Study of Radon Exposure Due To Storage Of Fossil Vertebrate Specimens At The Idaho Museum of Natural History

by

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Committee Approval

To the Graduate Faculty:

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ACRONYMS

DNA	deoxyribonucleic acid
EPA	United States Environmental Protection Agency
HFBNM	Hagerman Fossil Beds National Monument
HVAC	Heating, Ventilation, and Air Conditioning
IMNH	Idaho Museum of Natural History
MeV	Mega-electron volt
NPS	National Park Service
pCi/L	Pico-curies per Liter
SCE	sister-chromatid exchange

ABSTRACT

The aims of this thesis project were to investigate the emitted radon concentration from vertebrate fossils stored at the Idaho Museum of Natural History and assess the potential for exceeding the United States Environmental Protection Agency's recommended action level for Rn-222 concentration in buildings. The Natural History Museum's fossil storage facility and 292 fossil storage cabinets were analyzed for Rn-222 concentration in air using a silicon alpha detector. Rn-222 was not detected above the EPA recommended action level of 4pCi/L in the fossil storage facility but was, however, detected above 4pCi/L in 194 of the 292 fossil storage cabinets. Rn-222 was detected with wide activity concentration ranges and with an average value of 46.12 ±11.0 pCi/L and a peak value of 1,512 ± 81.2 pCi/L. Exposure studies performed in areas adjacent to open fossil storage cabinets resulted in the detection of Rn-222 concentrations of greater than 4pCi/L for up to 50 minutes after opening cabinets with established Rn-222 concentrations of greater than 100 pCi/L.

1.0 INTRODUCTION

1.1 Overview

The Idaho Museum of Natural History currently houses over 100,000 individual fossil elements in its collection. The vast majority of these pieces are stored in room 112A of the museum building. The fossil storage room has its own forced air ventilation system and a temperature/humidity monitoring system. Elements of the collection are stored both in the open air space around the room and in a large collection of movable storage cabinets. Depending on the time of year there may be up to 5staff members (1 Faculty, 4 Students) working in the facility. The fulltime Faculty member normally spends a minimum of 1hour each day working on the collection. During specific projects, a staff member could spend 4 to 8 hours per day working in front of open storage cabinets. Fossil specimens are required to be inventoried on a regular basis, which would consist of staff member entry into all 292 cabinets to complete an inventory.

The Idaho Museum of Natural History is currently in possession of 9,243 fossil elements from the Hagerman Fossil Beds, located in eastern Idaho[1]. Studies performed at the Hagerman Fossil Beds National Monument (HFBNM) show that some fossils collected at the Hagerman Fossil Beds have high concentrations of naturally occurring Uranium-238 (Williams et al, 2005). Most Hagerman fossil specimens are stored in the aforementioned storage cabinets. A radon monitoring program to determine radon concentrations in the storage cabinets or in room 112A has not been undertaken, although radon problems at HFBNM were reported by Williams, et al in 2005.

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[1] The Hagerman Fossil Beds National Monument office and visitor center is located at 221 North State St, Hagerman, ID 83332**.**

Radioactivity levels of the remaining ~90,000 fossil elements are unknown. A specific testing program has not been performed. These elements are also stored on shelving throughout the facility and in fossil storage cabinets. Elements are from areas such as American Falls Reservoir, Birch Creek, the Wayan Formation, and Moonshiner Cave, which are all located in Idaho but outside of the HFBNM.

According to the United States' Center for Disease Control, radon, a known carcinogen, is thought to cause more deaths each year than any other common danger, such as drowning, poisoning, and falls. It is believed that radon exposure is the cause of over 21,000 lung cancer deaths per year in the United States alone, resulting in over $2 billion in lost productivity and medical expenses (Centers for Disease Control and Prevention, n. d.). Thankfully, there exists a myriad of information on the hazards and risks of radon exposure. Scientists have been studying radon since it was discovered in 1899 (Marshall and Marshall, 2010) and most recently, 2015, the United States federal government, along with nine partner-organizations, has enacted a plan with the primary goal of preventing all avoidable deaths due to radon induced lung cancer (Environmental Protection Agency, 2016).

1.2 Research Objectives

The research objectives of this project are to determine if personnel working at the Idaho Museum of Natural History are exposed to greater than 4 pCi/L of radon (when the radon gas in is in equilibrium with its progeny) while working adjacent to open fossil storage cabinets. This effort also was able to categorize fossil storage cabinets into groups based on their radon concentrations, and assist the Idaho Museum of Natural History in developing a radon mitigation strategy specific to the fossil storage cabinets in order to maintain personnel exposure to radon as low as reasonably achievable.

During this research, the radon concentration of the Fossil Storage Facility and each individual fossil storage cabinet was determined to the extent practical. Exposure studies of work areas adjacent to fossil storage cabinets were also performed. These measurements were evaluated against the United States Environmental Protection Agency's recommend radon action level of 4 pCi/L. .

1.3 Hypothesis Statements

1.3.1 First Criteria

Null Hypothesis 1 H_0: Radon concentration levels in the Fossil Storage Facility do not exceed 4.0 pCi/L during 48-Hour EPA Protocol testing. Radon mitigation is not required.

Alternate Hypothesis 1 H_A: Radon concentration levels in the Fossil Storage Facility exceed 4.0 pCi/L during 48-Hour EPA Protocol testing. Radon mitigation actions are recommended.

Decision Rule: To test this hypothesis, radon concentration from the Fossil Storage Facility will be obtained from experimental data. The alternate hypothesis is accepted if the concentration of radon in the Fossil Storage Facility exceeds the EPA recommended action level (4 pCi/L).

1.3.2 Second Criteria

Null Hypothesis 2 H_0: Radon concentration levels in the workspace adjacent to an open fossil storage cabinet do not exceed 4.0 pCi/L during radon exposure studies. Radon mitigation is not required.

Alternate Hypothesis 2 H_A: Radon concentration levels in the workspace adjacent to an open fossil storage cabinet exceed 4.0 pCi/L during radon exposure studies. Radon mitigation actions are recommended.

Decision Rule: To test this hypothesis, radon concentration in the workspace adjacent to open fossil storage cabinets will be obtained from experimental data. The alternate hypothesis is accepted if the concentration of radon in the workspace adjacent to an open fossil storage cabinet exceeds the EPA recommended action level (4 pCi/L).

2.0 LITERATURE REVIEW

2.1 Radon and Progeny Characteristics and Health Effects

Radon-222 (commonly referred to as radon) is a naturally occurring radioactive gas found in the Earth's crust and is a decay-chain progeny of naturally occurring uranium-238. Radon has been given the chemical symbol Rn and has an atomic number of 86. Radon-222 has a half-life of 3.82 days and decays by alpha emission (5.48-MeV alpha particle). Its nucleus transforms into polonium-218 (Samet et al, 2009).

Polonium-218 is the first radon progeny and has a half-life of 3.05 minutes. Polonium-218 is an alpha emitter and its decay releases a 6.00-MeV alpha particle. Polonium tends to stick to surfaces that it comes into contact with via Coulombic interaction. Polonium is particularly attracted to dust particles. These dust particles can be inhaled and trapped in a person's lung tissue. Polonium-218 decays into lead-214 as it undergoes isobaric transitions emitting negatrons. Lead-214 is a beta emitter with a half-life of 26.8 minutes (Samet et al, 2009). Table 2.1 shows the short-lived radon progeny decay series. (Johnson and Birky, 2006).

Table 2.1: Short-lived Radon Progeny Decay Series

Element	Radiation	Energy (MeV)	Half-Life
Radon-222	Alpha	5.48	3.82 minutes
Polonium-218	Alpha	6.00	3.05 minutes
Lead-214	Beta	1.02	27 minutes
Bismuth-214	Beta	3.27	19.7 minutes
Polonium-214	Alpha	7.69	1 microseconds
Lead-210	Beta	0.06	22.3 years

It is the deposition of these alpha particles in the lungs that can be linked to the occurrence of lung cancer in humans. The high energy deposited in a target tissue by an alpha particle hit has been shown to damage the DNA of cells lining a person's airway. Evidence also exists of the bystander effect, whereas cells adjacent to the target cell are damaged by ancillary means following the hit of a single alpha particle damaging a cell in the cellular colony (Samet et al, 2009). This bystander effect has been demonstrated in both humans and rats and has been associated with the increased frequency of sister-chromatid exchange (SCE) aberrations (Nagasawa et al, 1990) (Nagasawa and Little, 1992).

It has been experimentally demonstrated that alpha particles produce large interstitial deletions in DNA molecules and are highly efficient at causing reciprocal translocations. Interstitial deletions of tumor suppressor genes (P53) are of great concern due to the efficiency at which alpha particles cause the deletions (Metting et al, 1992). Additionally, exposure to alpha particles has been shown to produce a to dose-dependent delay in a cell's progression through the G1 and G2 stages of the cell cycle, which adversely changes the complex interactions between the level and structure of cellular proteins (Lucke-Huhle, et al, 1992).

Radon is rapidly cleared from the lungs via exhalation and absorption, which following a concentration gradient results in steady state radon concentrations in the blood within 2 to 3 minutes. Radon's progeny, however, take much longer to clear from the respiratory tract. Radon progeny attached to dust particles have a clearance half-time of 10 to 13 hours, while unattached progeny have a clearance half-time of 16 to 68 minutes. Both radon and its progeny are widely distributed throughout the body via absorption through the stomach and small intestine. Removal of radon and its progeny occur via exhalation and excretion (urine/feces), respectively (Department of Health and Human Services, 2012).

2.2 Radon in Schools

The United States Environmental Protection Agency recommends all schools be tested for radon and that these areas with elevated concentrations be mitigated. The EPA justifies these actions based on the concept that school is thought to be the student's and staff's second largest contributor, behind the home. The EPA's recommended action level for radon mitigation in school buildings is 4 pCi/L in order to minimize radon exposure. However, the EPA documents, Radon Measurement In Schools, revised edition, and Reducing Radon in Schools: A Team Approach, only discusses radon entry into school buildings from an OUTSIDE source, i.e the ground adjacent to the building. Internal sources, i.e. fossil elements, are not addressed (USEPA, 1993) (USEPA, 1994).

2.3 Lung Cancer Risk from Radon Exposure

According to the United States Department of Health and Human Services' Agency for Toxic Substances and Disease Registry, the public often underestimate's the risk of lung cancer from radon exposure. It is this underestimation that could discourage people from having their homes or schools tested and mitigated for radon (Department of Health and Human Services, 2010). The EPA estimates that constant lifetime exposure to radon at its recommended action level of 4pCi/L increases a person's lifetime risk of lung cancer death by 0.7% for never-smokers, 2.3% for the general population, and 6.2% for current smokers. These estimates can change based on other influential risk factors for the population group. These risk factors include (but are not limited to): age during exposure, length of exposure, concentration of radon as a function of duration, and time-elapsed since initiation of exposure (USEPA, 2003).

2.4 Radon in Fossils at Hagerman Fossil Beds

The Hagerman Fossil Beds National Monument is a 4,394-acre site located near the Snake River and the town of Hagerman, Idaho. HFBNM lies about 90-miles southeast of Boise. Commissioned in 1988, the fossil beds were established to protect, preserve, and allow the study of the Hagerman Horse and other Pliocene Epoch mammalian fossils. There have been over 1,000 individual fossil discovery sites in the monument with at least 111 of them containing fossil elements that have been determined to contain measurable quantities of naturally occurring uranium-238. Although, naturally occurring radioactive material in fossils has been documented as early as 1954, elevated levels of naturally occurring radioactivity was not discovered at HFBNM until 1996 (Farmer et al, 2008).

It is believed that the uranium-238 was deposited in these fossil elements due to the chelation process that a fossil undergoes when it transitions from organic compounds into a mineral. The uranium takes up a location in the mineral's lattice structure normally taken up by a common ion, such as calcium. The ultimate source of the uranium at HFBNM is unknown (Farmer et al, 2008).

National Park Service staff have performed radon concentration measurements in areas were the radioactive fossils are stored. These areas include fossil storage rooms and cabinets. Peak and mean radon concentrations in the fossil storages room were found to be 26 pCi/L and 12 pCi/L, respectively. Fossil storage cabinet concentrations were found to be much higher at 544 pCi/L (peak) and 436 pCi/L (mean). The National Park Service determined that the potential risk due to radon exposure at these concentrations necessitated the development of safety precautions to ensure exposure to both NPS personnel and the public be kept as low as reasonably achievable (Farmer et al, 2008).

3.0 MATERIALS AND METHODS

3.1 Material

3.1.1 Durridge RAD7 Radon Monitoring Device

All radon concentration measurements during this research were made using the RAD7, Professional Electronic Radon Detector.[2] The RAD7 was calibrated at the Durridge Company's professional radon calibration facility on 30 April 2014. Durridge Company determines calibration factors based on direct comparison to "master" RAD7's that were compared to EPA and United States Department of Energy radon detection instruments. According to the RAD7 user manual, the RAD7's calibration accuracy is independently verified by direct determination of radon chamber level from the calibrated activity and emission of the standard radon source (Durridge Company, 2015).

[2] Durridge Company Inc. manufactures the RAD7 Professional Electronic Radon Detector. Durridge Company Inc. is located at 524 Boston Road, Billerica, Massachusetts 01821.

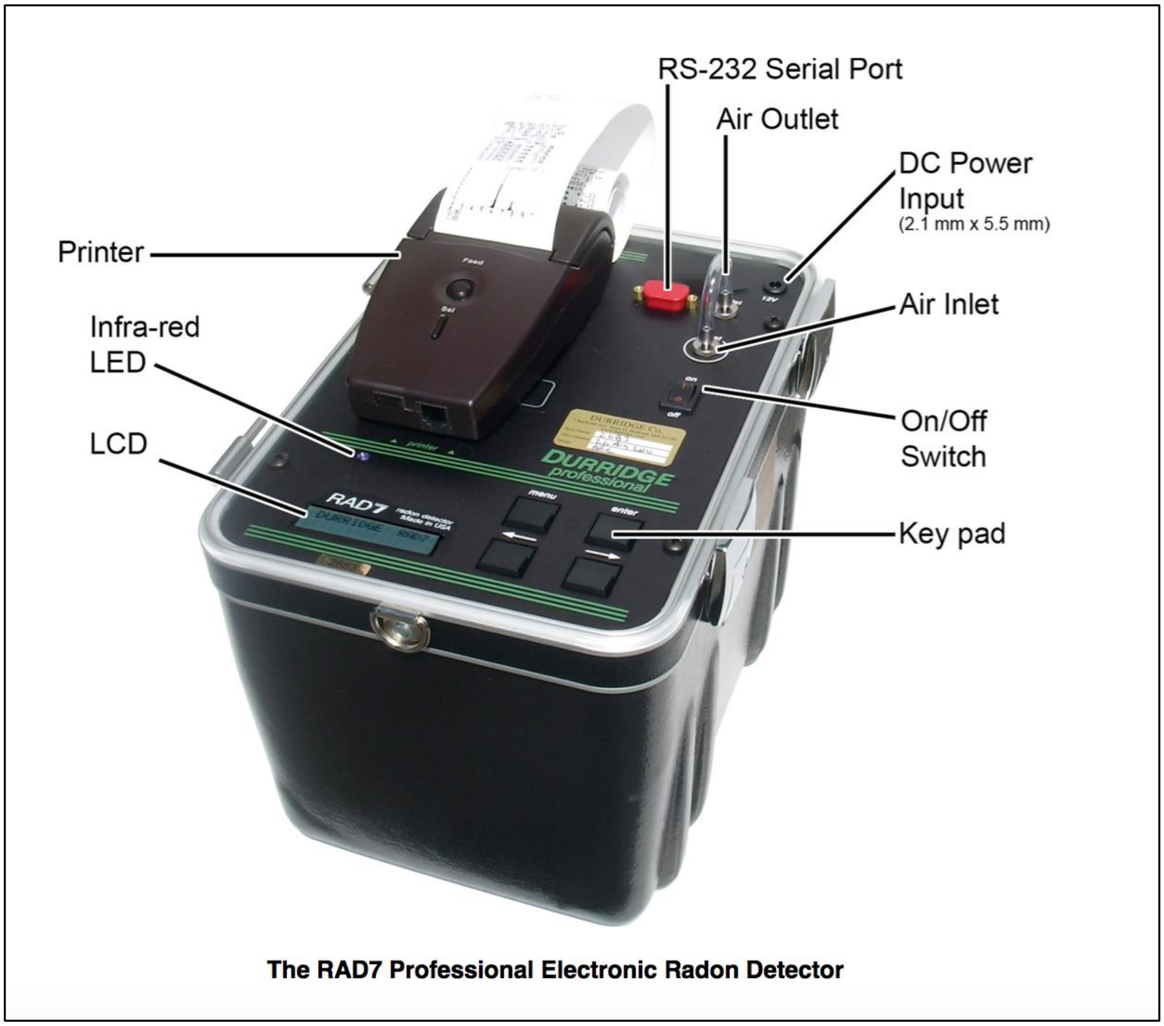


Figure 3.1: RAD7 Professional Electronic Radon Detector

3.1.1.2 Design and Operation

The Durridge RAD7 measures radon gas concentration by pulling samples of air through a filter medium and into a 0.7-liter hemispheric chamber for analysis. A solid-state, Ion-implanted, Planar, Silicon alpha detector is located in the center of the chamber. As radon in the chamber decays, alpha emitting progeny (such as polonium-218) are created and detected via electrical signals proportional to alpha particle energy.

Signals are amplified, filtered, counted and sorted according to their “strength” (Durridge Company, 2015).

The RAD7 organizes measured data on an energy scale called the RAD7 spectrum. The RAD7 spectrum is divided into 200 individual channels, each representing a 0.05-MeV wide channel. This produces a spectrum ranging of 0 to 10 MeV. The energy range between 6 and 9 MeV, which is the energy range of alpha particles produced by radon and thoron progeny is of particular importance (Durridge Company, 2015).

The spectrum’s 200 channels are divided into 8 separate “windows” or energy ranges. Each window has a specific function related to the acquisition and processing of alpha particle energy deposition. Active data collection requires all counts in each window be added up and divided by the duration of active data collection. This is performed by the RAD7’s microprocessor and results are stored in its memory (Durridge Company, 2015). A list of the RAD7’s windows and their respective functions are provided below.

1. Window A: Radon Sniffer Mode counts. Total counts of 6.0 MeV alpha particles produced from alpha decay of Po-218.
2. Window B: Thoron 1. Total counts of 6.78 MeV alpha particles produced from alpha decay of Po-216.
3. Window C: Radon Po-214 Counts. Total counts of 7.69 MeV alpha particles produced from alpha decay of Po-214.
4. Window D: Thoron 2 Window. Total counts of 8.78 MeV alpha particles produced from alpha decay of Po-212.

5. Window E: High Energy. Diagnostic window. Does not normally contain counts.
6. Window F: Low Noise counts. Diagnostic window. Gives total counts of the first 10 channels.
7. Window G: Medium Noise counts. Diagnostic window. Gives total counts in the region around channels 30 to 40 (between 1.5 and 2.0 MeV).
8. Window H: High Noise or Po-210. Total counts in the region of the 5.31 MeV alpha particle due to Po-210. Not used for calculating radon levels.
9. Window I: Others. Grouping of windows E, F, G, and H. Used to compare with grouping of windows A, B, C, and D.

Data collected for this experiment required the 2 different RAD7 modes: NORMAL and SNIFF. The RAD7's NORMAL mode is used when an experiment requires data to be collected in a single location over many hours. In this mode, the RAD7 uses windows A and C to calculate radon concentration. Instrument precision is increased by the analysis of 2 count rates versus only 1 count rate as used in SNIFF mode (Durridge Company, 2015).

SNIFF mode is used when experiments are made by a detector moving among different locations in a rapid fashion; over several minutes. The RAD7 only uses data in window A to calculate radon concentration and ignores data collected in window C when being operated in SNIFF mode. SNIFF mode achieves fast response to changes in radon concentration and allows for fast recovery from high concentrations (Durridge Company, 2015).

Precision of the RAD7 is dominated by counting statistics. When operated according to manufacturer's recommendations, environmental factors tend to contribute little to measurement uncertainty; at least within the normal operating domain of the instrument (Durridge Company, 2015). The magnitude of measurement uncertainty is dependent on the RAD7's sensitivity and background count rate. The RAD7 has a low intrinsic background count rate that is considered to be a negligible contributor to measurement precision if the radon concentration range measured is between 1 pCi/L and 100 pCi/L. The Durridge Company has determined that environmental and other factors may affect precision by no more than 2% in this range. Therefore uncertainty values (at the 95% confidence interval) reported by the RAD7 are measures of the variability in precision and are dependent on counting statistics primarily (Durridge Company, 2015).

3.1.1.3 Radon Measurement in Air

Radon concentration was measured using the RAD7 in either NORMAL or SNIFF mode. Both modes require a fully charged battery or an external source of alternating current electricity to obtain valid measurements. Sufficient active desiccant must be loaded into and available to the Laboratory Drying Unit, before testing in either mode. The RAD7's detection chamber must be purged for a minimum of 5 minutes prior to making viable measurements (Durridge Company, 2015).

The normal set-up configuration requires connecting a particulate filter and plastic tubing to the inlet port of the RAD7. The plastic tubing is then connected to a Laboratory

Drying Unit. The Laboratory Drying Unit is filled with desiccant and will decrease relative humidity in the detection chamber to less than 6%, which prevents the necessity for humidity correction of data. A separate piece of plastic tubing is attached to the outlet port (Durridge Company, 2015). Figure 3.2 shows the RAD7 in its normal configuration.

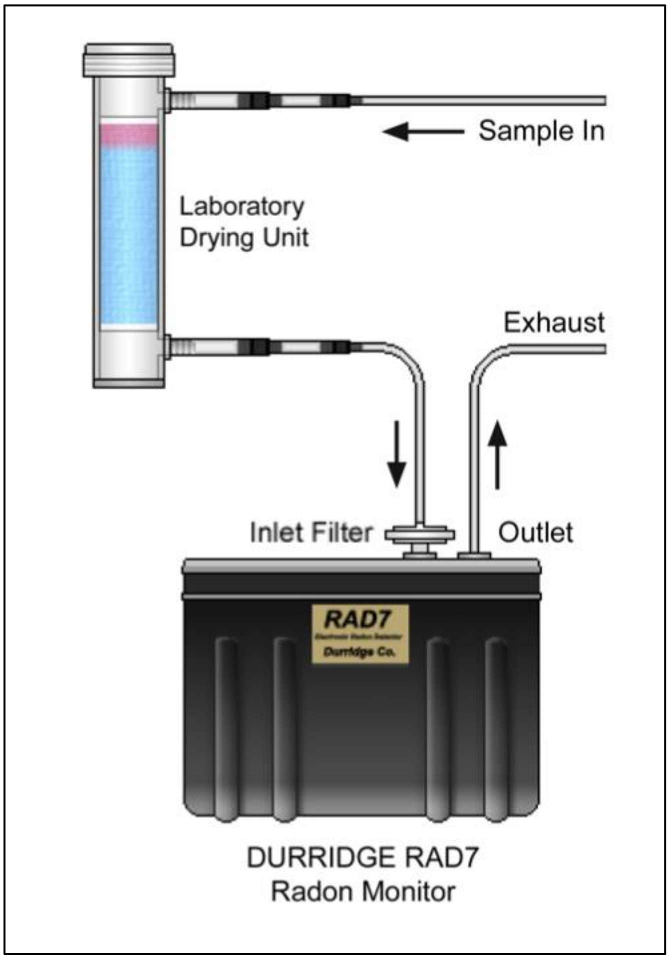


Figure 3.2: RAD7 Normal Configuration

3.1.1.4 The 48 Hour EPA Protocol Test

Testing of the 48-Hour EPA Protocol is conducted with the following parameters. The RAD7 is placed near the center of a room, at least 2-feet above the floor. Walls, vents, windows, drafts, and direct sunlight should be avoided. The detector should not be placed within 4 inches of other objects nor exterior walls. All access to and from the room should be secured during the test and all doors and windows shall remain shut (Environmental Protection Agency, 1993).

Prior to conducting the 48-Hour EPA Protocol Test, the RAD7 is prepared for operation as noted in paragraph 3.1.1.3. The procedural steps necessary to set-up and perform a 48-Hour EPA Protocol Test is listed in Appendix 1.

3.1.1.4 SNIFF Test Procedure

The SNIFF Test is conducted with the following parameters. The RAD7 shall be set up in accordance with paragraph 3.1.1.3 with the following exception: a small drying tube (provided by manufacturer) is used instead of the laboratory-drying unit. For portability, the external power source may be removed. The procedural steps necessary to set-up and perform a SNIFF test are listed in Appendix 1.

3.1.2 Temporary Cabinet Covers

Temporary plastic covers were installed on several cabinets in the Fossil Storage Facility in order to facilitate measuring a cabinet's radon concentration without the inclusion of outside-air. This was necessary due to the fossil storage cabinet's original airtight design, which only allows for air samples to be taken via opening the installed door. This sampling method provides a path for outside-air to mix with air inside a cabinet during air sampling operations. Allowing outside-air into a storage cabinet while performing a measurement will dilute the air inside the cabinet and provide data that would be artificially lower than the actual cabinet radon concentration.

Covers were made of 6-mm thick clear-plastic sheeting. A 3/8-inch air inlet and outlet port was installed in each cover for use with the RAD7 radon monitor air tubing. Covers were “cut-to-fit” each individual cabinet and installed using 3M-Professional Grade Duct Tape. After installation, each airport was sealed with 3M-Professional Grade Duct Tape. Standard dimensions for each temporary cover were 37-inch X 27-inch. Figure 3.3 is a graphical representation of the temporary plastic covers.

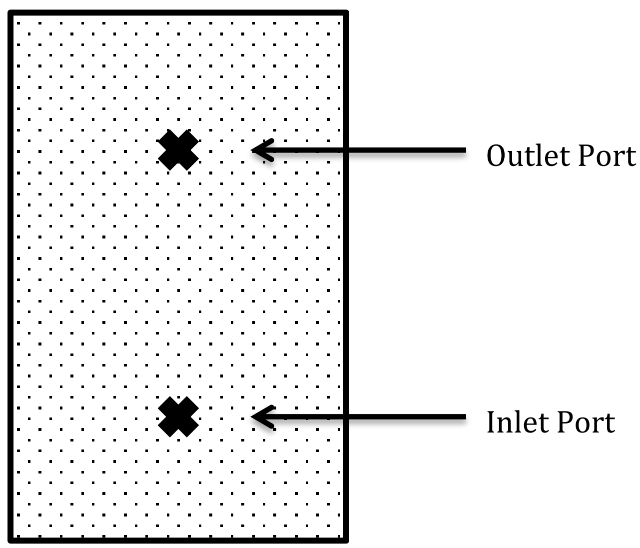


Figure 3.3: Temporary Plastic Cover

3.1.3. Idaho Museum of Natural History

The Idaho Museum of Natural History (IMNH) is located at 698 E. Dillon St in Pocatello, Idaho and is part of the Idaho State University campus (building 12). The building is 3-stories high and has a single basement level below ground. The Fossil Storage Facility is located on the basement level in room 112A, which is 2078 square feet in size, and has its own forced air ventilation system and a temperature/humidity monitoring system.

3.1.3.1 Fossil Storage Facility Dimensions and Contents

The IMNH Fossil Storage Facility contains over 150,000 individual fossil elements. Elements are stored in two different ways. The majority of fossil elements are stored in 37-inch x 27-inch x 24-inch metal cabinets that are manufactured by the Steel Fixture Manufacturing Company of Topeka, Kansas[3]. The remaining elements are stored on metal shelving units located throughout the facility. The metal shelving units are open-air, whereas the metal cabinets have airtight doors that are individually sealed with a rubber gasket. Figures 3.4 and 3.5 show fossil elements being stored on metal shelving.

Figure 3.4: Metal Shelving Unit

[3] Steel Fixture Manufacturing Company, 612 SE 7th St, Topeka, KS 66607.

The metal cabinets are stacked 2-units high; there are 292 cabinets of this type in the facility. The cabinets are built on a sliding rail system and are separated into rows. Each cabinet is fitted with sliding shelves. Most cabinets are loaded to capacity with fossil elements. These cabinets are built without ventilation ports and individual cabinets may remain closed for months at a time.

Figure 3.5: Metal Shelving Unit

The cabinet contents are segregated by fossil discovery location with a majority of discovery locations separated into rows. Fossil elements stored at the IMNH have been discovered in various locations in the western United States, with the majority coming from locations throughout the state of Idaho. Examples of fossil discovery locations are: the Hagerman Fossil Beds, the American Falls Reservoir, the Power County Landfill, Grasshopper Cave, and the La Brea Tar Pits (California). Figure 3.6 is an example of the metal cabinet units located in the IMNH Fossil Storage Facility.

Figure 3.6: Fossil Storage Cabinet

3.2 Methods

3.2.1 48-Hour EPA Test: Fossil Storage Facility

The 48-Hour EPA Protocol testing was performed in order to determine the average and peak radon concentrations of the Fossil Storage Facility (Room 112A). Two 48-Hour EPA Protocol tests were conducted using the Durridge RAD7 Radon Monitor in accordance with paragraph 3.1.1.3. The first test was conducted with room 112A's HVAC ventilation system in operation throughout the test. The second test was conducted with the HVAC ventilation system secured (i.e. not circulating or exchanging air). Per paragraph 3.1.1.3, the RAD7 monitor was placed in the center of room 112A, 22-feet from the room's outer walls, and 4-feet from the floor. All access to room 112A was prevented for the duration of testing.

3.2.2 The 48-Hour EPA Test: Adjacent Room

A 48-Hour EPA Protocol test was performed in order to determine the average and peak radon concentrations of an adjacent room in the basement of the Idaho Museum of Natural History. Room 127 was chosen due to its proximity to room 112A. One 48-Hour EPA Protocol test was conducted using the Durridge RAD7 Radon Monitor in accordance with paragraph 3.1.1.3. This test was conducted with room 127's HVAC ventilation system in operation throughout the test. Per paragraph 3.1.1.3, the RAD7 monitor was placed in the center of room 127, 5-feet from the room's outer walls, and 4-feet from the floor. All access to room 127 was prevented for the duration of testing.

3.2.3 Fossil Storage Cabinet Testing

3.2.3.1 Sniff Test – All Cabinets

Testing of the fossil storage cabinets was conducted using the RAD7 in SNIFF mode as described in paragraph 3.1.1.4. All 292-cabinets located in room 112A were tested in this manner. Prior to conducting each test, cabinets were verified closed for greater than 21 days in order to approach to the extent feasible equilibrium conditions inside the cabinet. This verification was determined via interview with IMNH staff. To perform a SNIFF test, cabinet doors were opened as little as practical and the RAD7 air inlet tubing was placed inside the cabinet. The cabinet door was closed as much as possible without pinching the air tubing. Tape was used to hold the door closed in order to ensure the cabinet door remained shut.

3.2.3.2 Sniff Test – Cabinets with Temporary Covers Installed

Testing of the fossil storage cabinets with temporary covers installed was conducted using the RAD7 in SNIFF mode as described in paragraph 3.1.1.4. Six cabinets located in room 112A were tested in this manner. Cabinets were identified for additional testing based on the results of the tests conducted in paragraph 3.2.3.1. Prior to conducting each test, the identified cabinet's door was removed and a temporary cover, as described in paragraph 3.1.2, was installed. Plastic covers were installed and cabinet access was secured for at least 21-days prior to testing in order to approach to the extent feasible equilibrium conditions inside the cabinet. To perform a SNIFF test, the RAD7 air inlet tubing was connected to the air-inlet port of the temporary cover and the RAD7 outlet tubing was connected to the air-outlet port of the temporary cover. Radon concentration results were logged at 5-minute intervals. Each cabinet was tested for a minimum of 30 minutes or until radon concentration stabilized.

3.2.3.3 Exposure Studies

Radon exposure studies of fossil storage cabinets were conducted using the Durridge RAD7 Radon Monitor. The RAD7 was setup in accordance with paragraph

3.1.1.4. Eleven cabinets located in room 112A were tested in this manner. Cabinets were selected for time-motion analysis based on radon concentration results from previous tests (paragraphs 3.2.3.2 and 3.2.3.3) with cabinets containing radon concentrations greater than 500pCi/L given priority. Other cabinets with radon concentrations less than 500pCi/L were also tested to provide a diverse cross-section of radon concentration data. Prior to conducting a time-motion analysis test, each cabinet was verified shut for at least 21 days in order to assure to the maximum extent feasible equilibrium conditions.

Testing was conducted with the nozzle of the RAD7's air-inlet tubing placed directly in the middle of each cabinet face (18.5-inches from bottom of cabinet door, 13.5-inches from cabinet side) and 8-inches away from the plane occupied by the cabinet door. This location approximated the location of a person's face if they were working in the cabinet. With the inlet nozzle in place, the cabinet door or temporary cover was opened and a SNIFF test was performed. Results were logged at 5-minute intervals. The test was terminated when radon concentration readings fell below 4pCi/L.

4.0 RESULTS AND ANALYSES

The results include analysis of 48-Hour EPA tests and Fossil Storage Cabinet testing. These results were used to evaluate the primary and alternate hypothesis statements.

4.1 Testing Results

4.1.1 48 Hour EPA Tests

48 Hour EPA Protocol tests were conducted to determine average and peak radon concentrations in the IMNH Fossil Storage Facility and an adjacent basement-level space. Results of these tests are shown in Table 4.1.

Table 4.1: 48 Hour EPA Test Results

Location	**Ventilation Status**	**Mean Radon Conc (pCi/L)**	**Dev (+/-)**	**Peak Radon Conc (pCi/L)**	**Dev (+/-)**
Rm 112a	Running	1.5	0.41	3.0	0.8
Rm 112a	Secured	2.29	0.12	3.53	1.3
Rm 127	Running	0.534	0.042	0.95	0.47

4.1.2 Fossil Storage Cabinet Testing

4.1.2.1 SNIFF Testing – All Fossil Storage Lockers

A total of 292-fossil storage cabinets were tested in accordance with section 3.2.3.1. The complete results of this testing are shown in tables A2.1 through A2.17 in

Appendix 1. Table 4.2 lists all cabinets with radon concentrations greater than 100 pCi/L.

Table 4.2: Cabinets With Radon Concentration Greater Than 100 pCi/L

Date Performed	**Cabinet**	**Radon Concentration (pCi/L)**	**Dev (+/-)**	**Note**
9/23/16	H-16	105	22.0	
7/20/16	M-14	105	22.0	
9/22/16	H-8	107	22.1	
9/23/16	H-17	108	22.2	
7/18/16	N-9	109	22.4	
6/15/16	P-14	109	22.5	
6/15/16	P-12	111	22.6	
5/25/16	O-4	113	23.0	Hagerman
5/25/16	O-6	119	23.7	Hagerman
6/28/16	Q-9	121	23.4	
7/8/16	N-5	162	26.8	
7/20/16	N-13	166	27.1	
7/18/16	N-11	185	28.6	
6/15/16	P-13	192	29.1	
4/25/16	O-7	227	31.7	Hagerman
5/25/16	O-14	233	31.9	Hagerman
7/8/16	N-6	259	33.5	
7/18/16	N-8	275	34.4	
3/31/17	G-8	307	36.3	
7/18/16	N-10	345	38.4	
4/25/16	O-13	439	43.4	Hagerman
4/25/16	O-11	549	48.2	Hagerman
5/25/16	O-8	589	50.3	Hagerman
4/25/16	O-9	657	52.7	Hagerman
5/25/16	O-10	762	57.0	Hagerman
5/25/16	O-12	1,280	73.8	Hagerman

4.1.2.2 SNIFF Testing with Temporary Covers

Six fossil storage cabinets were tested in accordance with section 3.2.3.2. Table 4.3 provides results of SNIFF testing with temporary covers installed on lockers O-12, Q-9, P-13, O-13, O-9, and O-14.

Table 4.3: Temporary Cover Test Results

Date Performed	Cabinet	Temp Cover Concentration (pCi/L)	Dev (+/-)	Initial SNIFF Concentration (pCI/L)	Dev (+/-)
1/17/17	O-12	1,530	81.8	1,280	73.8
1/17/17	Q-9	191	29.0	121	23.4
1/17/17	P-13	384	40.7	192	29.1
1/19/17	O-13	1,300	74.9	439	43.3
4/3/17	O-14	757	56.8	233	31.9
1/19/17	O-9	1,270	74.3	657	52.7

4.1.2.3 Exposure Studies

Eleven Cabinets were tested using the method discussed in paragraph 3.2.3.3. Cabinets were selected based on the results of both the initial SNIFF tests and cabinet testing with temporary covers installed. Cabinets were selected to study the broad range of results from 0 pCi/L to 1530 pCi/L in order to determine if/when personnel working in the storage cabinets could be exposed to radon concentrations greater than 4 pCi/L. Results of exposure studies are shown in Tables 4.4 through 4.14 and Figures 4.1 through 4.12.

Table 4.4: Exposure Study – Cabinet C-4*

Elapsed Time (Min)	Radon Conc (pCi/L)	Dev (+/-)	Notes
5	0.95	4.59	Locker Shut
10	0.95	4.59	Locker Open
15	1.90	5.20	
20	0.95	4.59	
25	0.95	4.59	
30	0.95	4.59	
35	1.90	5.20	Test Secured

*Initial radon concentration: 22.8 ± 11.4 pCi/L

Figure 4.1: Exposure Study – Cabinet C-4

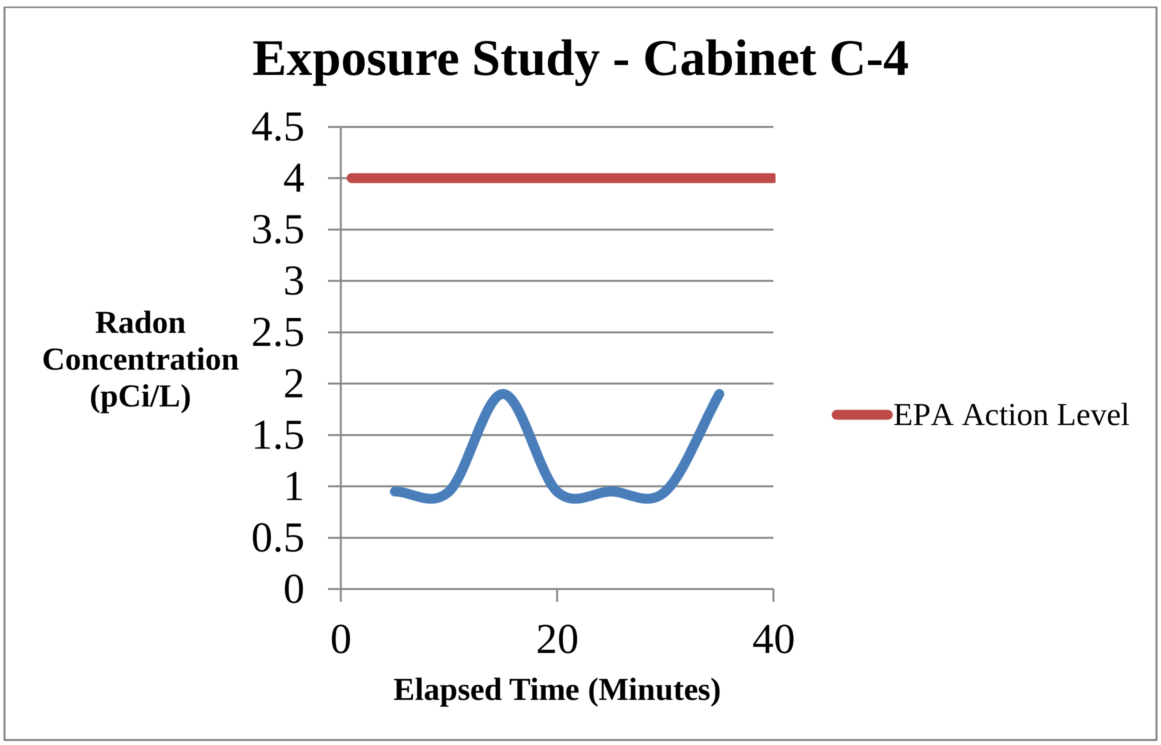


Table 4.5: Exposure Study – Cabinet C-8*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.95	4.59	Locker Shut
10	1.90	5.20	Locker Open
15	1.90	5.20	
20	2.85	5.71	
25	0.95	4.59	
30	0.00	3.81	
35	0.95	4.59	Test Secured

*Initial radon concentration: 28.6 ± 12.5 pCi/L

Figure 4.2: Exposure Study – Cabinet C-8

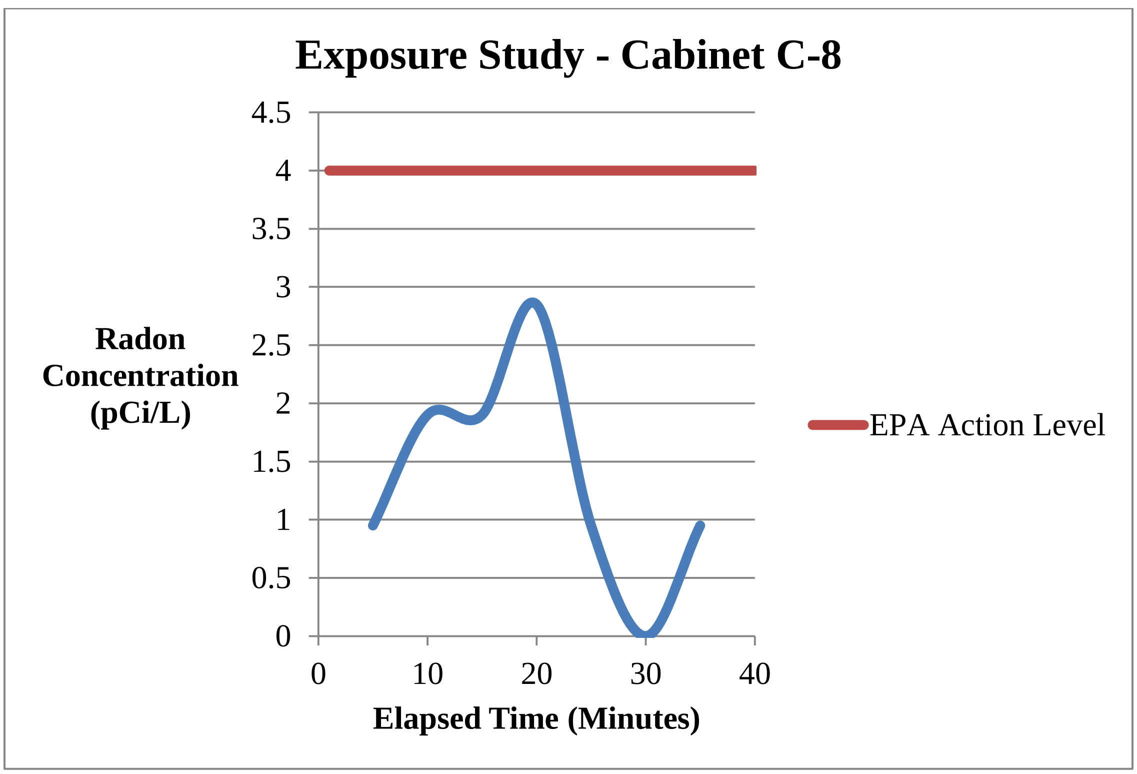


Table 4.6: Exposure Study – Cabinet H-8*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.95	4.59	Locker Shut
10	0.95	4.59	Locker Open
15	1.90	5.20	
20	0.95	4.59	
25	1.90	5.20	
30	2.85	5.71	
35	0.95	4.59	
40	0.00	3.81	Test Secured

*Initial radon concentration: 107 ± 22.1 pCi/L

Figure 4.3: Exposure Study – Cabinet H-8

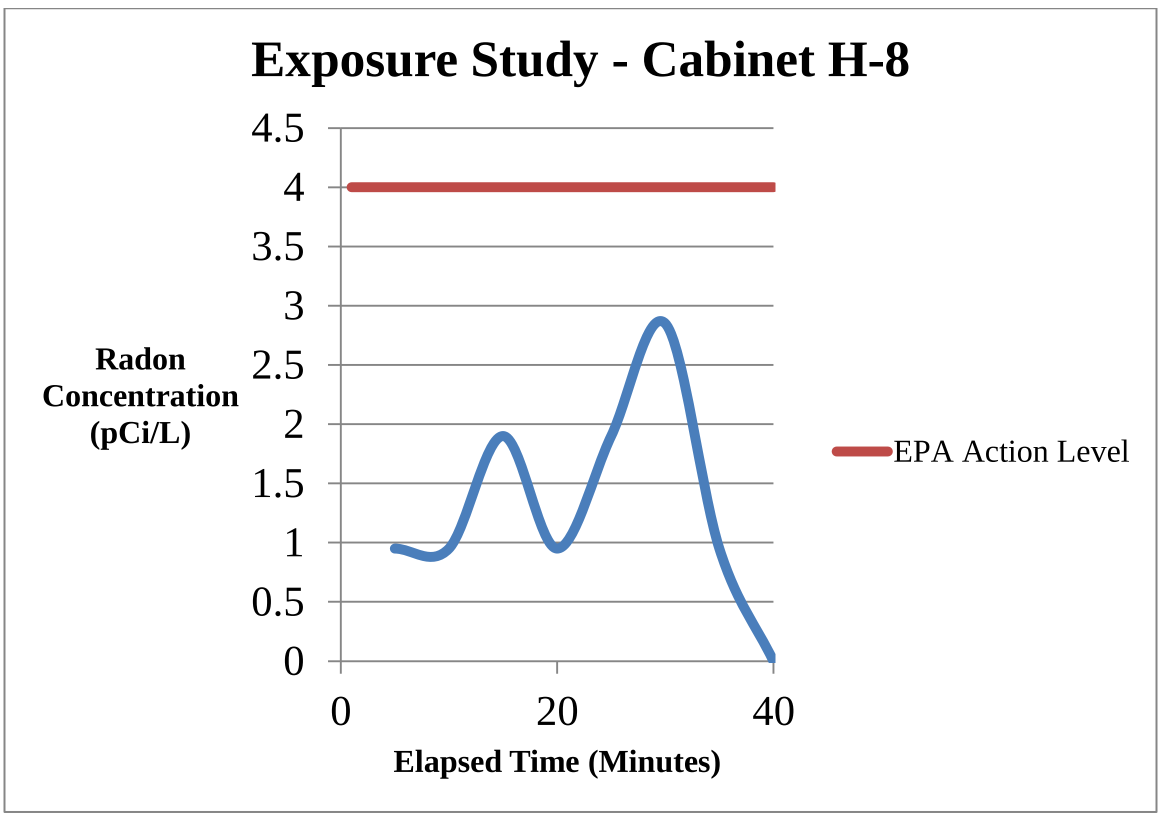


Table 4.7: Exposure Study – Cabinet Q-9*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	2.84	5.68	Locker Shut
10	2.84	5.68	Locker Open
15	0.00	3.81	
20	0.95	4.59	
25	2.85	5.71	
30	4.76	6.56	
35	2.85	5.71	Test Secured

*Initial radon concentration: 121 ± 23.4 pCi/L

Figure 4.4: Exposure Study – Cabinet Q-9

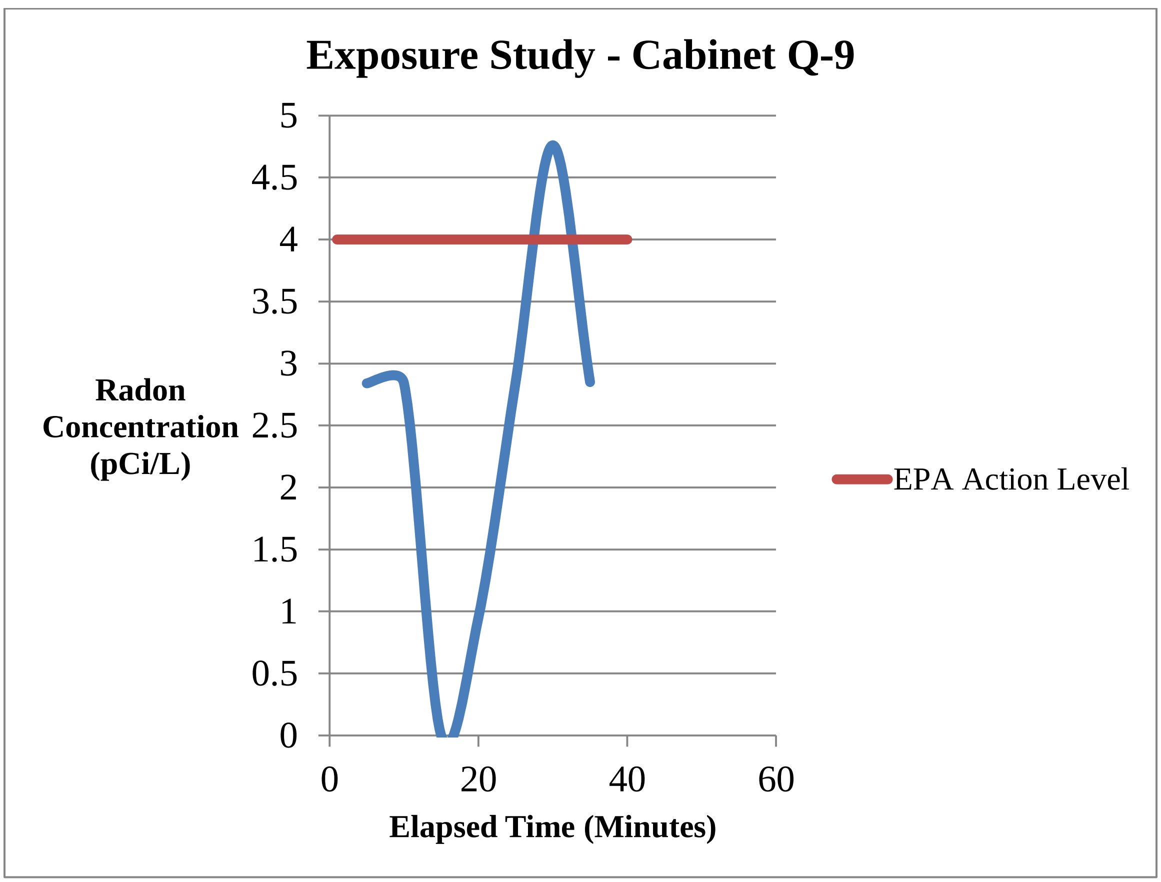


Table 4.8: Exposure Study – Cabinet P-13*

Elapsed Time (Min)	Radon Concntration (pCi/L)	Dev (+/-)	Notes
5	0.00	3.79	Locker Shut
10	6.66	7.29	Locker Open
15	6.66	7.29	
20	6.66	7.29	
25	5.71	6.94	
30	4.76	6.56	
35	2.85	5.71	
40	4.76	6.56	
45	2.85	7.29	
50	4.76	6.61	
55	5.71	6.16	
60	3.81	5.20	Test Secured

*Initial radon concentration: 192 ± 29.1 pCi/L

Figure 4.5: Exposure Study – Cabinet P-13

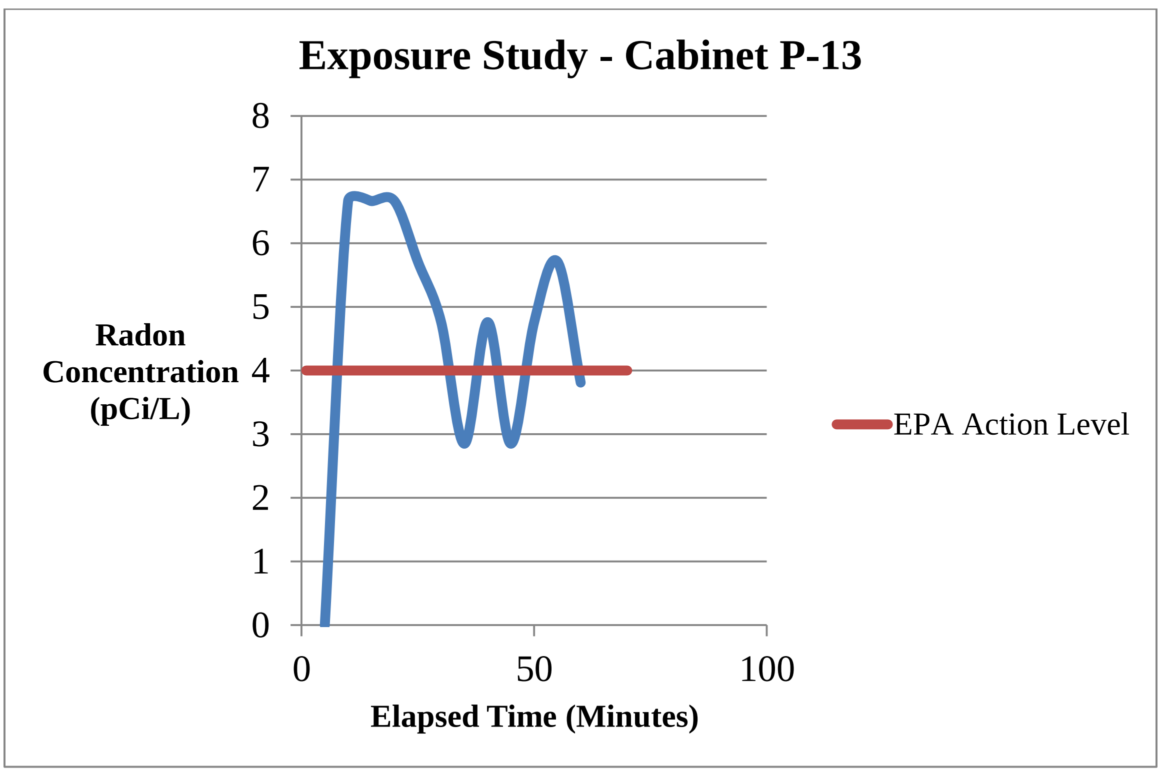


Table 4.9: Exposure Study – Cabinet O-14*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.95	4.57	Locker Shut
10	7.61	7.61	Locker Open
15	24.7	11.8	
20	6.66	7.29	
25	3.81	6.16	
30	5.71	6.94	
35	1.90	5.20	
40	1.90	5.20	
45	2.85	5.71	
50	1.90	5.20	Test Secured

*Initial radon concentration: 233 ± 31.9 pCi/L

Figure 4.6: Exposure Study – Cabinet O-14

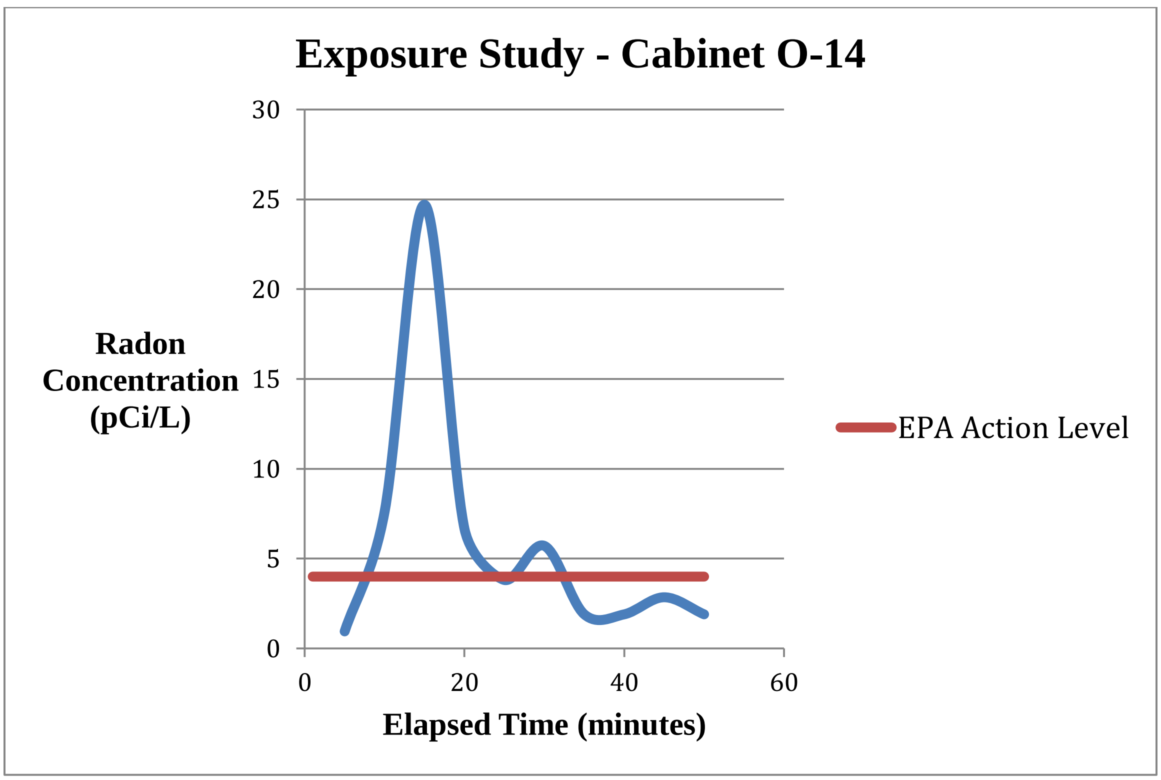


Table 4.10: Exposure Study – Cabinet G-8*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.00	3.81	Locker Shut
10	4.73	6.53	Locker Open
15	2.85	5.71	
20	0.95	4.59	
25	0.00	3.81	
30	0.95	4.59	
35	3.81	6.16	
40	0.95	4.59	
45	0.95	4.59	Test Secured

*Initial radon concentration: 307 ± 36.3 pCi/L

Figure 4.7: Exposure Study – Cabinet G-8

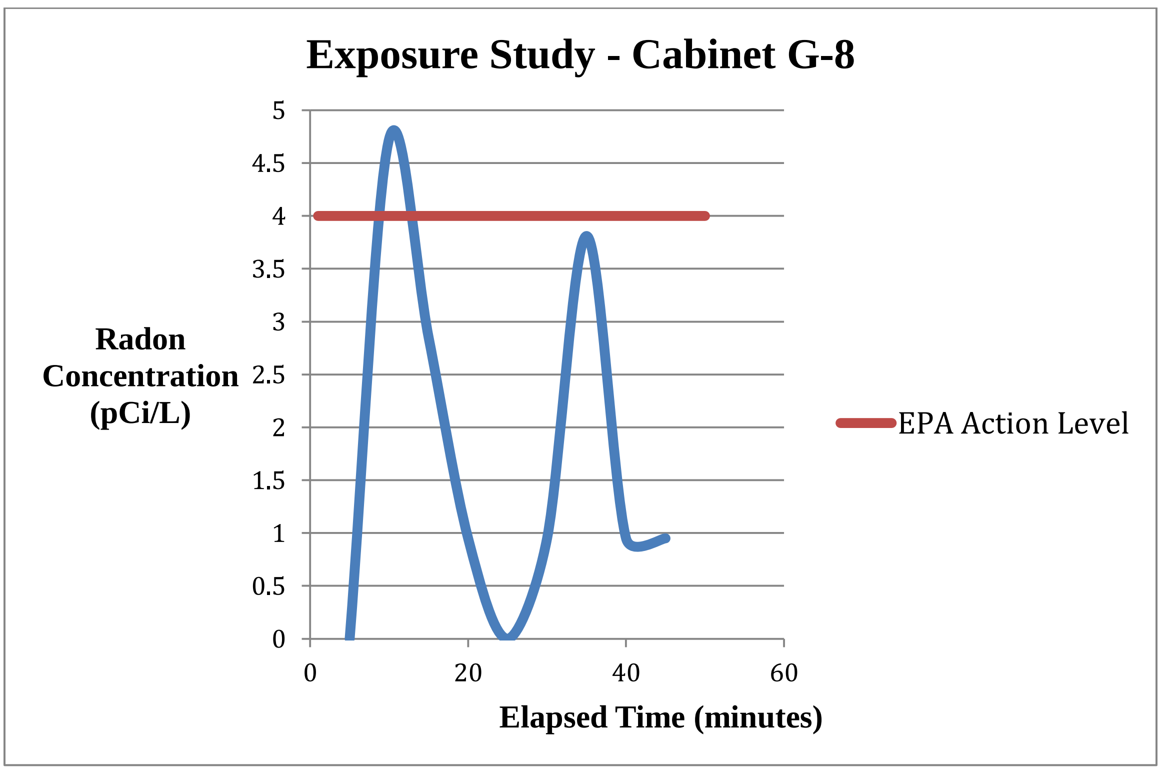


Table 4.11: Exposure Study – Cabinet N-10*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	1.90	5.20	Locker Shut
10	4.76	6.56	Locker Open
15	0.95	4.59	
20	1.90	5.20	
25	2.85	5.71	
30	0.00	2.85	
35	2.85	5.71	
40	0.95	4.59	
45	2.85	5.71	Test Secured

*Initial radon concentration: 345 ± 38.4 pCi/L

Figure 4.8: Exposure Study – Cabinet N-10

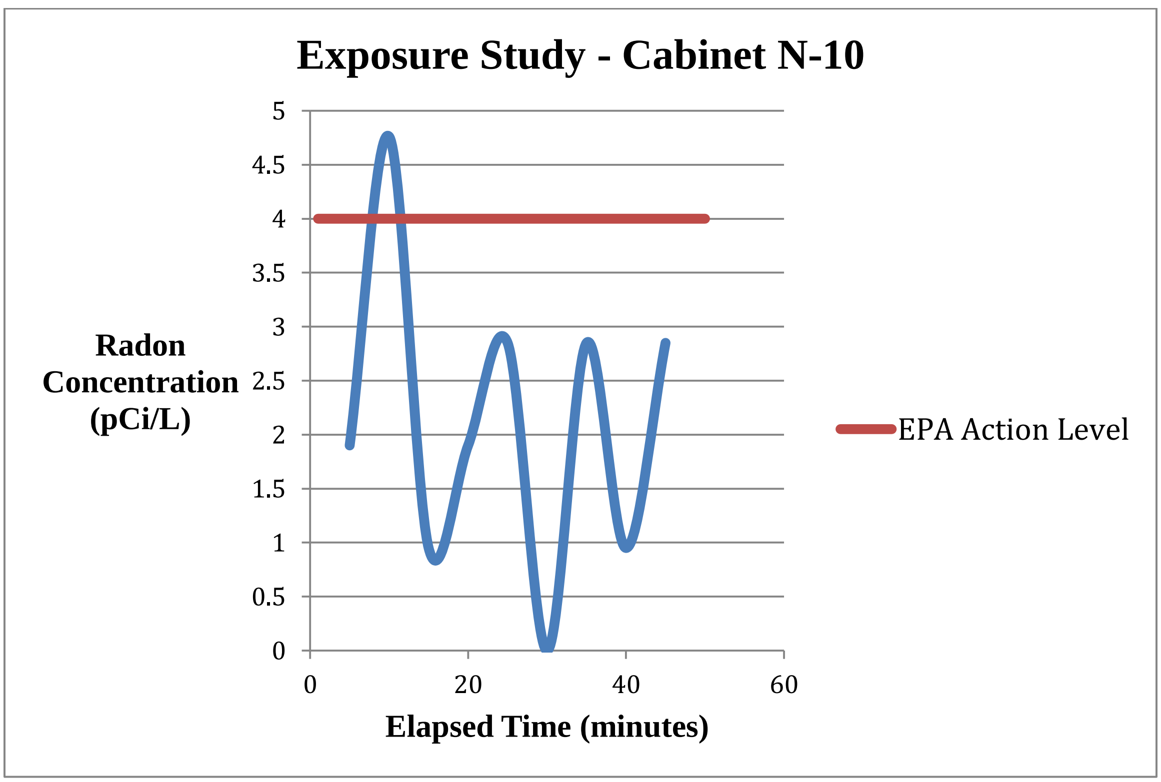


Table 4.12: Exposure Study – Cabinet O-13*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.95	4.57	Locker Shut
10	5.71	6.94	Locker Open
15	15.2	9.75	
20	17.1	10.2	
25	12.3	8.98	
30	2.85	5.71	
35	7.61	7.61	
40	0.95	4.59	
45	3.81	6.16	
50	1.90	5.20	
55	2.85	5.71	Test Secure

*Initial radon concentration: 439 ± 43.4 pCi/L

Figure 4.9: Exposure Study – Cabinet O-13

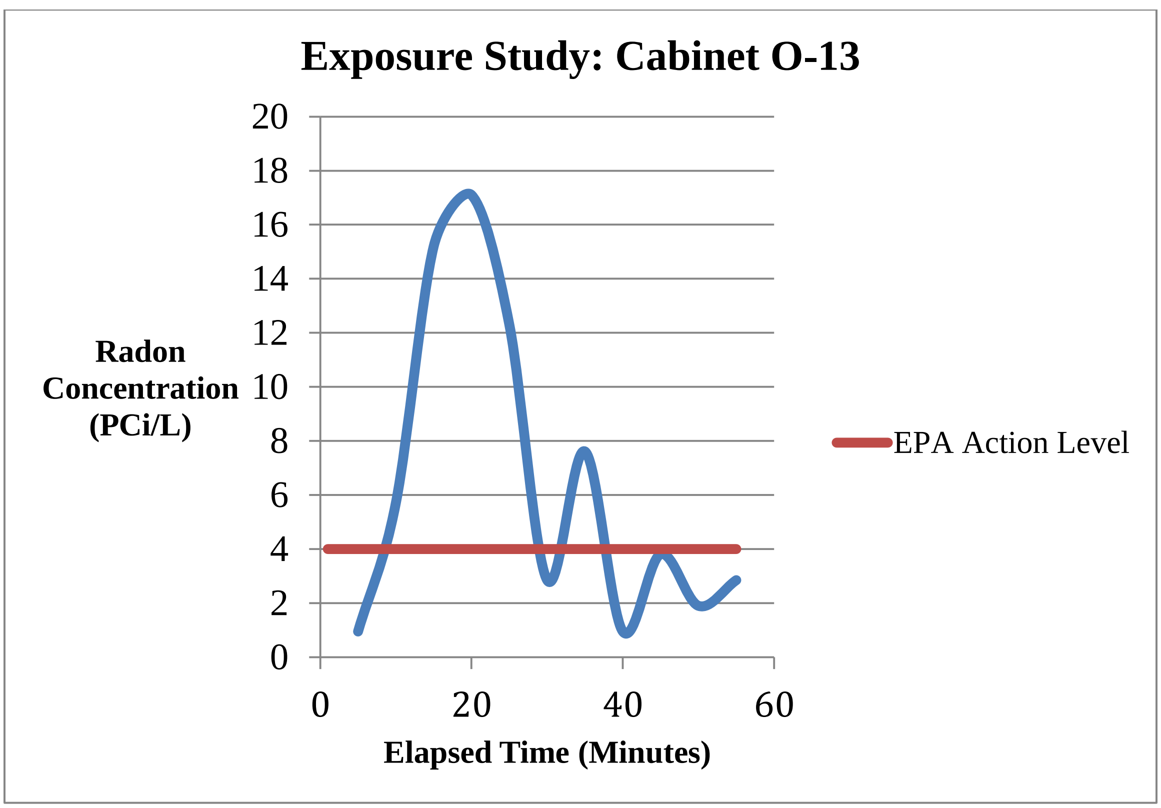


Table 4.13: Exposure Study – Cabinet O-9*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	1.92	5.77	Locker Shut
10	3.89	7.09	Locker Open
15	5.80	8.35	
20	4.84	7.05	
25	2.90	6.67	
30	0.00	5.26	
35	3.85	7.01	
40	3.85	7.37	Test Secured

*Initial radon concentration: 657 ± 52.7 pCi/L

Figure 4.10: Exposure Study – Cabinet O-9

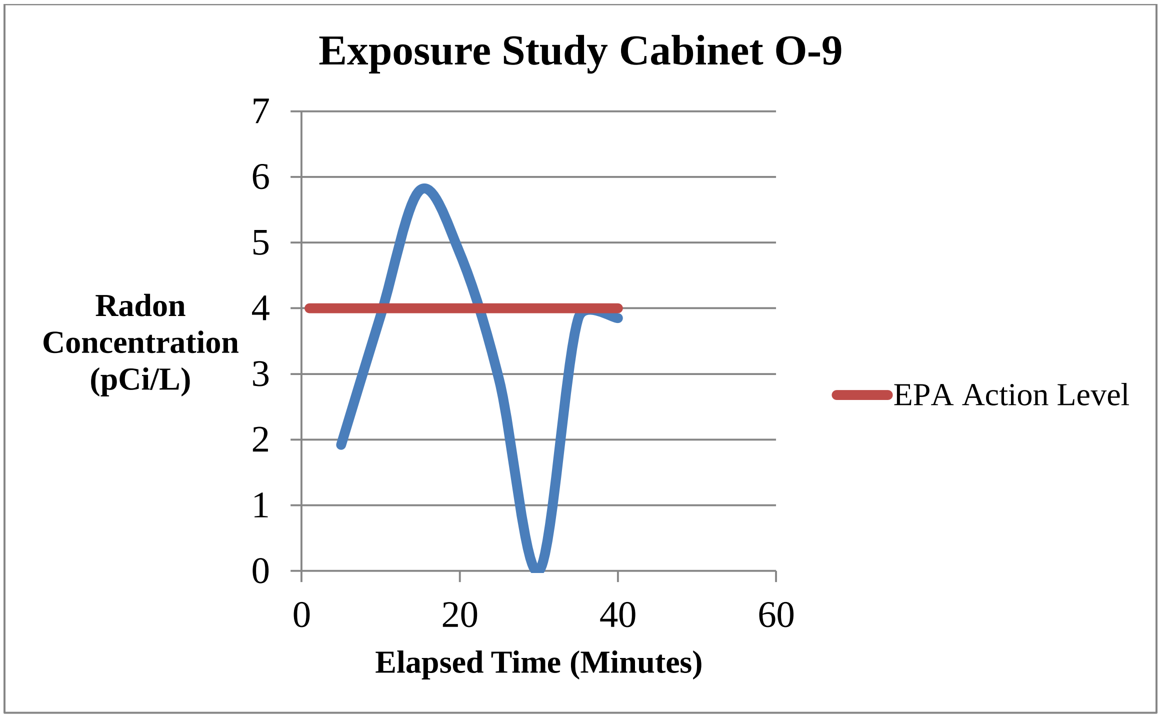
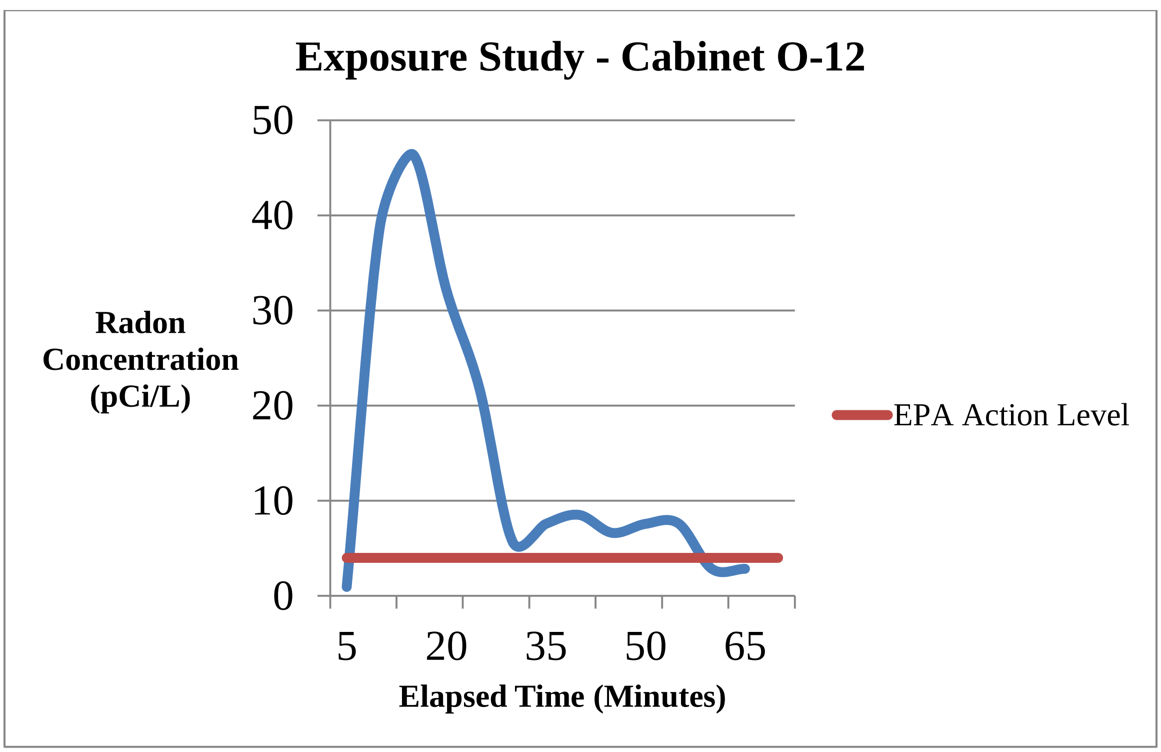


Table 4.14: Exposure Study – Cabinet O-12*

Elapsed Time (Min)	Radon Concentration (pCi/L)	Dev (+/-)	Notes
5	0.95	4.57	Locker Shut
10	38.8	14.2	Locker Open
15	46.4	15.3	
20	32.2	13.1	
25	21.8	11.2	
30	5.68	6.90	
35	7.57	7.57	
40	8.52	7.88	
45	6.63	7.25	
50	7.57	7.57	
55	7.61	7.61	
60	2.85	5.71	
65	2.85	5.71	Test Secure

*Initial radon concentration: 1,280 ± 73.8 pCi/L

Figure 4.11: Exposure Study – Cabinet O-12



4.2 Analyses

4.2.1 The 48-Hour EPA Testing

Three 48-Hour EPA Tests were performed, 2 in the Fossil Storage Facility and 1 in an adjacent basement-level room. Results are listed in section 4.1.1. None of the tests performed showed radon concentrations above the EPA action level, therefore, the Null Hypothesis 1 H_0 is supported and the Alternative Hypothesis 1 H_A is rejected.

4.2.2 Fossil Storage Cabinet Testing

A total of 292 fossil storage cabinets were tested using the Durridge RAD7's SNIFF function. Six cabinets were also tested with temporary covers installed. Peak and mean radon concentrations were determined to be 1,530 ± 81.8pCi/L and 46.12 ± 11.0pCi/L, respectively. Specific results for each cabinet can be found in sections 4.2.1.1 and 4.2.1.2.

SNIFF testing results were used to assess which cabinets would be the most beneficial to the performance of exposure studies. Eleven cabinets were chosen for exposure testing. The SNIFF results from these cabinets ranged from 22.8 ± 11.4pCi/L to 1512 ± 81.2pCi/L. Specific results from each exposure study are provided in section 4.1.2.3.

Results of the exposure studies showed that although 194 of the 292 cabinets had radon concentrations greater than the EPA Action Level, only cabinets with radon concentration's greater than approximately 100pCi/L resulted in possible exposures of greater than 4pCi/L when opened. Fossil storage cabinet Q-9 had an initial SNIFF test radon-concentration of 121 ± 23.4pCi/L. Cabinet Q-9's study resulted in a peak radon concentration of 4.76 ± 6.56pCi/L. This concentration was found 25 minutes after the cabinet was opened and it decreased below the 4pCi/L action level after 30 minutes.

The highest radon concentration during an exposure study was found in cabinet O-12, which had a peak radon concentration of 1,512 ± 81.2pCi/L during SNIFF testing. Cabinet O-12's radon concentration increased above 4pCi/L within 5 minutes of opening the cabinet and remained so for 50 minutes. The peak radon concentration was determined to be 46.4 ± 15.3pCi/L.

Radon concentration was found to frequently exceed the EPA Action Level while performing exposure studies on cabinets that contained radon concentrations greater than 100pCI/L. Table 4.2 lists all fossil storage cabinets that were found to have radon concentrations greater than 100pCi/L. Eight of eleven exposure studies found radon concentration to be greater than the EPA Action Level, therefore, Alternate Hypothesis 2 H_A is supported and Null Hypothesis 2_0 is rejected.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Although the 48-Hour EPA testing did not result in radon concentration greater than 4 pCi/L in the fossil storage facility, exposure study results indicate that personnel may potentially be exposed to radon concentrations greater than 4 pCi/L when working in front of open fossil storage cabinets with radon concentrations greater than 100pCi/L. Twenty-six fossil storage cabinets have radon concentrations that were found to be greater than 100pCi/L, which represents 8.9% of the total population of fossil storage cabinets at the Idaho Museum of Natural History. To maintain radon exposure as low as reasonably achievable, a radon mitigation program is recommended.

Fossil element-source radon mitigation techniques have been developed for the National Park Service by the United States Centers for Disease Control and Prevention and may be found in Health Hazard Evaluation Report: HETA 96-0264-2713 Hagerman Fossil Beds National Monument. HETA 96-0264-2713 lists seven radon mitigation recommendations regarding the storage of fossil elements found to contain measurable amounts of naturally occurring uranium-238. The following are some examples of the recommended techniques; minimize the amount of fossils stored, store fossil elements in mechanically ventilated, unoccupied rooms, and minimize the number of cabinets open at one time (Jiggins, Cardarelli, and Ahrenholz, 1996).

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APPENDICES

Appendix 1

A1.1 Setup and Operating Instructions for 48-Hour EPA Protocol Test.

The following steps; consistent with specifications in the users manual, are employed to set-up the RAD7 for the 48-Hour Protocol Test:

- Switch RAD7 ON using the ON/OFF switch.
- Using the Key Pad, depress the MENU key, followed by the ENTER key, then depress the "➔" key four times. At this point in the control cycle the LCD should display the status "Test Purge".
- Depress the ENTER key.
- After purging for a minimum of 5 minutes, depress the MENU key and then depress the "➔" key two times. The LCD should display "Setup".
- Depress the ENTER key twice. Press either arrow key until "Protocol: 2 Day Test" is displayed on the LCD. Depress the ENTER key.
- The LCD should display "Setup". Depress the ENTER key , then the "➔" key seven times. ">Setup Format" should be displayed on the LCD.
- Depress the ENTER key. Use arrow keys to select "Format: Short". Depress the ENTER key.
- Turn the RAD7 OFF using the ON/OFF switch.

The RAD7 is now ready to perform the 48-Hour EPA Protocol Test (Durridge Company, 2015).

Per the RAD7 User Manual, the following procedure is used to commence and perform the 48 Hour EPA Protocol Test:

- Turn the RAD7 ON using ON/OFF switch.
- Using the Key Pad, depress the MENU key, followed by the ENTER key, and then depress the "➔" key. At this point in the control cycle the LCD should display the status "Test Start".
- Depress the ENTER key. The air pump should start running.
- The test has commenced and will automatically secure after 48-hours. Data is automatically collected and stored in the RAD7 memory.
- Collected data may be downloaded via the manufacturer provided Capture application.

A1.2 Set-up and Operating Instruction for SNIFF Test

The following steps; consistent with specifications in the users manual, are employed to set-up the RAD7 for a SNIFF test:

- Switch RAD7 ON using the ON/OFF switch.
- Using the Key Pad, depress the MENU key, followed by the ENTER key, then depress the "➔" key four times. At this point in the control cycle the LCD should display the status "Test Purge".
- Depress the ENTER key.
- After purging for a minimum of 5 minutes, depress the MENU key and then depress the "➔" key two times. The LCD should display "Setup".

- Depress the ENTER key twice. Press either arrow key until the status "Protocol: Thoron" is displayed on the LCD. Depress the ENTER key.
- The LCD should display "Setup". Depress the ENTER key and then the "➔" key seven times. ">Setup Format" should be displayed on the LCD.
- Depress the ENTER key. Use the arrow keys to select "Format: Short." Depress the ENTER key.
- Turn RAD7 OFF using the ON/OFF switch.

The RAD7 is now ready to perform a SNIFF Test (Durridge Company, 2015). The following steps; consistent with specifications in the users manual, are employed to commence and perform a SNIFF Test:

- Turn the RAD7 ON using the ON/OFF switch.
- Depress the MENU key, followed by the ENTER key, and then depress the "➔" key. The LCD should display "Test Start".
- Depress the ENTER key. The air pump should start running.
- The SNIFF Test is now running. The LCD will display a radon concentration reading in 5-minute increments. The first 5-minute reading may be used for data collection. After moving to a new location, a new radon concentration will not be established until the 3rd 5-minute increment.
- Data may be collected manually from the LCD or via download from the manufacturer provided Capture Application.

Appendix 2

Sniff Testing Results – All Cabinets

Table A2.1: Fossil Storage Cabinets – Row A

Date Performed	**Cabinet Number**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
3/9/17	1	6.63	7.25	
3/9/17	2	22.8	11.4	
3/9/17	3	22.8	11.4	
3/9/17	4	23.8	11.6	
3/9/17	5	25.7	12.0	
3/9/17	6	20.0	10.8	
3/9/17	7	31.4	13.0	
3/9/17	8	60.9	17.3	
3/13/17	9	9.46	8.17	
3/13/17	10	1.90	5.20	Empty
3/13/17	11	0.00	3.81	Empty
3/13/17	12	0.00	3.81	Empty

Table A2.2: Fossil Storage Cabinets – Row B

Date Performed	**Cabinet Number**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
2/23/17	1	22.8	11.4	
2/23/17	2	18.1	10.4	
2/23/17	3	10.5	8.50	Empty
2/23/17	4	2.85	5.17	
2/23/17	5	0.95	4.57	Empty
2/23/17	6	1.90	5.20	
2/23/17	7	18.1	10.4	
2/23/17	8	28.6	12.5	
2/23/17	9	3.81	6.16	
2/23/17	10	14.3	9.52	
2/23/17	11	25.7	12.0	
2/23/17	12	1.90	5.20	Empty

Table A2.3: Fossil Storage Cabinets – Row C

Date Performed	Cabinet Number	Result (pCi/L)	Dev (+/-)	Note
2/16/17	1	0.95	4.57	
2/16/17	2	8.56	7.92	
2/16/17	3	16.2	9.98	
2/16/17	4	22.8	11.4	
2/16/17	5	4.76	6.56	
2/16/17	6	0.00	3.81	Empty
2/16/17	7	10.5	8.50	
2/16/17	8	28.6	12.5	
2/17/17	9	4.73	6.53	
2/17/17	10	12.4	9.02	
2/17/17	11	7.61	7.61	
2/23/17	12	2.85	5.71	

Table A2.4: Fossil Storage Cabinets – Row D

Date Performed	**Cabinet Number**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
12/14/16	1	0.00	3.79	
12/14/16	2	1.89	5.17	
12/14/16	3	1.89	5.17	
12/14/16	4	0.95	4.57	
3/28/17	5	0.00	3.79	
12/14/16	6	2.84	5.68	
12/14/16	7	1.89	5.17	
12/14/16	8	1.89	5.17	
12/14/16	9	0.00	3.79	
12/14/16	10	0.95	4.57	
3/28/17	11	0.00	3.81	
3/28/17	12	5.71	6.94	
3/28/17	13	0.95	4.59	
3/28/17	14	0.00	3.81	
3/28/17	15	0.95	4.59	
3/28/17	16	1.90	5.20	
3/28/17	17	0.00	3.81	
3/30/17	18	0.00	3.81	
3/30/17	19	0.95	4.59	
3/30/17	20	0.95	4.59	Empty
3/30/17	21	0.95	4.59	
3/30/17	22	4.76	6.56	
3/30/17	23	1.90	5.20	
3/30/17	24	1.90	5.20	

Table A2.5: Fossil Storage Cabinets – Row E

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
11/18/16	1	7.57	7.57	
11/18/16	2	19.9	10.8	
11/18/16	3	6.63	7.25	
11/18/16	4	18.9	10.6	
11/18/16	5	51.4	7.68	
12/1/16	6	50.2	15.8	
12/1/16	7	13.3	9.22	
12/1/16	8	6.63	7.25	
12/1/16	9	10.4	8.45	
12/1/16	10	20.8	11.0	
12/1/16	11	19.9	10.8	
12/1/16	12	24.6	11.7	
12/1/16	13	8.56	7.92	
12/6/16	14	11.4	8.72	
12/6/16	15	10.4	8.45	
12/6/16	16	20.8	11.0	
12/6/16	17	12.3	8.98	
12/6/16	18	88.5	20.4	
12/6/16	19	18.9	10.6	
12/6/16	20	80.9	19.6	
12/6/16	21	22.8	11.4	
12/7/16	22	16.1	9.92	
12/7/16	23	45.4	15.1	
12/7/16	24	6.63	7.25	Empty

Table A2.6: Fossil Storage Cabinets – Row F

Date Performed	**Cabinet**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
11/3/16	1	24.6	11.7	
11/3/16	2	15.2	9.75	
11/3/16	3	10.5	8.50	
11/3/16	4	51.4	16.0	
11/3/16	5	9.52	8.22	
11/9/16	6	14.2	9.46	
11/9/16	7	24.6	11.7	
11/9/16	8	14.2	9.46	
11/9/16	9	18.9	10.6	
11/9/16	10	9.46	8.17	
11/9/16	11	13.3	9.22	
11/9/16	12	12.3	8.98	
11/9/16	13	8.52	7.88	
11/16/16	14	3.79	6.13	
11/16/16	15	20.8	11.0	
11/16/16	16	18.9	10.6	
11/16/16	17	5.68	6.90	Empty
11/16/16	18	1.89	5.17	Empty
11/16/16	19	1.89	5.17	Empty
12/7/16	20	5.68	6.90	
3/31/17	21	1.90	5.20	
12/7/16	22	1.89	5.17	
12/7/16	23	9.46	8.17	
12/7/16	24	2.84	5.68	

Table A2.7: Fossil Storage Cabinets – Row G

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
10/6/16	1	7.57	7.57	
10/6/16	2	52.1	16.1	
10/6/16	3	78.0	19.2	
10/6/16	4	74.2	18.8	
10/6/16	5	5.68	6.00	
10/11/16	6	4.73	6.53	
10/11/16	7	4.73	6.53	
3/31/7	8	307	36.3	
10/11/16	9	7.57	7.57	
10/11/16	10	9.46	8.17	
10/13/16	11	1.89	5.17	
10/13/16	12	11.4	8.72	
10/13/16	13	12.3	8.98	
10/13/16	14	13.3	9.22	
10/13/16	15	9.46	8.17	
10/28/16	16	9.46	8.17	
10/28/16	17	3.79	6.13	
10/28/16	18	16.1	9.92	
10/28/16	19	5.68	6.90	
10/28/16	20	6.63	7.25	
10/28/16	21	1.89	5.17	
11/1/16	22	1.90	5.20	
11/1/16	23	2.84	5.68	
11/1/16	24	17.0	10.1	

Table A2.8: Fossil Storage Cabinets – Row H

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
9/20/16	1	11.4	8.72	
9/20/16	2	47.3	15.4	
9/20/16	3	64.4	17.6	
9/20/16	4	49.5	15.8	
9/20/16	5	75.2	18.9	
9/20/16	6	49.5	15.8	
9/20/16	7	20.8	11.0	
9/22/16	8	107	22.1	
9/22/16	9	18.9	10.6	
9/22/16	10	4.73	6.53	Empty
9/22/16	11	0.95	4.57	Empty
9/22/16	12	3.79	6.13	Empty
9/23/16	13	3.79	6.13	
9/23/16	14	61.5	17.3	
9/23/16	15	76.7	19.0	
9/23/16	16	105	22.0	
9/23/16	17	108	22.2	
9/23/16	18	4.73	6.90	Empty
10/5/16	19	0.00	3.79	Empty
10/5/16	20	35.0	13.6	
10/5/16	21	30.3	12.8	
10/5/16	22	53.3	16.3	
10/5/16	23	32.4	13.2	
10/5/16	24	34.1	13.4	

Table A2.9: Fossil Storage Cabinets – Row I

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
6/28/16	1	4.73	6.53	
4/3/17	2	5.68	6.90	
6/28/16	3	4.73	6.53	
6/29/16	4	0.00	3.79	
6/29/16	5	15.1	9.70	
3/30/17	6	1.90	5.20	Empty
6/29/16	7	12.3	8.98	
6/29/16	8	16.1	9.92	
6/29/16	9	5.68	6.90	
6/29/16	10	19.9	10.8	
6/29/16	11	1.89	5.17	
3/31/17	12	0.00	3.79	Empty
3/31/17	13	0.00	3.81	Empty
3/31/17	14	0.95	4.59	Empty
4/25/16	15	25.8	12.0	
7/7/16	16	2.84	5.68	
4/25/16	17	24.1	11.9	
7/7/16	18	8.52	7.88	
7/7/16	19	1.89	5.17	
7/7/16	20	28.4	12.4	
7/7/16	21	15.1	9.70	
7/7/16	22	46.4	15.3	
7/7/16	23	5.68	6.90	
7/7/16	24	18.9	10.6	

Table A2.10: Fossil Storage Cabinets – Row J

Date Performed	**Cabinet**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
8/31/16	1	3.79	6.13	
8/31/16	2	4.73	6.53	
8/31/16	3	1.89	5.17	Empty
8/31/16	4	0.00	3.79	Empty
8/31/16	5	0.95	4.57	
9/7/16	6	1.89	5.17	
9/7/16	7	3.79	6.13	
9/7/16	8	0.00	3.79	
9/7/16	9	0.95	4.57	
9/7/16	10	2.84	5.68	
9/7/16	11	0.95	4.57	
9/7/16	12	0.00	3.79	
9/7/16	13	0.95	4.57	
9/8/16	14	0.95	4.57	

Table A2.11: Fossil Storage Cabinets – Row K

Date Performed	**Cabinet**	**Result (pCi/L)**	**Dev (+/-)**	**Note**
8/25/16	1	3.79	6.13	
8/25/16	2	1.89	5.17	
8/25/16	3	0.00	3.79	
8/25/16	4	3.79	6.13	
8/25/16	5	0.95	4.57	
8/25/16	6	0.00	3.79	
8/25/16	7	1.89	5.17	
8/26/16	8	1.89	5.17	
8/26/16	9	2.84	5.68	
8/26/16	10	1.89	5.17	
8/26/16	11	0.95	4.57	
8/26/16	12	2.84	5.68	
8/26/16	13	0.95	4.57	
8/26/16	14	0.95	4.57	

Table A2.12: Fossil Storage Cabinets – Row L

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
7/27/16	1	4.73	6.53	
7/27/16	2	13.3	9.22	
7/27/16	3	15.1	9.70	
7/27/16	4	6.63	7.25	
7/27/16	5	3.79	6.13	
7/29/16	6	1.89	5.17	
7/29/16	7	3.79	6.13	
7/29/16	8	78.6	19.2	
7/29/16	9	1.89	5.17	
7/29/16	10	0.95	4.57	
8/25/16	11	0.95	4.57	
8/25/16	12	3.79	6.13	
8/25/16	13	1.89	5.17	
8/25/16	14	5.58	6.90	

Table A2.13: Fossil Storage Cabinets – Row M

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
7/27/16	1	10.4	8.45	
7/27/16	2	39.8	14.3	
7/27/16	3	3.79	6.13	
7/27/16	4	6.63	7.25	
7/26/16	5	20.9	11.0	
7/26/16	6	18.9	10.6	
7/26/16	7	93.3	20.8	
7/26/16	8	12.3	8.98	
7/26/16	9	41.6	14.6	
7/26/16	10	8.52	7.88	
7/20/16	11	26.6	12.2	
7/20/16	12	54.2	16.4	
7/20/16	13	73.3	18.7	
7/20/16	14	105	22.0	

Table A2.14: Fossil Storage Cabinets – Row N

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
7/8/16	1	2.84	5.68	
7/8/16	2	18.0	10.4	
7/8/16	3	42.6	14.7	
7/8/16	4	96.1	21.1	
7/8/16	5	162	26.8	
7/8/16	6	259	33.5	
7/18/16	7	4.73	6.53	
7/18/16	8	275	34.4	
7/18/16	9	109	22.4	
7/18/16	10	345	38.4	
7/18/16	11	185	28.6	
7/20/16	12	24.6	11.7	
7/20/16	13	166	27.1	
7/20/16	14	87.5	20.3	

Table A2.15: Fossil Storage Cabinets – Row O

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
5/25/16	1	0.95	4.57	
5/25/16	2	8.66	8.01	
5/25/16	3	18.0	10.4	
5/25/16	4	113	23.0	
4/25/16	5	3.79	6.13	Empty
5/25/16	6	119	23.7	
4/25/16	7	227	31.7	
5/25/16	8	589	50.3	
4/25/16	9	657	52.7	
5/25/16	10	762	57.0	
4/25/16	11	549	48.2	
5/25/16	12	1,280	73.8	
4/25/16	13	439	43.4	
5/25/16	14	233	31.9	

Table A2.16: Fossil Storage Cabinets – Row P

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
6/10/16	1	1.89	5.17	
6/10/16	2	8.52	7.88	
6/10/16	3	8.52	7.88	
6/10/16	4	27.5	12.3	
6/10/16	5	7.57	7.57	
6/15/16	6	2.84	5.68	
6/15/16	7	9.46	8.17	
6/15/16	8	16.1	9.92	
6/15/16	9	19.9	10.8	
6/15/16	10	4.73	6.53	
6/15/16	11	6.63	7.25	
6/15/16	12	111	22.6	
6/15/16	13	192	29.1	
6/15/16	14	109	22.5	

Table A2.17: Fossil Storage Cabinets – Row Q

Date Performed	Cabinet	Result (pCi/L)	Dev (+/-)	Note
6/24/16	1	1.89	5.17	
6/24/16	2	5.68	6.90	
6/24/16	3	6.63	7.25	
6/24/16	4	17.0	10.2	
6/24/16	5	5.68	6.90	
6/24/16	6	10.4	8.45	
6/28/16	7	9.46	8.17	
6/28/16	8	52.1	16.1	
6/28/16	9	121	23.4	
6/28/16	10	40.0	14.4	
6/28/16	11	54.2	16.4	
6/28/16	12	9.46	8.17	
6/28/16	13	9.46	8.17	
6/28/16	14	37.9	14.0	