1996_08

OCCUPATIONAL EXPOSURES AMONG RADON MITIGATION WORKERS

Thomas F. Bloom
National Institute for Occupational Safety and Health
Cincinnati, OH

DISCLAIMER

Mention of company or product name does not constitute endorsement by the Centers for Disease Control and Prevention.

ABSTRACT

During a study of occupational exposures of workers employed at six mitigation companies in three States, investigators from the National Institute for Occupational Safety and Health (NIOSH) measured concentrations of radon (^{222}Rn) and radon decay products in 19 residential basements and 2 first floor school rooms using direct reading instruments. Exposures to continuous noise and to organic vapors were also measured. For two residential basements, where pre-mitigation radon levels averaged 192 picocuries per liter (pCi/L) and 95 pCi/L, the average concentrations of radon decay products over the mitigation job were 106 milliWorking Levels (mWL) and 437 mWL, respectively. These levels, if experienced by workers on a 40 hour per week basis throughout the year, would exceed the NIOSH Recommended Exposure Limit (REL) of 1000 mWL Month (1 Working Level Month) per year. For the remaining 19 mitigations, average radon decay product concentrations ranged from 2 mWL to 66 mWL. Exposures to *short periods* of continuous noise ranged from 99-112 dBA. Maximum organic vapor exposures, sampled from ½ to 4 hours, were 23 ppm of acetone, 67 ppm of methyl ethyl ketone, and 32 ppm of tetrahydrofuran. Based on the limited exposure times, these levels were below the applicable 8-hour NIOSH RELs and Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PEL).

INTRODUCTION

The radon mitigation profession is made up of individuals who install radon gas reduction systems in commercial and residential buildings. These individuals are exposed to radon (^{222}Rn) gas as well as to radon decay products (RDP). They are also exposed to other hazards including: 1) organic vapors from the solvents contained in the glues and sealants used, and 2) to continuous noise from the use of cutting, grinding, and drilling tools. Investigators from the National Institute for Occupational Safety and Health (NIOSH) measured concentrations of radon gas and of RDP during mitigations carried out in 19 residential basements and 2 first floor school rooms. Personal exposures to continuous noise and to organic vapors were also measured. The NIOSH study included six mitigation companies--two each in the states of Pennsylvania, Iowa, and New York.

The primary objective for this study was determine if radon mitigators have potential health risks associated with exposures to physical and chemical agents. The primary exposure of interest is RDP.

OVERVIEW OF MITIGATION INDUSTRY

At the beginning of the NIOSH study (August 1991), 620 individuals in the United States were listed as meeting the requirements of the Environmental Protection Agency (EPA) Radon Contractor Proficiency Program. Collectively, these individuals were associated with approximately 600 companies.[1]

Mitigation technologies found to be effective in reducing radon levels in residential and commercial buildings include: 1) sub-slab depressurization, 2) covering drains and utility openings, 3) sealing cracks with caulking or epoxy sealants, and 4) covering exposed earth inside or under the residence with polymeric vapor barrier. Sub-slab depressurization, which involves drilling a hole(s) in the foundation slab and then running a pipe from the hole to a suction fan venting outside, is the preferred approach because of its effectiveness, applicability, and ease of installation.[2]

OCCUPATIONAL EXPOSURE CRITERIA

Radon Gas and Radon Decay Products

As a gas, radon can find its way into buildings and homes through cracks in foundation structures, through drain pipes, sump pump wells, and via the water supply.[3] Data from both human and animal studies clearly demonstrate a direct link between lung cancer and radon exposure.[4] The risk of lung cancer does not arise directly from exposure to radon, but rather to RDP. These decay products, unlike radon, are particulate in nature and can be retained by the respiratory tract after inhalation.[5] The first four decay products, ^{218}Polonium, ^{214}Lead, ^{214}Bismuth, and ^{214}Polonium, have short half-lives (all less than 30 minutes). These radio nuclides deliver the alpha radiation dose to bronchial tissue that is implicated in radiogenic lung cancer.[6] Figure 1 shows the radioactive decay scheme for radon.

For radon decay product exposure assessment, the traditional unit of measurement is the Working Level (WL). One WL is defined as any combination of the short-lived decay products---^{218}Polonium, ^{214}Lead, ^{214}Bismuth, and ^{214}Polonium---in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV (million electron volts) of potential alpha radiation energy. The Working Level Month (WLM) was introduced so that both duration and level of exposure could be considered. One WLM is equal to 170 WL hours. This corresponds to an exposure of 1 WL for 170 hours (approximately 1 working month).[5]

NIOSH has proposed a Recommended Exposure Level (REL) for RDP of 1 WLM per year for workers employed in underground mines.[7] The NIOSH REL corresponds to a continuous 8 hour workday exposure of 0.083 WL (83 milliworking levels (mWL)) during one year. In support of the REL, NIOSH notes that epidemiologic studies have indicated that a radon decay product exposure of 4 Working Level Months (WLM) per year over a 30-year lifetime poses a significant lung cancer risk. This level corresponds to a continuous 8 hour workday exposure of 0.33 WL.

The current occupational standard for RDP enforced by the Occupational Safety and Health Administration (OSHA) is incorporated by reference from 10 CFR Part 20, Standards for Protection against Radiation which are enforced by the Nuclear Regulatory Commission. The Permissible Exposure Limit (PEL) is 0.33 WL, based on an 8 hour per day exposure throughout the work year, and is equivalent to 4 WLM/year.[8]

Organic Solvents

Four organic solvents are frequently contained in the glues and sealants used by the mitigators to connect PVC pipe (for sub-slab ventilation) and to seal cracks in floors and foundations. They are methyl ethyl ketone (MEK), acetone, tetrahydrofuran, and cyclohexanone. Table I shows NIOSH RELs for these solvents as well as the basis for each REL.[9] Also shown are current OSHA PELs for these substances.[10]

Noise

During mitigations, workers may be exposed to elevated noise levels during drilling of sub slab holes, jackhammering, and during cutting, grinding, and chiseling tasks. Exposure to excessive noise levels found in the occupational environment has been linked to temporary and permanent hearing loss. The NIOSH REL for exposure to noise is 85 dBA for 8 hours continuous exposure.[11] The OSHA PEL limits employee exposure to 90 dBA to 8 hours continuous exposure. Whenever employee noise exposures equal or exceed an 8-hour time-weighted average of 85 decibels measured on the A-scale, the employer must establish an effective hearing conservation program. The elements of such a program are described in Title 29 of the Code of Federal Regulations, Part 1910.95, Occupational

Noise Exposure.[12] Table II shows noise exposure levels and daily durations for the NIOSH REL and the OSHA PEL.

STUDY METHODS

Selection of Mitigation Companies

As a pilot study of mitigation exposures, surveys were conducted at six companies--two companies from each of three states who were currently participating in EPA-sponsored state residential radon surveys. At the time of the study, radon gas data had been reported to EPA from 40 states. Data for these 40 states were obtained by NIOSH from the EPA Office of Radiation Programs. The three states chosen were those that reported the greatest percentages of residential radon levels that exceeded 20 pCi/L. The 20 pCi/L criterion, which is one of three percentiles reported by all states, is slightly above the 18 pCi/L, which is approximately equivalent to the current NIOSH REL (83 mWL) for RDP. The latter value is based on an equilibrium factor (EF) of 0.45, which is the mean EF for indoor air.[5] The assumption here was that mitigations performed in these states would be the *most* likely to pose occupational exposures to RDP that would exceed the current NIOSH REL.

Based on the state residential survey data, the three states with the highest percentage of reported measurements exceeding 20 pCi/L were Pennsylvania (7.9% of 2389 measurements), Iowa (7.5% of 1381 measurements) and New York (5.1% of 26400 measurements). By comparison, on the basis of 42 states reporting radon gas data, the EPA estimated in 1992 that 0.06 % of all homes would have radon gas levels exceeding 20 pCi/L.[13]

Rosters of those mitigators listed under the mitigator licensing program for each of the three states were obtained. To increase the likelihood of evaluating the highest radon decay product exposures, companies were further selected from those serving the counties with the highest percentage of measurements exceeding 20 pCi/L.

Survey methods

Exposure data for RDP, solvents, and continuous noise were collected during week long surveys of the mitigation jobs performed by each of the six selected mitigation companies. Each company performed 3-4 mitigations during the week. Although all six companies reported that the number of mitigations performed were not representative of a normal workweek, such weekly schedules were possible.

All surveys were originally planned to be conducted during the heating season (October through April), when radon decay product levels were more likely to be the highest. Residential radon levels average about 40% higher in winter than in summer.[14] This has been attributed to decreased home ventilation during the winter months.[15] However, so called "closed house" conditions, which involve decreased home ventilation, do occur during the cooling season when residents employ the use of air-conditioning. However, the pressure differential driving radon into the house, brought about by the difference in temperature between the warmer air in the house and the cooler air outside, is absent during the summer. This would result in the heating season being associated with higher radon levels.

Since survey scheduling was dependent on business activity of the participating companies, the end result was that three companies were monitored in November and December, one company was monitored in April, one company was monitored in September, and one company was monitored in June.

Measurement Methods

Radon decay products

Measurements of RDP were made using a Thomson & Nielson TN-WL-02 Radon Working Level Meter (RWLM)[16]. The RWLM was connected to a data logger that provided real time measurement of RDP. The instrument operates by sampling air at a rate of 1 liter per minute. RDP are collected on a filter and the emitted alpha particles are detected by a silicon detector and counted. The instrument reads out the alpha activity in mWL.

The RWLM has a nominal limit of detection of 0.2 mWL for a sampling time of 1 hour. For concentrations anticipated during this survey--25 mWL to 100 mWL, the manufacturer advised that the overall accuracy would be ±15% for sampling times less than 8 hours.

Radon

Measurements of radon were made using a femto-TECH model R-210F continuous radon monitor[17], with hourly readings output to a printer. This monitor employs passive diffusion sampling and detection is based on pulsed ion chamber technology. As radon gas enters the sensing volume, the alpha particles released by ^{218}Polonium and ^{214}Polonium are counted. The total counts within a given time period are related to the radon concentration in pCi/L. The nominal limit of detection of this instrument is 0.5 pCi/L of radon for a 1 hour measurement. The accuracy is ±10% in the concentration range of 4.0-100 pCi/L radon.

To measure RDP and radon gas that workers would be exposed to at the time mitigation begins, instrument were set up at the location the night prior to the mitigation.

Organic Solvents

Personal samples for organic vapors were obtained by drawing air at a rate of approximately 100 cubic centimeters per minute through a coconut charcoal tube attached to the lapel. Sample times ranged from ½ to 4 hours. Analysis for methyl ethyl ketone, acetone, and cyclohexanone was by gas chromatography using NIOSH analytical method 1300; analysis for tetrahydrofuran was by NIOSH analytical method 1609.[18] The calculated minimum detectable concentrations for all solvents was 0.38 ppm (based on a 9-liter air sample).

Noise

Sound pressure levels were measured during noise generating operations using a Quest Sound Level Meter (SLM) Model 215 set on the A-scale, slow response. The meter was calibrated at 110 dBA, 1000 Hertz using a Quest Calibrator, Model CA-12. During noise measurement, the SLM microphone was held in a vertical position and placed near the ear of the worker. Placement was well within the hearing zone defined as a sphere with a two foot diameter surrounding the ear.[19] The total exposure time for a given noise generating activity was also noted.

RESULTS AND DISCUSSION

General Observations

Based on the six companies evaluated during this study, it is clear that most if not all mitigation companies can be classified as small employers employing less than 10 employees. Table III provides an overview of the companies, employment sizes, states, and number of mitigations surveyed.

During the study, mitigation procedures and methods varied little from job to job. Most mitigations involved installation of sub-slab ventilation requiring drilling holes in basement concrete and in a wall leading to the outside, sealing of cracks in the floor, joining ventilation pipe together, and installation of PVC pipe to vent radon gas which collects beneath the basement slab to the outside.

Over the course of a mitigation, employees spend about 25% of the time outside the basement while getting parts from their work vehicle, drilling exterior holes in the residential structure, and installing exterior PVC pipe for sub-slab ventilation.

Pre-ventilation of the mitigation area using a mechanical fan placed in an open window was done in 6 of the 21 mitigations. Pre-ventilation was used because radon gas levels determined from the premitigation measurement survey indicated that radon gas levels would likely be considerably above 4 pCi/L, which is the level that EPA recommends installation of mitigation systems.[3] For these locations, mechanical ventilation was also carried out during the mitigation. For the two school rooms, windows and doors were open during the mitigation. For the remaining 13 mitigations, no ventilation of any type was used.

Radon Decay Products/Radon

Table IV shows RDP and radon data for each of the 21 mitigations monitored. For two residential basements,, where pre-mitigation radon levels averaged 192 pCi/L and 95 pCi/L, the average concentrations of radon decay product during the mitigation job were 106 mWL and 437 mWL. These levels, if experienced by workers on a 40 hour per week basis throughout the year, would exceed the NIOSH REL of 1 Working Level Month per year. For the remaining 19 mitigations, average RDP concentrations during the mitigation ranged from 2 mWL to 66 mWL, which are below the NIOSH REL.

Organic Vapors

Table V shows organic vapor measurements during the mitigation surveys. For the four chemicals evaluated---methyl ethyl ketone, acetone, tetrahydrofuran, and cyclohexanone---exposures were well below established NIOSH RELs and OSHA PELs. Maximum organic vapor exposures, sampled from ½ to 4 hours, were 23 ppm of acetone, 67 ppm of methyl ethyl ketone, and 32 ppm of tetrahydrofuran. Exposures to cyclohexanone were less than the analytical limit of detection. These levels are below the applicable 8-hour NIOSH RELs and OSHA PELs.

Noise

Table VI shows noise level data obtained during the study for a variety of noise generating activities--most connected with drilling of sub-slab ventilation holes. Noise levels near the ear ranged 99-112 dBA. Based on the short exposure times for these activities, noise levels were below the NIOSH RELs and the OSHA PELs.

Ear protection was worn during 19 of 25 measurements. While Noise Reduction Ratings (NRR) were not available for the ear protection used, NRRs for currently available muffs and plugs range between 20 and 30. Based on a formula used in computing the approximate "field" attenuation offered by the use of muffs and plugs, the actual noise reduction would range between 6.5 and 11.5 dBA respectively.[17] Accordingly, actual exposures to the measured noise levels would be less assuming that ear protection is worn correctly.

CONCLUSIONS AND RECOMMENDATIONS

Occupational exposures to RDP measured during mitigation surveys were, in most cases, considerably less than the NIOSH REL. Since mitigation employees spend a portion of the work day outside, the 8-hour time weighted average exposures would be less than that measured by the RWLM. However, these measurements indicate that the mean mWL level during mitigation occasionally may exceed the NIOSH REL (2 of 21 cases for this study). Their occurrence reinforces the need for adequate ventilation of the mitigation location (usually the basement) prior to and during each mitigation.

Exposures to organic vapors as a result of use of solvent containing sealants and glues do not appear to present a health hazard. One company did not use any glues or sealants containing organic solvents, and their use would remove the potential for any exposure to organic solvents.

While there is the potential for exposure to excessive noise levels during activities associated with preparation of sub-slab ventilation, the limited exposure time and the use of ear protection would appear to preclude development of any hearing loss.

In summary, data obtained during this study of 21 mitigations indicate that mitigation worker exposures are generally below the levels recommended by NIOSH to protect workers health. Adequate ventilation of the work area prior to and during the mitigation will minimize unnecessary exposure to RDP and to organic vapors. Use of ear protection during noise generating activities will provide additional protection against development of hearing loss.

REFERENCES

1. Environmental Protection Agency (EPA): *The National Radon Contractor Proficiency Program: Proficiency Report.* EPA, Washington, DC (1991).

2. EPA: *Technical Support Document for the 1992 Citizen's Guide to Radon.* EPA, Washington, DC (1992).

3. EPA: *A Citizen's Guide to Radon (Second Edition: The Guide to Protecting Yourself and Your Family from Radon.* EPA, Washington, DC (1992).

4. National Academy of Sciences (NAS)/National Research Council (NRC): *Health Risks of Radon and other Internally Deposited Alpha-Emitters.* Committee on the Biological Effects of Ionizing Radiations of the NAS/NRC, Washington, DC. National Academy Press, (1988).

5. International Commission on Radiological Protection (ICRP). *Lung Cancer Risk from Indoor Exposures to Radon Progeny.* ICRP Publication No. 50. Pergamon Press, New York (1987).

6. National Council on Radiation Protection and Measurements (NCRP): Measurement of Radon and Radon Daughters in Air. NCRP Report No. 97. NCRP, Bethesda, Maryland (1988).

7. National Institute for Occupational Safety and Health (NIOSH): *A Recommended Standard for Occupational Exposure to Radon Progeny in Underground Mines.* NIOSH, Cincinnati, Ohio (1987).

8. Code of Federal Regulations: Title 29, Chapter XVII, Part 1910.96, Federal Register, Vol 61, p. 5508 (as amended) (1996).

9. NIOSH: *Testimony of NIOSH on the Occupational Safety and Health Administration (OSHA) Proposed Rule on Air Contaminants.* Docket No. H-020. Presented at the OSHA Informal Public Hearing, Cincinnati, OH. (1988).

10. Federal Register: Vol 58, p 35340, June 30, 1993.

11. NIOSH: *Criteria for a Recommended Standard...Occupational Exposure to Noise.* NIOSH, Cincinnati, Ohio (1972).

12. Federal Register: Vol 61, p 5508, February 13, 1996.

13. EPA: *National Residential Radon Survey: Summary Report.* EPA, Washington, DC (1992).

14. Cohen B.L.: *Measured Radon Levels in U.S. Homes.* In: Proceedings of the Twenty-fourth Annual Meeting of the National Council on Radiation Protection and Measurements, Washington, DC (1988).

15. NCRP: *Exposures from the Uranium Series with Emphasis on Radon and its Daughters:* NCRP Report No. 77. NCRP, Bethesda, Maryland (1984).

16. NIOSH: *NIOSH Manual of Analytical Methods*, 4th ed. (DHHS/NIOSH Pub. No. 94-113). NIOSH, Cincinnati, OH (1994).

17. Occupational Safety and Health Administration (OSHA): Noise Measurement. OSHA Technical Manual, Section II, Chapter 5 (1995).

Table I

NIOSH RELs and OSHA PELs for Organic Solvents

Chemical	NIOSH REL			OSHA PEL
	TWA[A] ppm[B]	STEL[C] ppm	Basis	TWA[A] ppm
Methyl Ethyl Ketone	200	300	Prevent narcosis, eye irritation	200
Acetone	250	---	Preclude sensory irritation	1000
Tetrahydrofuran	200	250	Prevent narcosis, systemic effects	200
Cyclohexanone	25	---	Prevent eye, nose, throat irritation, central nervous system effects	50

[A]Time weighted average as measured over an 8 hour workday.
[B]Parts of contaminant per million parts of air by volume.
[C]Short-term exposure limit as measured over a 15 minute sample period.

Table II

NIOSH RELs and OSHA PELs for Noise

Duration (hrs/day)	Sound Level (dBA)	
	NIOSH REL	OSHA PEL
8	85	90
6	87	92
4	90	95
3	92	97
2	95	100
1.5	97	102
1	100	105
0.5	105	110
0.25 or less	110	115

Table III

Mitigation Company Survey Data

Company	State	# Mitigations	Mitigation Time Range (hrs)	# Employees	Month of Survey
A	PA	3	6-10	2	September
B	PA	3	6-8	3	December
C	IA	4	9-10	2	April
D	IA	4	7-10	2	June
E	NY	4	5-10	2	November
F	NY	3	7-8	3	December

Table IV

Radon and Radon Decay Product Levels Summary Data

Company	State	Job #	Time hrs	Radon Decay Products Pre Mitigation mean mWL	Radon Decay Products Mitigation mean mWL[A]	Radon Pre Mitigation mean pCi/L	Radon Mitigation mean pCi/L
A	Penn	1	10	15	2	4	1
A	Penn	2	6	NA	2	NA	2
A	Penn	3	6	NA	12	NA	6
B	Penn	4	6	NA	106	192	85
B	Penn	5	8	23	8	8	4
B	Penn	6	7	19	9	5	2
C	Iowa	7	10	2	15	2	8
C	Iowa	8	10	55	20	9	6
C	Iowa	9	10	39	24	12	8
C	Iowa	10	9	61	66	19	19
D	Iowa	11	8	17	13	7	6
D	Iowa	12	8	11	14	3	4
D	Iowa	13	10	40	21	15	10
D	Iowa	14	7	67	10	14	4
E	NYork	15	5	47	39	12	11
E	NYork	16	10	50	39	17	15
E	NYork	17	5	534	437	95	72
E	NYork	18	5	18	37	10	18
F	NYork	19	5	133	41	44	16
F	NYork	20	7	63	32	18	9
F	NYork	21	7	14	3	14	4

[A]NIOSH REL is 83 milliworking levels (mWL) for continuous exposure of 170 hours per month for each of 12 consecutive months.

Table V

Organic Vapor Concentrations

Company	Sample Time Range min	Methyl Ethyl Ketone		Acetone		Tetrahydrofuran		Cyclohexanone	
		# samples	Range[A] ppm	# samples	Range[B] ppm	# samples	Range[C] ppm	# samples	Range[D] ppm
A	89-214	6	2-8	No data	No data	6	3-16	6	0.07-0.3
B	78	1	4	No data	No data	1	8	No data	No data
C	65-142	4	0.1-4	4	1-12	No data	No data	No data	No data
D	27-126	2	47-67	2	3-23	No data	No data	No data	No data
E[1]	No data	No data	No data	No data	No data	No data	No data	No data	No data
F	30-102	2	13-36	2	0.2-0.7	1	0.32	1	0.4

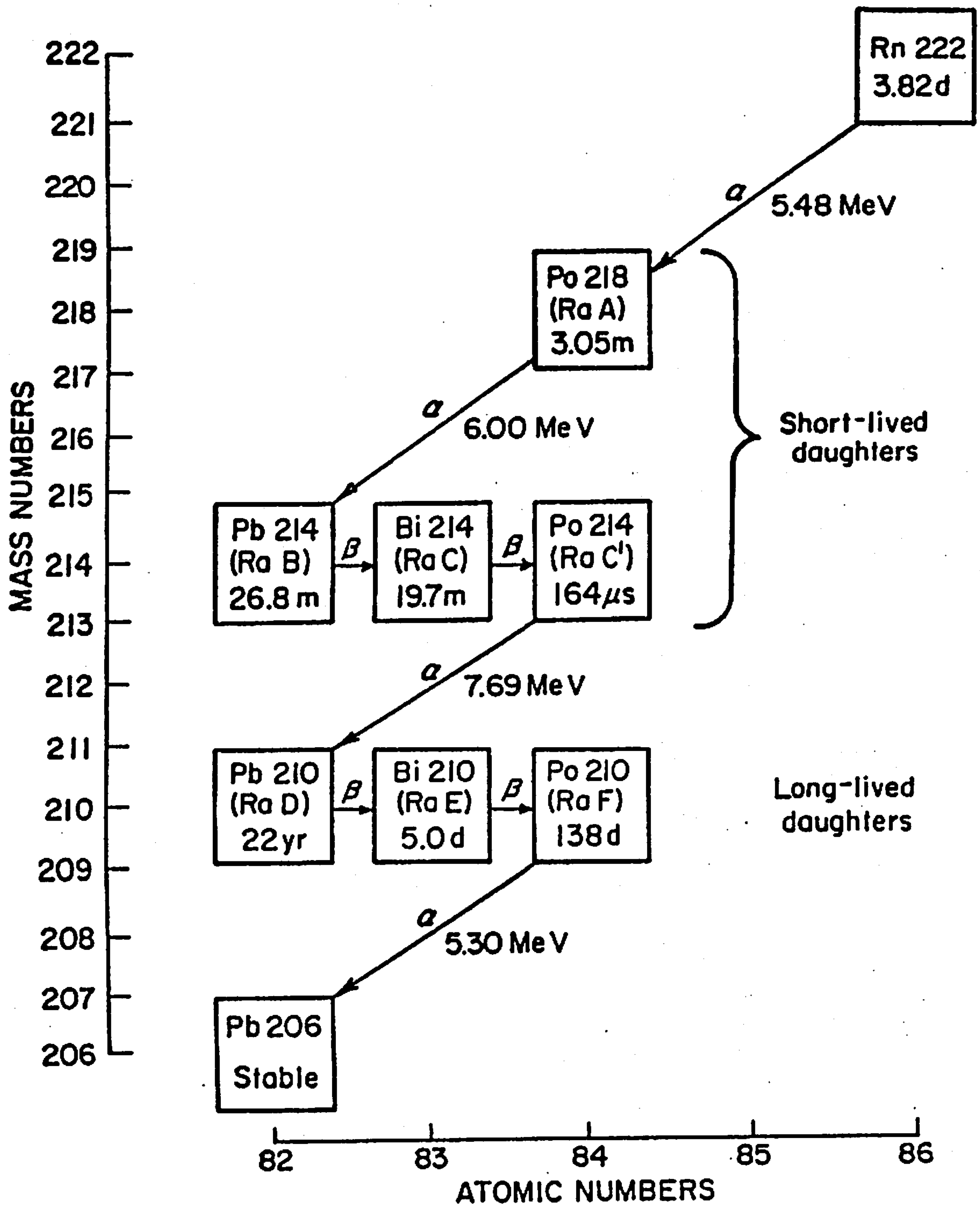
[1]Company did not use any solvent containing glues or sealants.
[A]Limit of detection is 0.38 ppm for a 9 liter air sample.
[B]Limit of detection is 0.38 ppm for a 9 liter air sample.
[C]Limit of detection is 0.38 ppm for a 9 liter air sample.
[D]Limit of detection is 0.38 ppm for a 9 liter air sample.

Table VI

Noise Data Summary

Company	Job #	Activity	Low dBA	High dBA	Time min	Ear Protection
A	1	Hilti	99	103	2	Plugs
A	1	Drilling	101	101	20	Plugs
A	1	Drilling	102	102	20	Plugs
B	4	Drilling	94	94	1	Plugs
B	5	Drilling	105	105	10	Muffs
B	5	Drilling	96	102	10	Muffs
C	10	Cutting	100	---	30	Muffs
C	10	Drilling	103	---	5	Muffs
C	10	Chiseling	104	---	20	Muffs
C	10	Augering	96	---	50	Muffs
C	10	Drilling	104	---	10	Muffs
C	10	Vacuum	96	---	30	Muffs
C	11	Drilling	104	---	10	Muffs
C	11	Cutting	100	---	5	Muffs
C	11	Drilling	108	---	10	Muffs
C	11	Chiseling	109	---	10	Muffs
C	11	Vacuum	92	---	2	Muffs
D	13	Drilling	108	110	25	Muffs
D	15	Drilling	109	112	25	Muffs
D	17	Drilling	98	98	13	None
D	19	Drilling	101	101	3	None
D	19	Hammer Drill	101	101	10	None
D	21	Drilling	100	100	20	None
D	21	Drilling	100	100	30	None
D	23	Jackhammer	108	108	2	None

Figure 1
Radon decay scheme



Source: Mine Safety and Health Administration. Radiation Monitoring, United States Department of Labor, Washington, DC (1979).