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OCCUPATIONAL SAFETY DURING RADON MITIGATION FIELD EXPERIENCE AND SURVEY MONITORING RESULTS

Jean-Claude F. Dehmel, CHP
S. Cohen & Associates, Inc.,
McLean, VA 20101
Peter Nowlan
R.F. Simon Company, Inc.
Barto, PA 19504
Eugene Fisher
U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, DC. 20460

ABSTRACT

The U.S. Environmental Protection Agency (EPA) has initiated a radon mitigation project in homes located in Montclair, West Orange, and Glen Ridge, New Jersey. In these communities, numerous properties are contaminated with radium tailings which were initially introduced around homes as backfill and used as construction materials. In these homes, ambient radon concentrations are well above the 4 pCi/L EPA guideline. In support of radon mitigation activities, a comprehensive occupational health and safety (H&S) monitoring program has been implemented to assess working conditions. H&S activities include monitoring airborne concentrations for radon, asbestos, organic vapors, radioactivity, and total suspended particulates, and radiation exposures and loose surface alpha contamination levels.

Survey results indicate that all exposures are well within occupational radiation protection standards and OSHA criteria. Survey measurement results have been observed to vary depending upon existing conditions and type of on-going mitigation work. Typically, average radon levels vary from 0.4 to 32.5 pCi/L; radiation exposure rates range from 6 to 460 uR/h; surface contamination is generally below detection limits of 9 to 17 dpm/100 cm^2; long-lived radionuclides concentrations are $\leq 6.8 \times 10^{-13}$ uCi/mL; asbestos fiber concentrations vary from ≤ 0.002 to 0.016 fibers/cm^3; total suspended particulates personnel exposure limits vary from ≤ 0.01 to 0.65 mg/m^3; and organic vapors concentrations range from <0.36 to 13 ppm-TWA for compounds typically found in caulking compounds and PVC cements.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and, therefore, the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

INTRODUCTION

The installation of radon mitigation systems involves potential exposures to different types of occupational hazards. Such hazards include exposure to radon and to those routinely experienced in light construction and building trades, e.g., home remodeling and improvement. In the context of this project, radiological occupational hazards, in addition to radon, include exposures to elevated ambient radiation levels due to the presence of soils contaminated with such radionuclides as Ra-226, U-238, and Th-232, and their decay products. Possible exposure pathways include ambient radiation, airborne radionuclides (radon gas, radon daughters, and resuspended particulates), and the presence of radioactive contamination (in soils and as loose surface). The installation of radon mitigation systems (e.g., subslab) requires that holes be drilled into concrete floors and foundation walls in order to tap soil gases and also necessitates the removal of some soils. Such activities have the potential to increase exposures and cause the spread of contamination.

The following presents and summarizes health and safety (H&S) monitoring data and results obtained during the course of radon mitigation activities conducted in 17 homes (1, 2). H&S activities include monitoring airborne concentrations for radon, asbestos fibers, organic vapors, long-lived nuclide particulates, and total suspended particulates/dusts (TSP), radiation exposure rates, and loose surface alpha contamination levels.

H&S MONITORING RESULTS

SOIL RADIONUCLIDE CONCENTRATIONS

In these communities, numerous properties are contaminated with radium tailings which were initially introduced around homes as a backfill and used as construction materials. The tailings originated from the extraction and purification process of radium from uranium bearing ores to produce luminous paints. Tailings and contaminated soils were discarded in adjacent properties and used by nearby communities. Previous characterization studies indicate that surface and subsurface Ra-226 concentrations are on the order of 1,500 and 4,500 pCi/g, respectively (3). The range of Th-232 concentration is approximately the same as radium. The concentrations of U-238 and U-234 are lower, with the highest concentration being reported at 310 pCi/g.

In support of the field work, several soil samples were taken and analyzed for the presence of U-238, Ra-226, Th-232, and K-40. The analyses were performed by GeLi gamma spectroscopy. The results of such analyses are shown below (Table 1).

The data indicate that none of the soil sample concentrations approach the results of earlier characterizations. For the radionuclides considered here, the maximum soil concentrations are 27 pCi/g for U-238, 59 pCi/g for Ra-226, and 5.9 pCi/g for Th-232. Background concentrations of these radionuclides in Northern New Jersey soils are typically <1.0 pCi/g. The presence of naturally occurring K-40 was determined for the purpose of providing additional information with which to assess the response of portable radiation survey meters. Past experience has shown that since the concentration of K-40 in soil varies, the detection of elevated exposures rates could be interpreted as radium contamination, especially when Ra-226 is present at lower concentrations. Soil sample analyses confirm that K-40 concentrations vary by a factor of two, from 7.0 to 15.0 pCi/g.

SURFACE CONTAMINATION

The presence of surface contamination was monitored by conducting smear surveys and by scanning areas with portable alpha ZnS(Ag) survey meters. Typically 10 to 20 smears were taken in each home whenever contaminated soils were exposed. The number of smears taken and their survey locations were based on

TABLE 1. MAXIMUM SOIL RADIONUCLIDE CONCENTRATIONS

Residence ID No.	Radionuclide concentrations* - pCi/g U-238	Ra-226	Th-232	K-40
1 A-211	4.4	18.0	2.9	11.0
153 C-315	<1.0	1.4	1.6	13.0
30 F-142	8.1	9.2	1.8	9.4
32 F-143	12.0	16.0	2.1	7.0
6 J-242	4.2	4.6	2.1	9.7
8 J-243	9.4	10.0	2.0	9.2
21 L-321	<1.0	1.1	5.9	15.0
26 L-322	2.2	1.7	1.6	10.0
53 N-163	<0.5	2.9	0.8	8.8
56 N-164	2.4	3.1	2.2	13.0
64 N-166	27.0	35.0	2.6	9.2
66 N-167	24.0	59.0	1.6	9.2
26 V-173	21.0	40.0	1.6	9.7
28 V-174	<2.0	3.7	2.1	11.0
37 V-178	13.0	6.7	1.9	7.3

* Soil sample analyses performed by GeLi gamma spectroscopy. Concentrations results are expressed for dry weights.

the results of direct reading radiation survey meters and the type of intrusive activities being conducted. All smears were counted for five minutes using a bench-top alpha ZnS(Ag) counter in order to resolve the maximum contamination limit of 20 dpm/100 cm^2. The results of such analyses are shown below (Table 2). The data indicate that all results, except for a few, are below the maximum contamination limit.

In a few instances, smear results were found to hover about the limit of 20 dpm/100 cm^2. When those smears were recounted, typically 2 to 3 later hours, all results fell within the instrumentation's lower limit of detection, indicating that the initial activity was due to radon decay products. This conclusion was also confirmed by submitting such smears to more rigorous laboratory analyses.

TABLE 2. TYPICAL ALPHA SURFACE CONTAMINATION LEVELS

	Surface contamination levels* - dpm/100 cm^2	
Residence ID No.	Results at or below the lower limit of detection	Results above the lower limit of detection
1 A-211	≤11.9	
2 A-212	≤ 9.4	
145 C-312	≤12.2	
153 C-315	≤12.2	
30 F-142	≤11.9	
32 F-143	≤11.9	
6 J-242	≤ 9.4	
8 J-243	≤ 9.4	
21 L-321	≤13.2	15.3
26 L-322	≤13.2	
53 N-163	≤13.2	
56 N-164	≤17.1	
64 N-166	≤11.9	
66 N-167	≤14.1	
26 V-173	≤ 9.4	
28 V-174	≤11.9	
37 V-178	≤10.4	13.1 - 25.0

* Analyses were performed by gross alpha counting using a ZnS(Ag) counter/ratemeter. Contamination results are for smears or wipes taken over an area of 100 cm^2, ca 4" x 4".

RADIATION EXPOSURE RATES

Ambient radiation exposure levels were monitored in all work areas, including basements, lowest ground floors, crawl spaces, and outdoor areas requiring access or where work was being performed. Measurements were made using portable NaI(Tl) micro-R-meters. Survey measurement points included ambient areas at one meter above the floor or ground, and on contact with floors, foundation walls, and soil. The results of such surveys are shown below (Table 3). The data indicate that ambient exposure rates vary greatly, typically up to 10 times above the ambient background level of 8 to 9 uR/hr. Any measurement results in excess of twice background is generally considered to be anomalous. Contact radiation levels were shown to vary even more significantly, ranging from about 15 to 460 uR/hr. In terms of characterizing radiation doses, ambient radiation levels are more representative of personnel exposures than contact measurements. Exposures to higher contact radiation levels, when they did occur, were of relatively brief durations.

RADON CONCENTRATIONS

Radon concentration levels were measured using continuous radon monitoring equipment. Radon levels were printed hourly during the course of the work. All general work areas and zones were ventilated using portable ventilation systems and vacuum cleaners, respectively. Ventilation systems introduced fresh air from the outside and vacuum cleaner exhausts were discharged outdoors. Radon monitoring results are shown below (Table 4). The data indicate that average and maximum ambient radon concentration levels were typically less than 5 pCi/L and as high as 66 pCi/L, respectively. In one instance, basement radon levels shot up to 66.1 pCi/L over a four hour period in spite of the on-going active ventilation. This sudden radon excursion was corrected by pressurizing the basement instead.

LONG-LIVED PARTICULATE RADIONUCLIDES

Air samples were taken to assess ambient airborne radionuclide concentrations whenever intrusive work or sampling activities were in progress. Monitoring involved taking air samples through 47 mm glass fiber filters. Sample durations typically reflected the length of on-going work activities, up to 9 hours per day, and a nominal sampling flow rate of 40 LPM. All filters were counted for ten minutes using a bench-top alpha ZnS(Ag) counter in order to resolve the concentration limit of 4.4 E-12 uCi/mL for total gross alpha.

TABLE 3. AMBIENT AND CONTACT RADIATION EXPOSURE RATES

Residence ID No.	Range of radiation exposure rates* - uR/hr. Ambient radiation exposure rates at waist height (1 m.)	Contact radiation exposure rates on ground and floor
1 A-211	10 - 25	10 - 32
2 A-212	7 - 20	7 - 32
145 C-312	10 - 190	11 - 460
153 C-315	11 - 17	14 - 26
30 F-142	10 - 90	11 - 150
32 F-143	13 - 75	12 - 200
2 J-241	8 - 20	8 - 34
6 J-242	9 - 23	9 - 36
8 J-243	6 - 12	7 - 18
21 L-321	7 - 11	8 - 13
26 L-322	7 - 12	9 - 14
27 L-S27	7 - 12	7 - 15
53 N-163	8 - 13	9 - 14
56 N-164	10 - 15	10 - 30
64 N-166	15 - 80	13 - 240
66 N-167	20 - 50	15 - 100
26 V-173	8 - 18	9 - 28
28 V-174	8 - 60	8 - 140
37 V-178	10 - 34	10 - 40

* Measurements taken using a portable NaI(Tl) micro-R survey meter. Results represent range of exposures rates routinely observed in basements or lowest floor levels, and outdoors in areas such as sidewalks, yards, and drive and walkways.

The filters were counted again, typically 2 to 3 hours later, to discern the presence of long-lived radionuclides from radon decay products. The results of such sampling surveys are shown below (Table 5). The data indicate that airborne concentrations were typically below the instrumentation's lower limit of detection, about $\leq$6.8 E-13 uCi/mL. This conclusion was also confirmed by subsequently subjecting air sample filters to more rigorous laboratory analyses.

TABLE 4. RANGE OF RADON CONCENTRATION LEVELS

Residence ID No.	Typical radon concentration levels* - pCi/L.		
	Average	Low	High
1 A-211	1.0	0.4	1.7
2 A-212	1.0	0.1	2.4
145 C-312	2.7	2.4	3.9
153 C-315	0.4	0.4	1.2
30 F-142	4.3	2.8	7.2
32 F-143	1.5	0.4	2.7
6 J-242	0.9	0.3	1.8
8 J-243	0.7	0.3	1.7
21 L-321	2.7	1.0	11.8
26 L-322	0.6	0.1	1.2
53 N-163	1.9	0.1	4.7
56 N-164	1.7	0.1	23.4
64 N-166	32.5	2.8	66.1
66 N-167	1.2	0.9	3.5
26 V-173	3.4	1.1	15.1
28 V-174	2.3	1.0	2.6
37 V-178	1.3	0.9	1.7

* Measurements taken using portable Femto-Tech Model R210F radon monitors equipped with continuous data recorders. Results were printed out hourly to monitor levels. Radon concentrations represent ambient levels in basements or lowest ground floors measured with on-going active ventilation.

TOTAL SUSPENDED PARTICULATES (TSP)

Some work activities, such as drilling, grinding, etc, have the potential to generate airborne suspended particulates (TSP). The air sampling program and system described above were also used to assess the presence of TSP in the work environment. All filters were pre-weighed before being used and then weighed again when sampling was completed. Both weighings were performed using a laboratory micro-balance. The associated airborne dust concentrations are shown in above (Table 5). The data indicate that all results are below the OSHA limit of 10 mg/m^3 (4). The highest and lowest measurable TSP concentrations observed were 0.65 and 0.04 mg/m^3, respectively.

TABLE 5. GROSS ALPHA AIRBORNE RADIONUCLIDE AND TOTAL SUSPENDED PARTICULATE CONCENTRATIONS

Residence ID No.	Airborne concentrations*		
	Sampling time (hr.)	Gross alpha concentrations (uCi/mL)&	Suspended Particulates (mg/m^3)#
1 A-211	6.9	≤4.0E-13	0.17
2 A-212	7.9	≤5.2E-13	0.26
145 C-312	8.5	≤6.5E-13	no data
153 C-315	6.7	≤2.4E-13	≤0.03
30 F-142	7.1	≤6.8E-13	≤0.01
32 F-143	7.7	≤5.5E-13	0.18
6 J-242	6.9	≤2.1E-13	≤0.03
8 J-243	5.2	≤1.5E-12	≤0.03
21 L-321	8.0	≤4.7E-13	0.15
26 L-322	6.5	≤4.3E-13	0.15
53 N-163	7.7	≤4.8E-13	0.16
56 N-164	8.5	≤3.9E-13	≤0.02
64 N-166	8.8	≤4.8E-13	0.04
66 N-167	8.3	≤3.8E-13	0.20
26 V-173	9.0	≤4.5E-13	0.65
28 V-174	8.0	≤1.9E-13	≤0.02
37 V-178	8.9	≤3.2E-13	0.09

* Measurements taken using a portable sampling pump and 47 mm glass fiber filters. Sampling flow rate is typically 40 LPM. Air concentrations represent ambient levels in basements or lowest floors measured with on-going active ventilation. Sampling times represent typical duration of intrusive work which could result in the generation of elevated airborne suspended dust and radioactivity concentrations. A single filter was used to simultaneously assess the presence of both long-lived particulate nuclides and total dust.

& Filter samples were analyzed first for gross alpha activity using a ZnS(Ag) alpha scaler at the work site and then subjected to laboratory GeLi gamma spectroscopic analyses.

Filters were pre-weighed before being used and weighed again after sampling was completed. Both weighings were performed using a micro-balance under laboratory conditions.

FIBER (ASBESTOS) CONCENTRATIONS

Since the work was performed in homes which are known to have asbestos containing materials (ACM), air samples were taken to determine the presence of airborne fibers in all work areas. Samples were taken by drawing air through a 25 mm open cassette with a mixed cellulose ester filter (MCE). The selected sampling and analytical methods were based on OSHA approved methods (NIOSH 7400 - Phase Contrast Microscopy) (5). Sampling durations and flow rates were adjusted to reflect the constraints of the NIOSH procedure for total fiber loadings. The airborne fiber concentrations are shown below (Table 6). The data indicate that all results are below the OSHA limit of 0.2 fiber/cm^3, 8-hr TWA (4). It should be noted that PCM resolves all fibers with a specific aspect ratio (length and diameter), whether they are asbestos or not. In order to assess the presence of asbestos fibers, one sample with the highest fiber density (43.3 f/mm^2) was subjected to further analysis (transmission electron microscopy - TEM) (6). The results revealed that a fewer number of non-asbestos fibers were measured (14.4 f/mm^2). Such fibers were identified to be gypsum, cellulose, and material containing calcium.

ORGANIC VAPOR CONCENTRATIONS

The installation of radon mitigation systems require the use of caulking and sealing compounds, sealing foams, and PVC pipe cements. As these compounds are applied, and during the curing process, organic vapors are released in the work environment. In order to assess personnel exposures to such chemical compounds, organic vapor monitor (passive diffusion) were worn by individuals involved in applying caulks, sealants, and PVC cements. The monitors were worn for the duration of these activities since such functions are typically of short duration (2 to 4 hours). The monitors were supplied and analyzed by 3M (7). The organic vapor concentration results are shown below (Table 7). The selection of organic compounds to be analyzed by 3M was based on the information contained in the MSDS supplied with such commercial products. The organic vapor concentration results represent exposure levels in all work areas routinely accessed to support the installation of radon mitigation systems. The data indicate that for the selected compounds, ambient concentrations were well below the OSHA permissible exposure limits and ACGIH threshold limit values (4, 8). The highest observed organic vapor concentrations was due to methyl ethyl ketone (MEK), at 13 ppm. The corresponding 8-hour TWA limit is 200 ppm.

TABLE 6. FIBERS (ASBESTOS) CONCENTRATION LEVELS

Residence ID No.	Airborne fibers concentration levels* - f/cm³		
	fibers/cm³	fibers/mm²	
1 A-211	≤0.005	12.7	
2 A-212	≤0.005	10.2	
13 A-112	≤0.005	16.6	
120 C-311	≤0.005	33.1	
153 C-315	≤0.005	28.0	
14 E-121	0.012	62.4	
26 F-173	≤0.005	29.3	
30 F-142	0.007	19.1	
32 F-143	0.016	43.3	PCM data&
32 F-143	≤0.003	14.0	TEM data&
6 J-242	≤0.005	19.1	
8 J-243	≤0.006	30.6	
21 L-321	≤0.005	0.0	
26 L-322	0.011	28.0	
27 L-S27	≤0.005	30.6	
25 M-251	0.007	25.5	
46 N-161	≤0.002	0.0	
53 N-163	≤0.005	8.9	
56 N-164	0.007	24.2	
58 N-168	0.007	33.1	
64 N-166	≤0.005	12.7	
66 N-167	≤0.005	34.4	
33 R-341	0.006	31.8	
55 R-343	≤0.005	24.2	
26 V-173	0.008	29.3	
28 V-174	0.012	24.2	
35 V-177	≤0.005	15.3	
37 V-178	≤0.005	11.5	

* Fiber concentrations represent ambient levels in basements or lowest floor levels measured with on-going active ventilation. Measurements were taken using a portable sampling pump and 25 mm MCE filters in open face cassettes. MCE filters were analyzed by NIOSH method 7400 - Phase Contrast Microscopy (5).

& One sample, 32 F-143, was also analyzed via transmission electron microscopy (TEM) using U.S. EPA Level II Method (6). Analysis was performed following the results of the PCM analysis. The same sample was used for the TEM analysis.

TABLE 7. ORGANIC VAPOR MONITOR CONCENTRATION LEVELS

Residence ID No.	Work activity	Typical organic vapor concentrations* - ppm: Organic compounds	Vapor concentrations	TWA& limit
53 N-163	Sealing & caulking	MEK	< 1.00	200
		Toluene	< 0.84	100
		Xylene	< 0.66	100
64 N-166	PVC cementing	MEK	13.0	
		Cyclohexanone	0.53	25
66 N-167	PVC cementing	MEK	6.55	
		Toluene	< 0.43	
		Cyclohexanone	< 0.49	
66 N-167	Sealing & caulking	Toluene	< 0.56	
		Perchloro-ethylene	< 0.36	25
		P. Glycol mono methyl ethyl acetate	< 0.46	5#
37 V-178	Sealing & caulking	Acetone	< 2.30	75
		MEK	< 1.83	
		Xylene	< 1.21	

* Measurements taken using 3M Model 3510 passive diffusion organic vapor monitors issued to personnel. Selection of organic compounds was based on information provided in MSDS supplied with commercial products routinely used in radon mitigation. Organic vapor concentrations represent exposure levels in all work areas routinely accessed to support the installation of radon mitigation systems with on-going active ventilation in the lowest ground floors and normal ventilation in the remaining upper floors.

& TWA limits reflect OSHA permissible exposure limits (PEL) (4).

Based on ACGIH threshold limit values (TLV) (8).

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The results shown above indicate that all personnel exposures were well within recognized radiation protection standards as well as project administrative limits. The adopted radiation exposure limit for this project was set at 500 mrem, same as for the general public, as opposed to 5,000 mrem for occupationally exposed radiation workers. Furthermore, an action level of 100 mrem was established for the purpose of assessing on-going work activities and associated radiation exposures. Dosimetry results from radiation badges (TLDs) revealed that monthly exposures were below the TLD's response level of 10 mrem for X and gamma rays (9). Personnel radon exposures were monitored by using alpha track etch detectors (ATDs) (10). ATD radon concentration results ranged from 0.3 to 5.2 pCi/L. Cumulative radon exposures ranged from 30 to 104 pCi-days/L for one month monitoring periods. Exposures to airborne long-lived particulate radionuclides, total suspended solids, asbestos fibers, and organic vapors were well within the applicable OSHA permissible exposure limits.

RECOMMENDATIONS

The H&S monitoring results revealed that by adopting simple protective measures, personnel exposures can be maintained well below occupational standards and, in some instances, at the threshold of measurement detection limits. Some of the applied protective measures include working in well ventilated areas, judicious use of local exhaust ventilation at the source of contaminants, application of dust suppression techniques, use of the functional sections of a mitigation system to minimize radon exposures and resuspended particulates while completing its installation, use of containment methods to minimize the spread of contaminants, and restricting personnel traffic in work areas. The use of monitoring equipment has shown to be also helpful in the detection of trends in ambient radiation exposure rates and levels of contaminants. Routine surveillance of all work activities has also allowed the timely detection of potentially problematic situations. The radon concentration excursion and interpretation of radon decay products to alpha surface contamination were two such examples. In both instances, simple monitoring and measurement techniques were applied to identify and correct the situation. Excluding the presence of contaminated soils, these H&S monitoring results indicate that such protective measures and monitoring methods can also be applied in the installation of radon mitigation systems under conventional conditions.

REFERENCES

1. S. Cohen & Associates, Inc. Work Plan - House Evaluation Program Applied to Superfund Sites - Montclair, West Orange, and Glen Ridge, New Jersey, prepared for the U.S. Environmental Protection Agency, Office of Radiation Programs under contract No. 68D90170, Work Assignment No. 1-39, May 1990

2. S. Cohen & Associates, Inc. Health and Safety Plan - House Evaluation Program Applied to Superfund Sites - Montclair, West Orange, and Glen Ridge, New Jersey, prepared for the U.S. Environmental Protection Agency, Office of Radiation Programs under contract No. 68D90170, Work Assignment No. 1-39, May 1990

3. Camp Dresser & McKee, Inc. Supplemental Feasibility Study for the Montclair/West Orange and Glen Ridge Radium Sites, Vol. 4, prepared for the U.S. Environmental Protection Agency, Region II, Edison, NJ, April 3, 1989.

4. Occupational Safety and Health Administration, Air Contaminants - Permissible Exposure Limits, Title 29, Code of Federal Regulations, Part 1910.1000, OSHA 3112, 1989.

5. National Institute for Occupational Safety and Health, NIOSH Method 7400, Fibers, 2/15/84, Cincinnati, OH.

6. Yamate, G., Agarwal, S.C., and Gibbons, R.D. Methodology for the Measurement of Airborne Asbestos by Electron Microscopy, Draft Report, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC, 1984.

7. Occupational Health & Safety Products Division, Organic Vapor Monitors #3500/3510 - Instruction and Use Manual, 3M, St. Paul, MN.

8. American Conference of Governmental Industrial Hygienist, Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, 1990-1991, Cincinnati, OH.

9. Tech/Ops Landauer, Inc. Gardray TLD Dosimetry, Radiation Dosimetry Reports, 6/30/1990 to 11/30/1990, Glenwood, IL.

10. Tech/Ops Landauer, Inc. Radon DDOS ATDs, Radon Monitoring Reports, 4/3/1990 to 11/12/1990, Glenwood, IL.