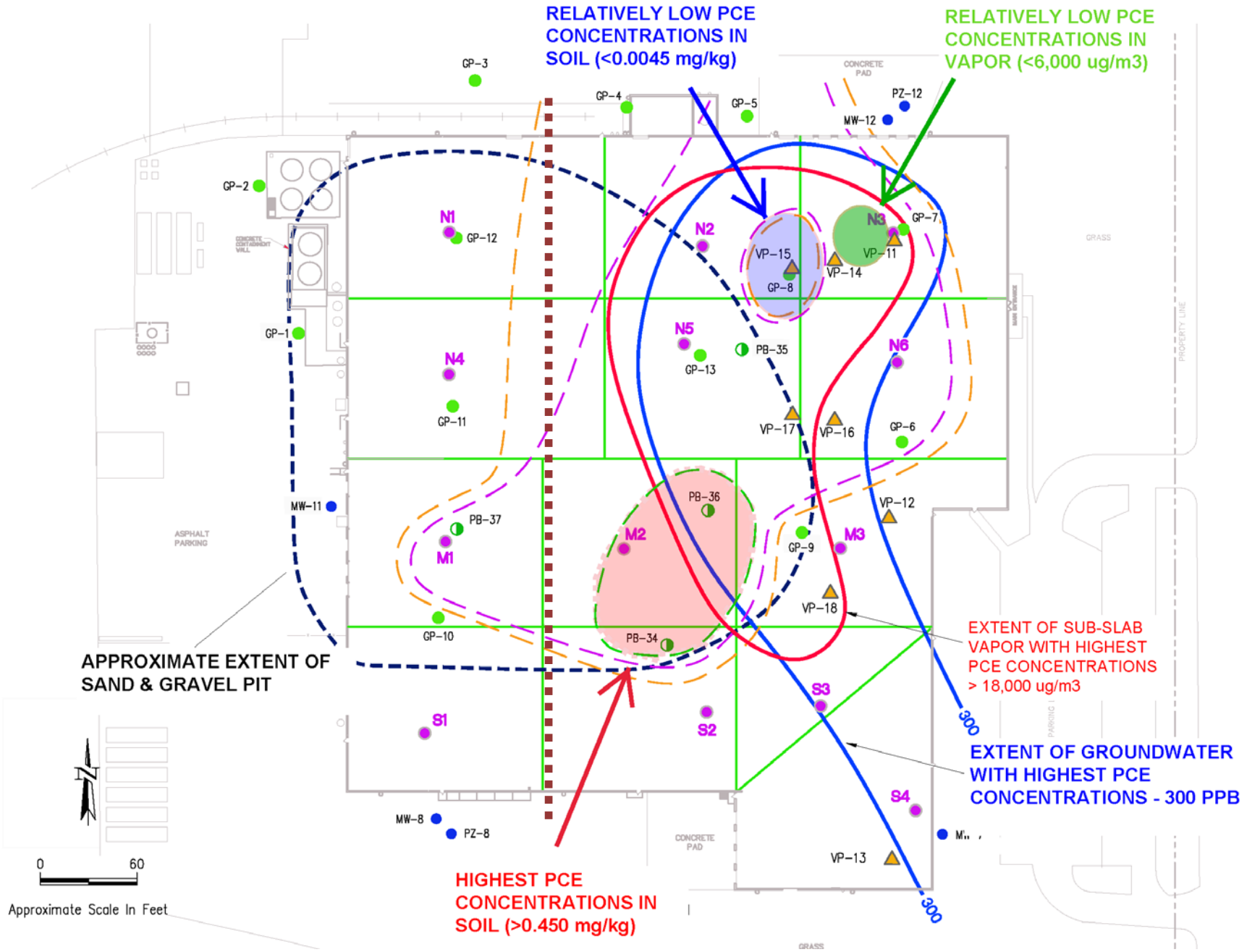
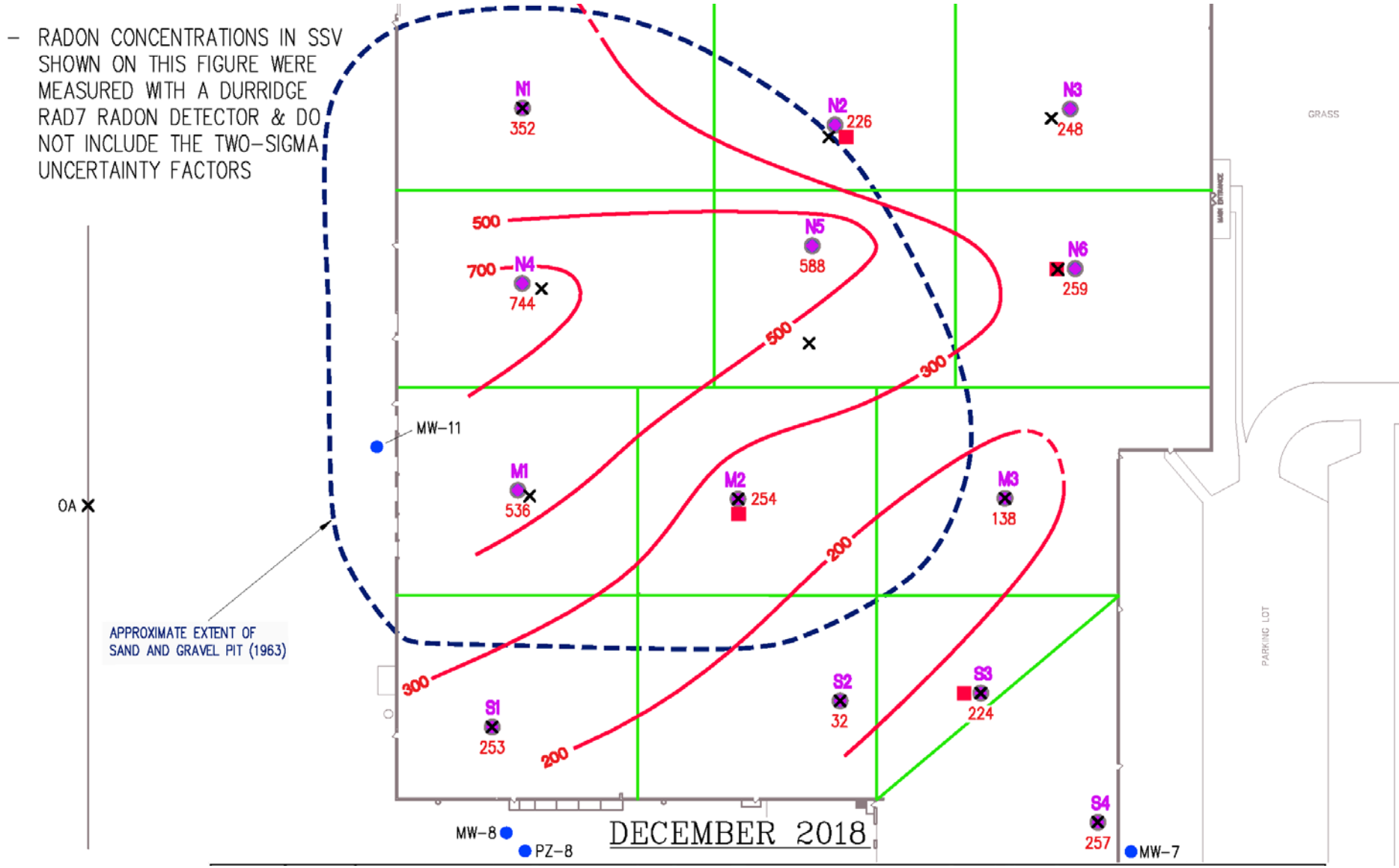
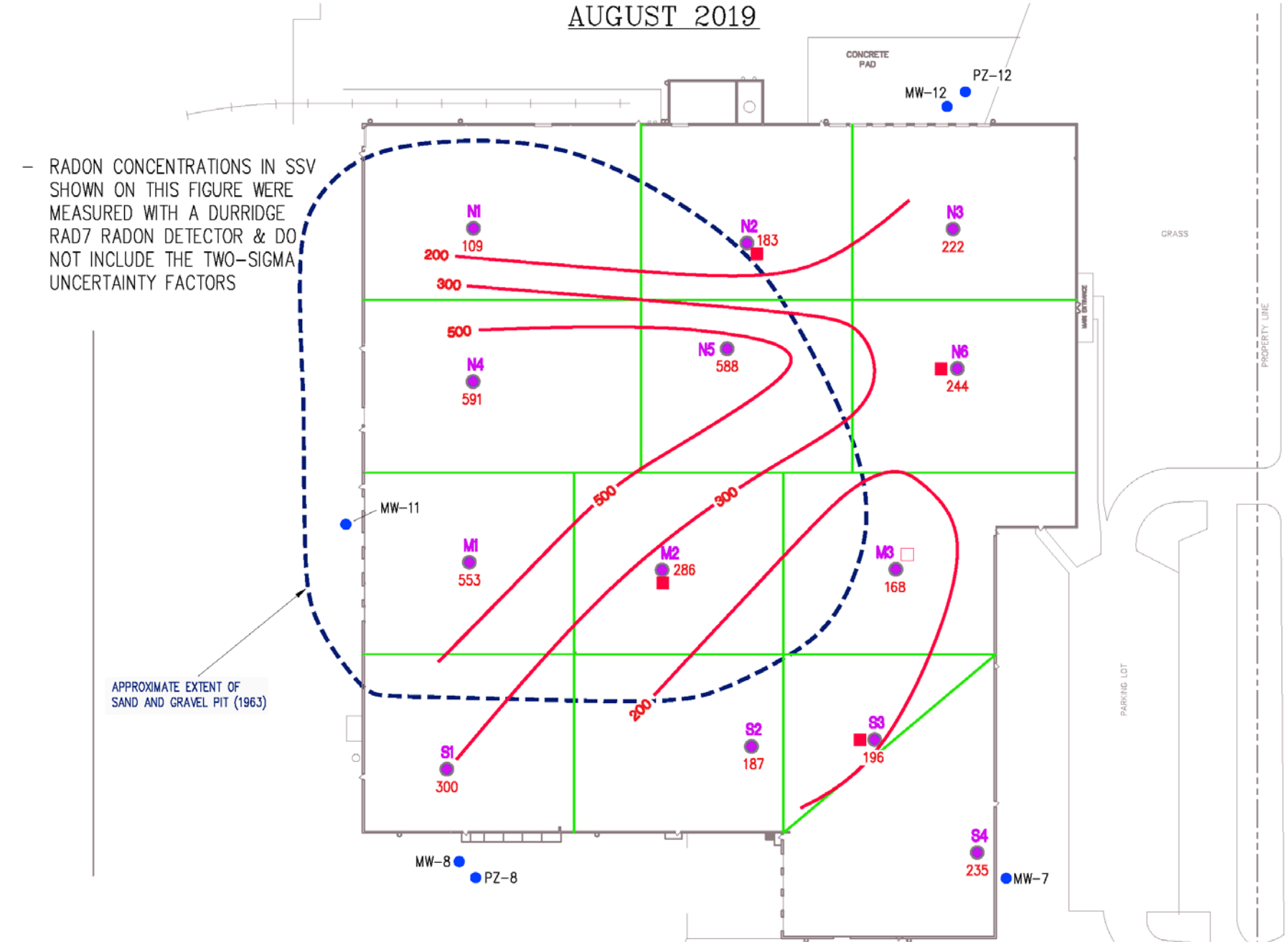

RELATIVELY LOW PCE CONCENTRATIONS IN SOIL (<0.0045 mg/kg)
RELATIVELY LOW PCE CONCENTRATIONS IN VAPOR (<6,000 ug/m3)
GP-3
GP-4
GP-5
PZ-12
MW-12
GP-2
N1
GP-12
N2
N3
GP-7
VP-15
VP-14
VP-11
GP-8
GP-1
N5
PB-35
GP-13
N6
N4
GP-11
VP-17
VP-16
GP-6
MW-11
PB-36
VP-12
PB-37
M2
M3
M1
GP-9
VP-18
GP-10
PB-34
APPROXIMATE EXTENT OF SAND & GRAVEL PIT
EXTENT OF SUB-SLAB VAPOR WITH HIGHEST PCE CONCENTRATIONS > 18,000 ug/m3
S3
S1
S2
300
EXTENT OF GROUNDWATER WITH HIGHEST PCE CONCENTRATIONS - 300 PPB
S4
MW-8
PZ-8
VP-13
300
HIGHEST PCE CONCENTRATIONS IN SOIL (>0.450 mg/kg)
0
60
Approximate Scale In Feet
ASPHALT PARKING
CONCRETE PAD
GRASS
PROPERTY LINE

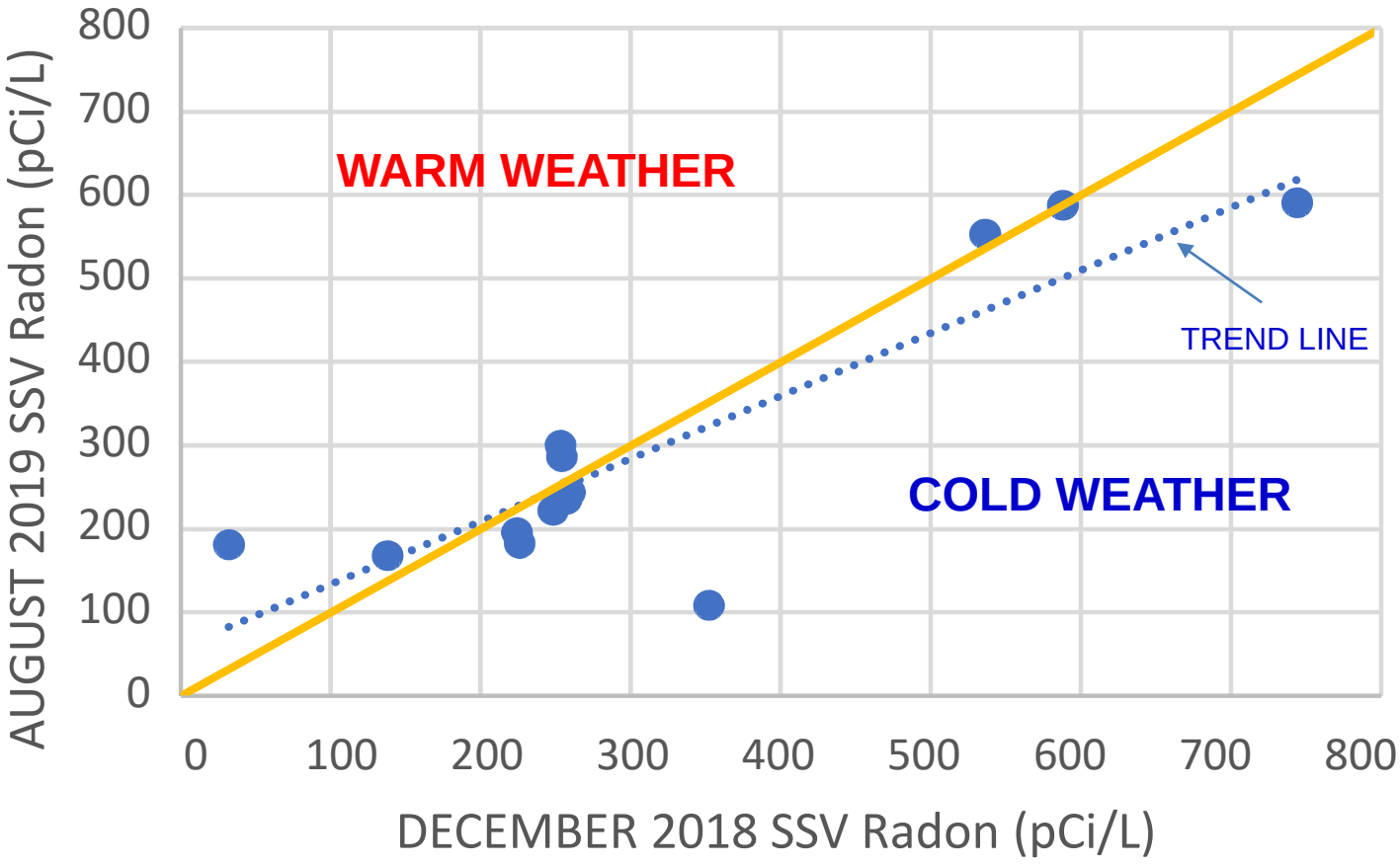
RADON CONCENTRATIONS IN SUB-SLAB VAPOR – DECEMBER 2018





RADON CONCENTRATIONS IN SUB-SLAB VAPORS – AUGUST 2019

TEMPORAL VARIABILITY OF RADON IN SUB-SLAB VAPOR



Background Information (Cont)

- **December 2018 & August 2019 -**
  - Paired Radon & PCE concentrations measured in IA & Sub-Slab Vapor at:
    - 4 locations in December 2018
    - 7 locations in August 2019

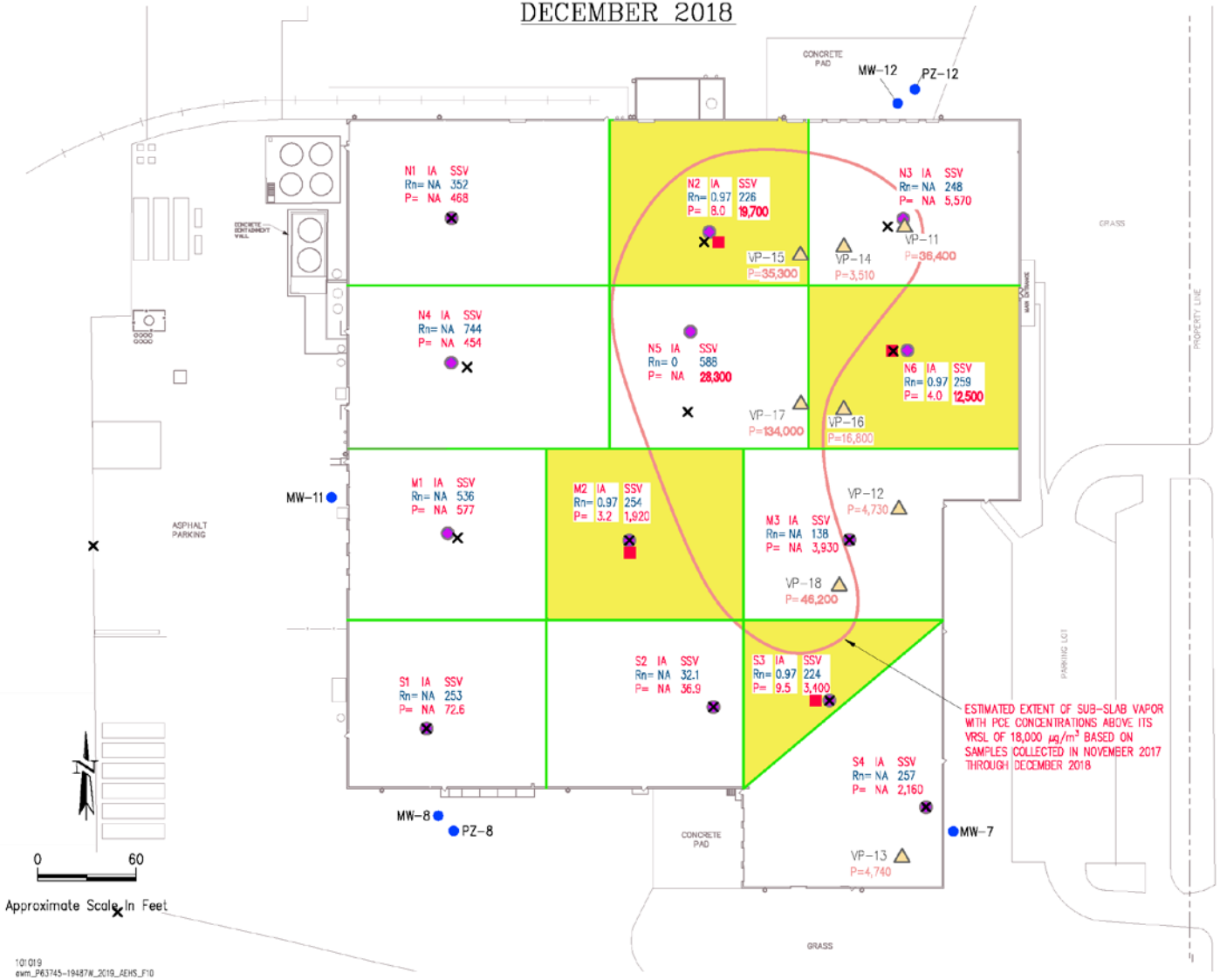


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FIGURE 10

LEGEND

- SUB SLAB VAPOR SAMPLE LOCATION (11/17 & 2/18)
- INDOOR AIR SAMPLE (12/18 & 8/19)
- VAPOR PIN SAMPLE LOCATION (12/18 & 8/19)
- RSSI RADON SENSOR LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY
- IA = INDOOR AIR
- SSV = SUB-SLAB VAPOR
- Rn – RADON CONCENTRATIONS MEASURED WITH A RAD7 RADON DETECTOR ARE IN PICO CURIES PER LITER (pCi/L) AND DO NOT INCLUDE THE TWO-SIGMA STATISTICAL UNCERTAINTY VALUES
- P – PCE CONCENTRATIONS IN INDOOR AIR VAPOR SAMPLES ARE IN MICROGRAMS PER CUBIC METER (µg/m³). CONCENTRATIONS ABOVE THE PCE VRSL OF 18,000 µg/m³ ARE IN **BOLD**.
- NA = NOT ANALYZED
- VRSL = VAPOR RISK SCREENING LEVEL

RADON AND PCE CONCENTRATIONS MEASURED IN INDOOR AIR AND SUB-SLAB VAPOR SAMPLES (DECEMBER 2018)

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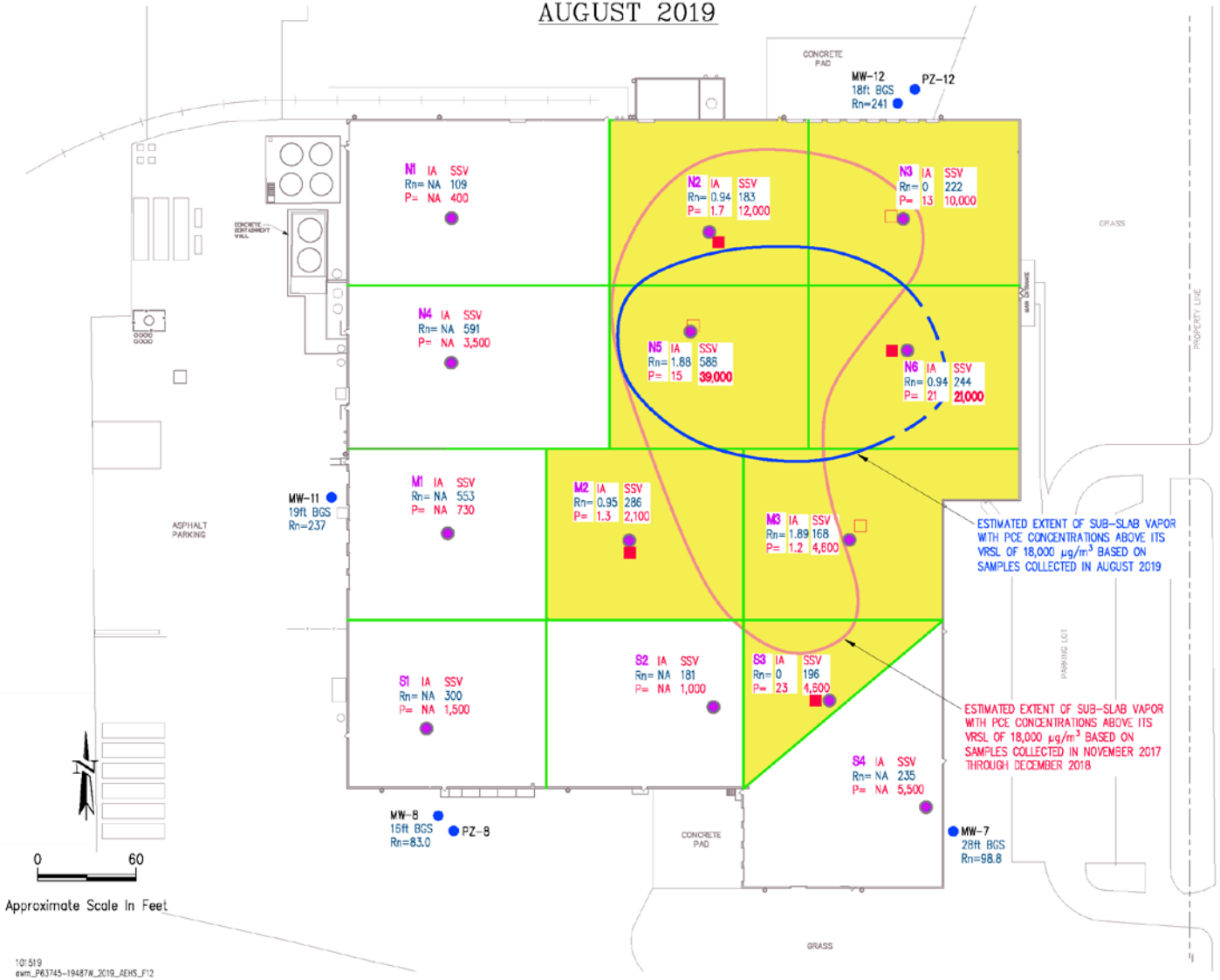

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FIGURE 12

LEGEND

- INDOOR AIR SAMPLE (12/18 & 8/19)
- INDOOR AIR SAMPLE LOCATION (8/19)
- VAPOR PIN SAMPLE LOCATION (12/18)
- MONITORING WELL OR PIEZOMETER LOCATION
- BUILDING AND SAMPLE REFERENCE BOUNDARY
- N3 SAMPLE SECTION ID FOR NORTHERN (N), MIDDLE (M), AND SOUTHERN (S) PORTION OF THE FACILITY.
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RADON AND PCE CONCENTRATIONS MEASURED IN INDOOR AIR AND SUB-SLAB VAPOR SAMPLES (AUGUST 2019)

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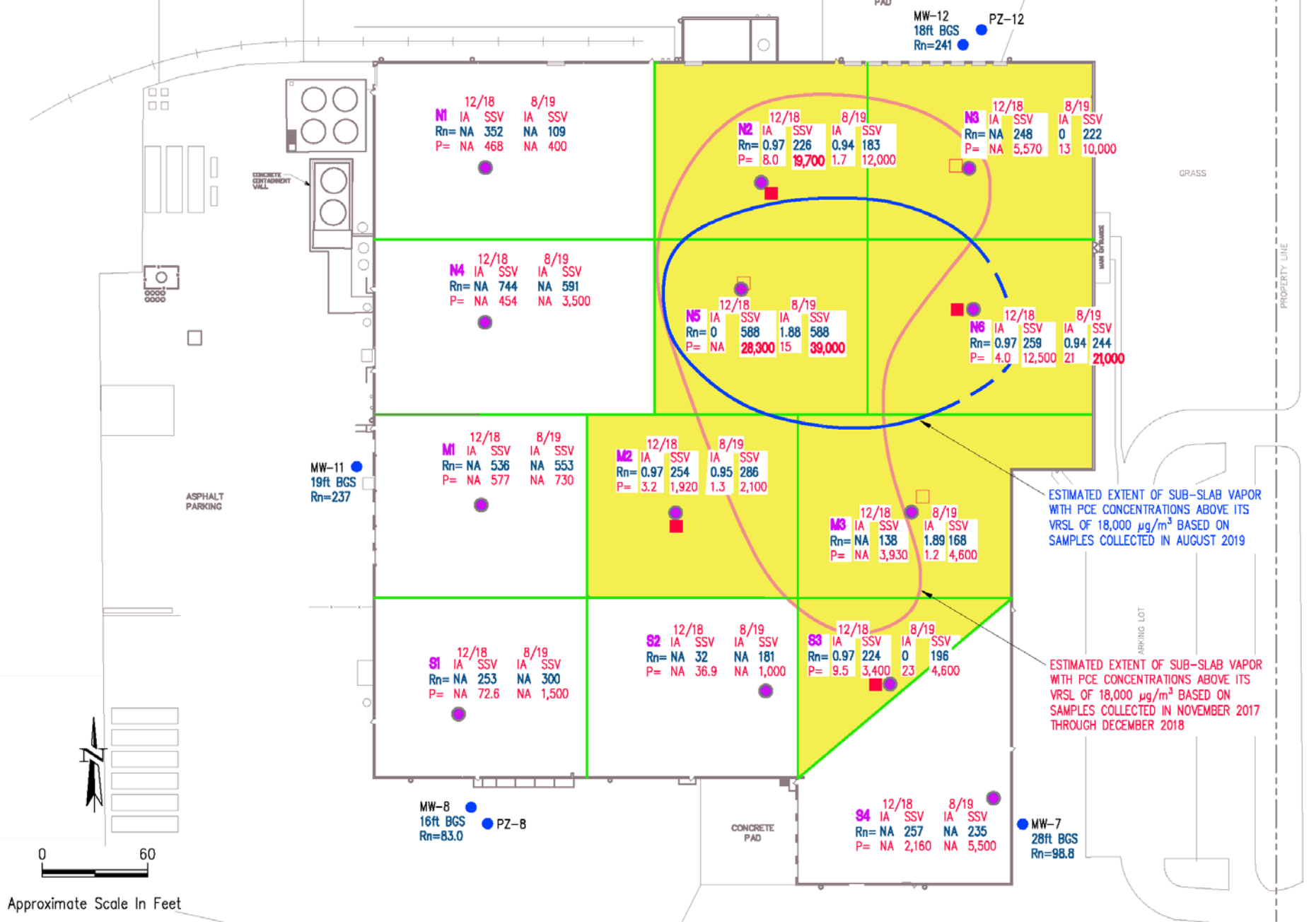
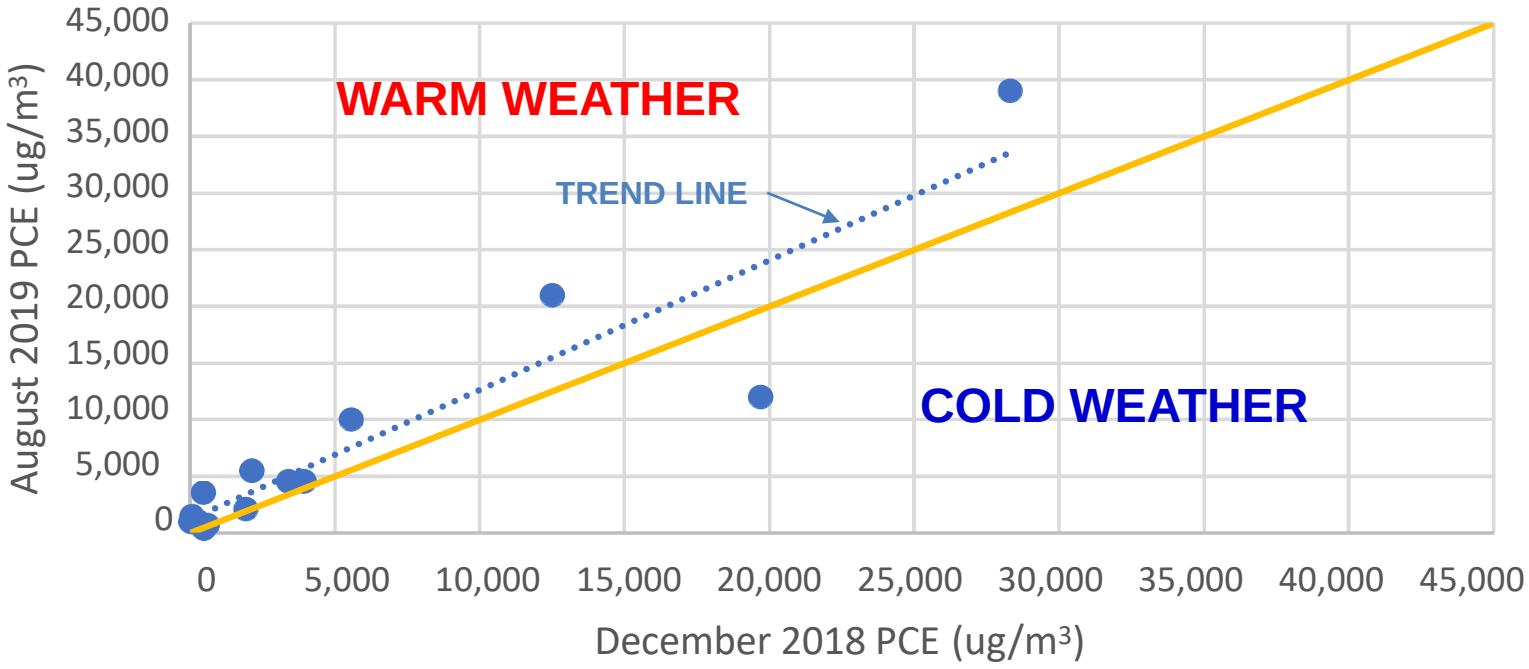
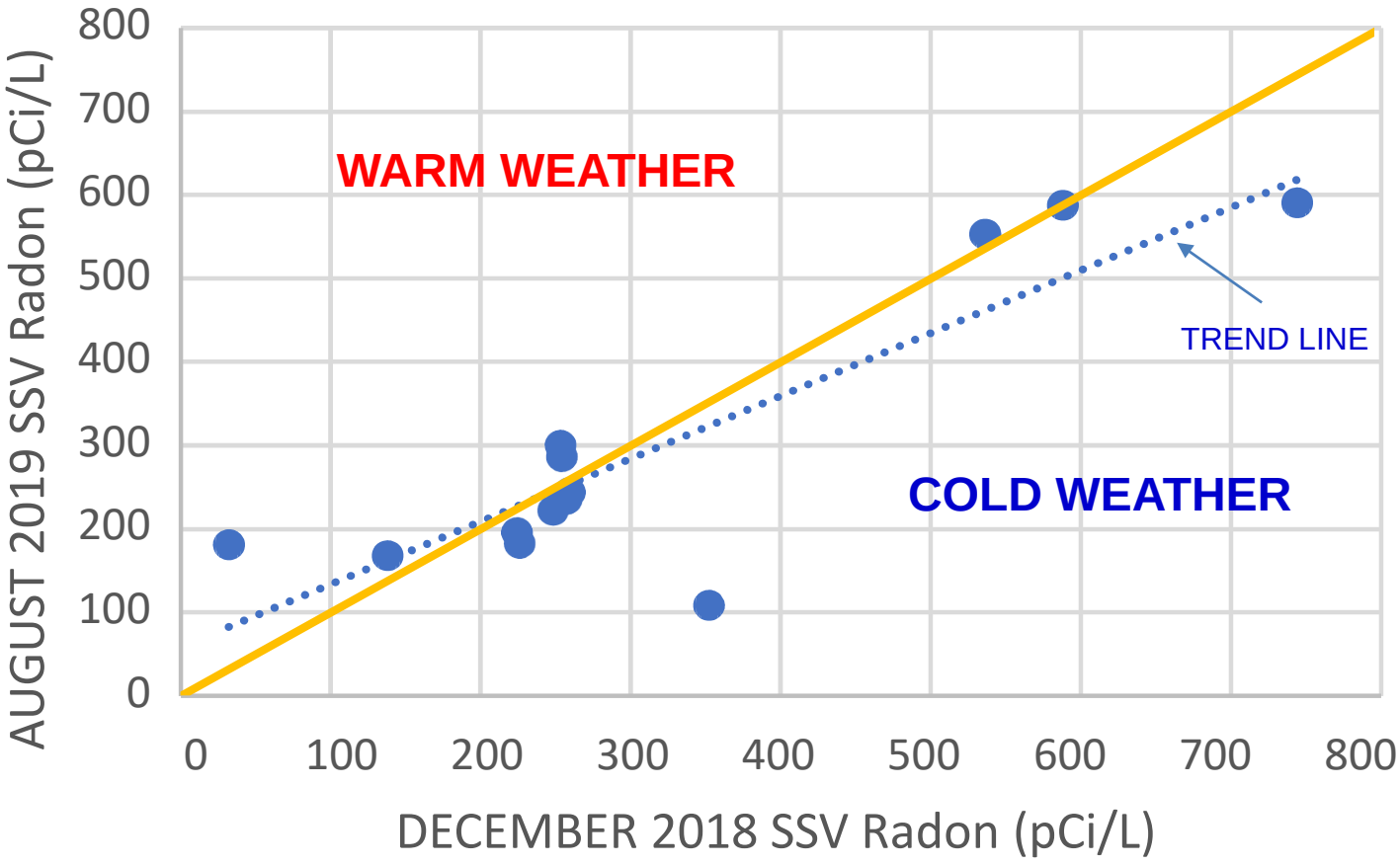


RADON & PCE CONCENTRATIONS IN IA & SSV – DEC 2018 & AUG 2019

TEMPORAL VARIABILITY OF PCE IN SUB-SLAB VAPOR



TEMPORAL VARIABILITY OF RADON IN SUB-SLAB VAPOR



Summary of Findings
Radon in Vapor & Indoor Air

- **Radon concentrations in Sub-Slab Vapor varied widely across the site (32 to 744 pCi/L or about 24X) but did not vary as much temporally (generally less than 1.5X)**

- **Radon concentrations in Indoor Air did not vary as much spatially or temporally (most less than 2X)**

- **Instrument (RAD7) limitations & low/ND of Rn may account for most(?) of variability in IA**

Summary of Findings
PCE in Sub-Slab Vapor

- **PCE concentrations in Sub-Slab Vapor varied widely across the site (up to 25X) due to proximity of PCE sources in fill and groundwater and perhaps sub-surface frost walls between the building sections**

- **PCE concentrations in Sub-Slab Vapor at the same locations also varied temporally (up to 20X) but did not show a clear overall increase or decrease between winter and summer samples**

Summary of Findings
PCE in Indoor Air

- **PCE concentrations in Indoor Air also showed a wide range (up to 17X) across the site but less so temporally at the same locations (up to 5X) between December 2018 & August 2019**
- **The highest PCE and Radon concentrations in Indoor Air were measured during non-heating season in August 2019, not December as expected. May be due to the time of sampling event on a Saturday when facility was not operating but 2 overhead doors were open & large fans blowing out of the building**

Summary of Findings
Final Thoughts on This Site

- **Entry points in foundations do not necessarily overlap areas with high concentrations of PCE and radon in the sub-slab vapor, so if external factors do not act across the building in unison, it could skew some results**

- **Monitoring antecedent site conditions before sampling event would shed more light on sample results and the correlation between radon and PCE concentrations in SSV & IA**

THANK YOU

QUESTIONS?

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