United States Environmental Protection Agency

CEMM QUALITY ASSURANCE PROJECT PLAN

Office of Research and Development
Center for Environmental Measurement and Modeling (CEMM)
Atmospheric and Environmental Systems Modeling Division (AESMD)
Emissions Systems Analysis Branch (ESAB)

Radon Measurement and Mitigation in Puerto Rico

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Distribution List

Copies of this plan and all revisions will be sent to the following individuals. It is the responsibility of the U.S. Environmental Protection Agency Office of Research and Development Principal Investigator (PI) to make copies of the plan available to all project personnel.

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Disclaimer and Acknowledgments

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Acronyms and Abbreviations

AARST	American Association of Radon Scientists and Technologists
AEMD	Air and Energy Management Division
ANSI	American National Standards Institute
CEPD	Caribbean Environmental Protection Division
CH	Corentium Home Radon Devices
COC	chain of custody
COV	Coefficient of variation
CRM	Continuous radon monitors
DQI	data quality indicator
DSBB	Distributed Source and Buildings Branch
DPT	Device Performance Test
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
HASP	health and safety plan
IPE	Individual percent error
KSU	Kansas State University
NRMRL	National Risk Management Research Laboratory
NRPP	National Radon Proficiency Program
NRSB	National Radon Safety Board
ORD	Office of Research and Development
OSL	On-site Student Leader
OTL	On-site Technical Leader
pCi/L	Picocuries per liter of air
PI	Principal Investigator
PR	Puerto Rico
PSI	PSI Services
QA	quality assurance
QAO	quality assurance officer
QAPP	quality assurance project plan
QC	quality control
RLS	Research Laboratory Support
RTP	Research Triangle Park
SME	Subject matter expert

SOP	Standard operating procedure
UPR	University of Puerto Rico
UPRM	University of Puerto Rico at Mayagüez
USGS	United States Geological Survey

1.0 Project Description and Objectives

1.1 Background

Radon is one of the most widely studied environmental pollutants and has some of the most extensive human data to provide proof of its harmful effects. Radon has been found to be the second leading cause of lung cancer, and first amongst non-smokers. EPA estimates that radon is responsible for approximately 13% of lung cancer deaths in the United States, and 26% among non-smokers each year. Despite the wealth of information available on radon, there is still little knowledge of its extent in Puerto Rico (PR). The data that are available did not follow the methodology the EPA employed to produce the Radon Zone Maps (EPA, 1992). This lack of information creates a barrier in the path of successfully reducing the risk of radon exposure in the region. Educating the communities in the seven identified municipalities with geologic potential, as well as testing a subset of indoor radon levels will aid in addressing these discrepancies.

Although the typical methods of testing, such as charcoal canisters and alpha-track detectors, are considered cheap, they are simply not logistically feasible in PR. This is because these methods require access to a certified lab for analysis. The majority of PR does not have access to these labs. The samples collected via the traditional methods would have to be shipped to a certified lab for analysis. Additionally, these methods are sensitive to humidity and time, so utilizing them proves to be impractical for use in the tropical climate of PR. To remedy these issues the EPA is implementing the New Testing Method for Community Mapping of Radon. The new method uses the Corentium Home (CH) radon detection device by Airthings (Airthings Inc, 2021). The device is compact, portable, and delivers readings without needing to be delivered to a certified lab for testing. It will be used to test radon levels in homes. The devices will be distributed throughout seven target municipalities. Project team members will receive training on both radon and the radon detection equipment in order to maintain capabilities during the project period. Once the tests are complete, devices and data will be collected and analyzed. E-Perm® EIC radon monitors will be used for duplicate and confirmatory measurements. If a building requires remedial action, trained individuals will advise the occupants of their options. Additional information on training can be found under 2.2.3 Training.

Project team members will receive training on both radon measurements and the radon detection equipment in order to maintain capabilities during the project period. The radon measurement training will be provided by the National Radon Proficiency Program's (NRPP) approved course provider. After passing the exam, team members will be able to obtain NRPP certification.

Absence of knowledge regarding the extent of radon in PR presents a barrier to success to reduce radon risk, as well as, for Region 2 to fully and informatively distribute radon resources across the Region. A summary of radon measurements in PR was published by USGS (USGS, 1995), but the data collected were not based on

the methodology that EPA employed in a larger, statistically valid study that produced the Radon Zone Maps. The maps are important pieces to guide Region 2 policy as they were developed to assist national, state and local organizations to target their resources and to implement radon-resistant building codes (EPA, 2021). Without knowing where to direct radon policies, PR is unable to protect citizens and visitors from radon. In addition, citizens themselves are not armed with knowledge to protect themselves even if they wanted to. In 2017, PR experienced back to back hurricanes, Irma and Maria, which resulted in severe devastation on the island. As part of the long-term recovery effort, PR is undergoing massive renovation and rebuilding, and as such, has begun to investigate adoption of sustainability practices with new construction and renovations. Having a better understanding of the extent of radon in these newer homes will allow the territory to inform future policy. The PR Department of Health-Environmental Protection Division, in collaboration with EPA, determined radon data and education to be science priorities.

Past radon monitoring of PR conducted by USGS as noted above, has demonstrated the potential for high radon levels. USGS found that several areas of PR have the geologic potential to generate indoor radon levels exceeding 4 picocuries per liter of air (pCi/L), perhaps locally reaching very high levels (>50 pCi/L), if house construction and ventilation allow the soil-gas radon to enter and concentrate within structures. Higher than average indoor radon levels occur primarily in the areas of northern and northwestern PR that are underlain by residual limestone soils. The island of PR is divided into 20 municipalities and with the two additional islands: Vieques and Culebra. Neighborhoods in known or suspected high radon areas as noted in the USGS report (USGS, 1995) will be targeted for testing. The city of Camuy recorded 8% of homes exceeding the 4.0 pCi/L recommended limit (EPA action level), in addition the cities of Ciales 10%, Hatillo 6%, Lares 18%, Morovis 5%, and San Sebastian 15% also tested high percentages of homes exceeding the 4.0 pCi/L limit. The City of Arecibo was added at the request of the Health Department of Puerto Rico. These results include a total of 10% of tests exceeding the action level (11 of 111 tests). Though none of the 13 measurements taken in the USGS study were found above the action level for Arecibo, this additional municipality will be targeted as it surfaced as another area with potentially high radon levels as outlined in the August 1996 report published by the Puerto Rico Department of Health (PR DOH, 1996).

Newer building practices that include tightening homes and relying more on air-conditioning and, increased populations building homes over a wider range of geological structures has ensued. As part of long-term disaster recovery effort to rebuild PR wisely and utilizing the Healthy Buildings (Homes/Public Housing/Schools) Initiative. the territories are primed to build their capacity on radon testing and implementing radon-reducing features into sustainable building practices, if needed.

While EPA maintains that testing is cheap, this statement is general and doesn’t consider the remote areas that don’t enjoy typical access to credentialed radon service

providers or devices that require laboratory testing. Typical devices, such as charcoal canisters and alpha-track detectors don't allow users to see the current radon level and they require shipping on and off the islands. Canisters are particularly time and humidity sensitive, which can fluctuate more in the Caribbean climate. Alpha-track detectors need to be deployed for several months in order to obtain reliable results. Radon professionals can be costly for low-income citizens and are starkly, if at all, available on the islands.

Monitoring radon in neighborhoods will provide citizens with information and inform local and regional policy on the health benefits for radon protection, including, building sustainable radon monitoring capacity at the local level and incorporating radon-reducing features into newly-adopted or pending sustainable building practices in the disaster recovery renovation/rebuild effort. Radon technology has improved considerably over the years, yet charcoal canisters are often the recommended device; this project updates the approach to radon test devices.

1.2 Project Objectives

The primary objective of this project is to safeguard the communities of Puerto Rico from radon risk through education, testing, and remedial action as necessary. The long-term objective is to build capacity on the island if radon is a serious issue. Extensive home interventions (i.e. radon mitigations) are beyond the scope of this project; however, this project includes identifying hot spots where homes, schools, and other public buildings reside for next steps, such as needs for testing, mitigation, and new construction features, and to provide technical assistance to communities and the UPRM Team to build local technical capacity for reducing radon risk.

The Healthy Buildings (Homes/Public Housing/Schools) Long-Term Recovery Initiative has developed strategic partnerships with Universities (UPR-Mayaguez-DHS Coastal Resilience Center of Excellence; Dept.'s of Engineering & Surveyors, Environmental Science), community organizations (Servicios Legales, Heart to Heart, HopeNow, etc), PR Mayors Association, and the territorial agencies. Those partnerships will be leveraged to train and empower community leaders in the identified municipalities in PR.

Innovation Approach: This project involves both citizen science and crowdsourcing and advanced monitoring technologies. The neighborhood focused sampling strategy engages the communities by empowering them to be directly involved in testing for radon in their homes. This project will be creating new opportunities for the utilization of new, citizen-friendly, cost-effective monitoring equipment for remote areas.

2.0 Project Organization and Responsibilities

2.1 Project Personnel

The primary project personnel from EPA are as follows:

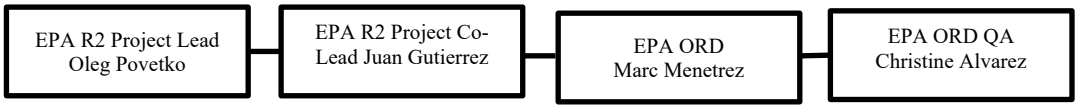


Figure 2-1. Organizational Chart

Table 2-1. Organizational Table

Roles and Main Activities, Project Team/Personnel and Affiliation

Radon Technical Lead/EPA Project Lead, give presentation at UPR, fact sheet, provide training, Contract Alternate WAM	Oleg Povetko	EPA R2
Radon Communications Lead, EPA Project Co-Lead, give presentation at UPR, provide training, community engagement, fact sheet,	Juan Gutierrez	EPA R2
Onsite Facilitator, Onsite Project Logistics, Onsite Quality Assurance/Control	Alex Rivera, John Aponte	EPA R2-CEPD
Radon Spanish Communications Lead, EPA Project Logistics, Onsite Coordinator for UPR Team Activities, Develop Spanish Materials, Radio Communications, HQ-R2 Liaison	Carmen Torrent	EPA HQ
Radon Spanish Communications, HQ-R2 Liaison	Brenda Reyes	EPA R2-CEPD
Science Oversight, Quality Assurance/Control, sampling methodology	Marc Menetrez	EPA ORD
Review/Approve QAPP for EPA ORD QA requirements, provide QA/QC guidance as requested	Christine Alvarez	EPA ORD
Onsite Technical Lead (OTL), attend training, and Communications Team member, pre-post-interventions	Lupita Montoya Contractor	EPA ORD

Radon Technical Advisor, give presentations at UPR, provide training, Technical Team member	David Grammer Contractor	Jacobs
Onsite Technical Lead (OTL), attend training, lead OSL and Student Team, post-interventions	Contractor	UPRM
Onsite Student Lead (OSL), attend training, sampling, post-interventions	Contractor	UPRM
Onsite Student Team, attend training	Contractor	UPRM
Subject Matter Expert (SME), provide training, technical radon consultations and lead field adjustment activities and post-interventions	Contractor	N/A
Technician, fact sheet, field adjustments	Contractor	N/A
Community Lead(s), attend training	Contractor	Varies

2.2 Project Schedule

The project schedule is split into distinct categories which overlap at times. Categories described include:

- Planning (Sept 2020-May 2021),
- Scoping/Outreach (Jan-July 2021),
- Training (June-Aug 2021),
- Kick-off/Sampling (June-July 2021),
- Analysis/Documentation (June 2021-Aug 2022),
- Communications/Reporting (June 2021-Dec 2022)

2.2.1 Planning

Project Planning Meetings—Planning meetings are intended to plan travel dates, ensure and practice consistent messaging that will be communicated in the field and to onsite project leaders and community members.

Community Leader Identification—EPA and other partners (UPR, CEPD), Mayor's Association, etc) will utilize partnerships and relationships to identify leaders and meeting hosts who will aid in shepherding the flow of information and radon test devices within communities in the seven targeted municipalities. Phone meetings will be attended by EPA with leaders and hosts and plans to meet in person will be made. Meetings and project decisions will be documented in Microsoft Word files and stored by date on the Agency SharePoint site and then shared with contractors and project

team via e-mail.

Purchases—95 Corentium Home (CH) Radon Measurement Devices that read in pCi/L have been purchased (Airthings Inc, 2021). The project will use about 90 devices. Purchase additional 360 AAA batteries for the devices. Purchase four EIC E-Perm® ST chambers and 60 electrets. Purchase incentives in the following maximum denominations $1000 for the onsite student leader (OSL) (not to exceed $1,000), 12 of $100 for the Onsite Student Team Members (not to exceed 12 members and $1,200), and $1000 for the Technician (not to exceed $1,000). Purchase travel in terms of lodging, airline tickets, and rental car for 5-7 days for subject matter expert (SME); lodging, and airline tickets for 5-7 days for Technician; lodging for 5-7 days for OTL and OSL. Alternatively, a lump sum can be paid to SME, OTL, OSL and Technician at an agreed upon amount not to exceed project budget. Other purchases shown under 2.2.3 Training.

2.2.2 Scoping/Outreach

Seminar for UPRM Students—EPA to provide a two-hour presentation and informational session for UPRM engineering students and other community members with interest. The purpose is to provide project information and to garner interest from students with the desired outcome of identifying onsite project leadership. EPA has begun identifying two individuals to become certified radon measurement and mitigation professionals who reside on the island and will work on this project. Those individuals are referred to as the OTL and OSL.

Community Scoping—EPA to visit as many communities as possible for further informational and questions and answers sessions with community members prior to radon sampling. The purpose is to identify a subset of communities where sampling can begin first. EPA and Technician to prepare a project-specific fact sheet prior to visits.

2.2.3 Training

Radon Certification Courses—Purchase the courses. OTL and OSL will attend radon measurement and mitigation online courses designed specifically to lead to National Radon Proficiency Program (NRPP) or National Radon Safety Board (NRSB) Radon Measurement and Mitigation certification (Courses: https://radoncourses.com/online, last accessed 2/23/2021).

Radon Mitigation Field Training—Purchase the training. SME will conduct 8-hour radon mitigation field training sessions attended by the OTL and OSL which specifically lead to NRPP or NRSB Radon Mitigation certification (NRPP: https://nrpp.info/certification/how-to-become-certified/, last accessed 2/23/2021), NRSB: www.nrsb.org/, last accessed 2/23/2021).

Radon Certification—Purchase the exams. OTL and OSL will take the measurement

and mitigation exam proctored by a third party: PSI Services Exams: https://candidate.psiexams.com/, last accessed 2/23/2021.

Train-the-Trainer—EPA and SME will provide training to the project team that will include training on data entry methods in sampling methodology, RadResponder (Chainbridge Technologies, 2021) E-Perm® system (Rad Elec Inc., 2021), RAD7 device (Durridge Inc., 2021), interventions, and project-specific topics. RadResponder accumulated large online Resource Library that will be used in training (Chainbridge Technologies, 2021). Copies of User's Manuals for CH and E-Perm® will be provided to the Team Members (copies are available in the Attachments). In addition, EPA will provide training to Project team members on citizen science, crowdsourcing, and the best approaches in engaging communities. The community training sessions attendance, instructors and content will be tracked and documented.

2.2.4 Kick-off/Sampling

Kick-off and Operations Meeting— After the UPRM students have completed coursework and certification, we will schedule a EPA-UPRM-RaData (RaData, 2021) tutorial training secession. The sampling plan is simple. When six to ten homes have been selected in a target area, a UPRM student will arrange an appointment for each home, gather an appropriate number of monitors (always carrying one or two extras, they may have a neighbor that wants their home measured, or a monitor malfunctions), and forms for signature and handout.

Covid-19 protocols issued by local and territorial jurisdictions, UPRM and EPA will be followed at the meeting and during all fieldwork. Personal Protective Equipment (PPE) will be provided for all team members engaged in field activity. The meeting is intended for team members to meet, plan the following days' field activities, check instruments for batteries and operations, and ensure consistent messaging regarding project goals, standards, and sampling methodologies. Team members will be provided radiation and radon measurement training. EPA field work guidelines contained in EPA Guidelines (EPA, 2020) or later revision of the Guidelines will be shared with the Project Team members. Radon monitors, appropriate Personal Protective Equipment and supplies will be assigned and distributed at the meeting.

Then the work finally begins. All radon monitor placement and retrieval will be performed by UPRM or EPA team members. Each house will receive one Monitor which is started and runs for seven days. At least 10 percent of homes will also receive one E-Perm® monitor as a QA confirmation check. One communication package form also is given to the homeowner. After seven days, the student returns, retrieves and disinfects monitors, documents results on information sheet in writing, transmits results to the OTL and uploads results into RadResponder database (Chainbridge Technologies, 2021). At UPRM all database requirements are completed, and the process starts again. If there is an opportunity for a student to pick-up a monitor and

immediately drop it off in another home, to save a trip and save time. We require seven-day minimal integrated samples. Monitors can keep running for a longer period if a pick-up date is not convenient for the student or the homeowner.

Community Informational Meetings—Communities slated for sampling will be provided informational meetings where the Project Team Leads will provide citizen-level radon related information to Community Leads and the public and provide technical assistance for questions from attendees.

Radon Sampling—Sampling will occur in a total of seven municipalities listed in Section 1.1 Background. Project team members (i.e., Data Collectors) will comply with the then current Covid-19 Health and Safety protocols imposed by local, territorial jurisdictions, UPRM and their contracts. In addition to local and territorial protocols, EPA staff will comply with the field work guidelines issued by EPA (EPA, 2020) or their most updated revision. CH and E-Perm® radon measurement devices will be distributed among sampling team members. A radon measurement device will be disinfected and deployed in each home and upon completion of the test period, collected and disinfected by the Data Collector. A data point representing the seven-day average radon level will be recorded in project documents and RadResponder cloud-based database (Chainbridge Technologies, 2021), and then the device will be reset and transferred to the next sampling location. EPA Project Leads will work with Community Leads via the UPRM Team to ensure radon data are collected and home assistance is provided. See Section 4.2 Sampling Equipment and Calibration for more details about the devices.
See Sections 3.0 Scientific Approach and 4.0 Sampling Procedures for further details about sampling.

Quality Assurance Testing—Duplicate or sequential testing with a certified device (such as E-Perm®, Corentium Pro, RAD7) or alternate approved device will occur at a rate of 10% of all homes that demonstrated indoor radon levels of 4 pCi/L or higher. Homes identified for interventions will be tested by the RAD7 or other certified device after the interventions. An alternate approved device may substitute for the RAD7 if necessary; however, all efforts will be made to utilize the RAD7 for follow up sampling. See and Section 3.1 Sampling Design and 6.2 Quality Control Sampling for further QA details.

Data Collection - Monitors will be collected, disinfected and readings recorded by members of the Project Team.

2.2.5 Analysis/Mapping

Data analysis—For purposes of identifying areas of policy implications, clustering of radon levels (hot spots) will be identified by community, municipality, or geographical area, depending on how the results of the data fall out. Mean radon level is the most logical identifier at this point; however, UPRM and Department of Health may find

unique ways to utilize the data points. Individual occupants will be provided verbal information on their own home's radon level and what that means in terms of risk and if further action is needed. Town Mayors will be included to the extent practicable on reporting out of the average radon levels in their jurisdiction.

Mapping— The measured radon value, along with the address and coordinates will be uploaded from sampling location to the RadResponder, cloud-based EPA sponsored radiological database (Chainbridge Technologies, 2021). This information will not be publicly shared. Data Collectors will be able to have access only to the data that they uploaded to RadResponder themselves, not to any other data and maps. Generalized geolocations, with generalized addresses and coordinates, excluding personally identifiable information (PII), will be utilized in conjunction with radon test results to generate a workable geodatabase for radon levels in Puerto Rico. This dataset will be created within ArcGIS and will be used to create a geospatial map of radon levels for the various communities being tested, including a story map. See Section 8.2 Data-Related Deliverables for additional details.

Interventions—The Project Team will perform limited building manipulations and inform adult occupants of next steps needed, such as sealing connections with soil gas, recommending ventilation strategies, and manipulating pressure points in the homes. Post-intervention activities include follow-up radon measurements.

2.2.6 Communications/Reporting

Maintenance Calls—After sampling begins, the Project Team will attend by phone weekly conference calls for Q&A, troubleshooting, updates, and communication with partners and communities. Conference call notes will be documented in Microsoft Word files and stored by date on the Agency SharePoint site and then shared with contractors and project team via e-mail.

Reporting—Final activities reporting, data reports, summaries, charts and maps for post-project communication pieces. Produce final report of results, lessons learned, and scalability to other communities. Produce final report of selected policy options to municipalities based on results of sampling. See Section 8.0 Reporting for further details.

3.0 Scientific Approach

3.1 Sampling Design

Technical description:
Five rounds of seven-day sampling periods per cohort in each municipality is expected, resulting in at least 350 samples. Sampling cohorts are defined as 10 devices deployed at a time in one community such that 10 samples begin on day one and end on day

seven resulting in one round of sampling. As an example, after kick-off, at least three communities receive 10 devices (excluding duplicates for simple illustrative purposes), to commence round one sampling, resulting in 30 samples. The first round is complete after the first seven-day sampling period, and those devices will then be re-deployed for another round of sampling in other community members' homes. Project Team and Community Leaders shepherd the devices from one home to the next and record a final radon reading for analysis. The CH devices read out a seven-day average radon level in pCi/L.

Approach: General instructions, sampling strategy and the health benefits of monitoring radon will be provided to citizens as appropriate via the Community Leads and by the Project Team when practicable, preferably remotely.

RAD7, CH, E-Perm® and other certified devices will be utilized for home indoor radon sampling, as well as undergo QA testing according to project-modified versions of three radon measurement national standards: ANSI/AARST MS-PC 2015 (ANSI/ARST, 2015), ANSI/AARST MS-QA 2019 (ANSI/AARST, 2019), ANSI/AARST MAH 2019 (ANSI/AARST, 2019). and according to this QAPP. The scope of these standards is briefly described below.

- ANSI/AARST MS-PC 2015 (ANSI/ARST, 2015) standard specifies minimum performance criteria and testing procedures for instruments and/or systems designed to quantify the concentration of ^{222}Rn gas in air
- ANSI/AARST MS-QA 2019 (ANSI/AARST, 2019) standard specifies minimum requirements for quality systems designed to quantify the concentration of ^{222}Rn gas in air by qualified professionals and laboratories, whose data are intended to be used to determine the for radon mitigation
- ANSI/AARST MAH 2019 (ANSI/AARST, 2019) standard specifies procedures and minimum requirements when measuring ^{222}Rn gas concentrations in single-family residences for determining if radon mitigation is necessary to protect occupants

A standard operating procedure is under development to describe the approach succinctly for the project team. See 9.0 References for links to view the standards online. The project-specific modification is essentially in how the CH devices are treated in this project for regular experimental sampling and for QA testing. Section 4.0 Sampling Procedures describes the radon home sampling project-specific modifications. Section 4.2 Sampling Equipment and Calibration describes the devices used in this project. Section 6.0 describes of the QA project-specific modifications.

3.2 Process Measurements

The amount of radon in the air is measured in pCi/L. A Curie is a unit of radioactivity that describes the quantity of radium emanation (radon gas) in equilibrium with 1 gram of radium, and the prefix "pico" means a trillionth.

- Radon levels will be measured in pCi/L.
- Test duration will be measured in days (six to nine).
- All other data will be measured in metric units. (e.g. centimeters, Celsius, liters, etc.)

4.0 Sampling Procedures

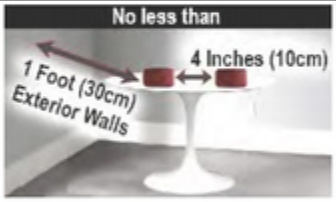
At least one CH radon device will be deployed in each home. Some homes will receive one test, some simultaneous (duplicate) tests and others will receive sequential testing. In addition, if the home is greater than 189 m^2, an additional device will be placed for each additional 189 m^2, and the test result will become part of the average radon result for that home. Monitors will remain in the structure for sample collection at least one week. If the home is being re-tested post-intervention, then a two-day diagnostic test is approved by the manufacturer. See Section 4.2 Sampling Equipment and Calibration for more information about the test devices used.

According to EPA recommendations, homes should be tested according to best practices in the most updated consensus-based standards of practice, ANSI/AARST MAH(ANSI/AARST, 2019). Accordingly, the lowest livable area of the home should be tested. Most homes in PR have no basements, so the lowest livable areas will likely be the first floor. The devices should be placed in a secure position in an area representative of the scenario that will best represent radon exposure including:

- 12 hours of closed home condition before any 44-48-hour testing,
- all windows remain closed on every level of the building during the test, and doors opened only long enough for entry and exit until completion of the test,
- placed in lowest livable area,
- normal entry/exit,
- normal/average use of ventilation,
- placed in normally occupied living space (not closet, kitchen, bathroom or storeroom).
- device should not be exposed to direct sunlight for long periods of time or in humid locations.

Upon completion of the test, residents will be advised of any subsequent testing or risk reduction needs. The monitors will be set up at least 50 cm above the floor, 90 cm away from any doors, windows, or ventilation points, 30 cm from exterior walls, and at least 30 cm below the ceiling. Duplicates (simultaneous testing) should be placed no more than 20 cm apart. Figure 4-1 shows the ANSI/AARST MAH (ANSI/AARST, 2019) advisement for device placement.

Figure 4-1. MAH Test Locations

Table 3.3	Requirements for Test Locations Within a Room	
Detectors shall be located not less than:	3 feet (90 cm) from exterior doors and windows or other potential openings to the outdoors.	
	20 inches (50 cm) above the floor.	
	1 foot (30 cm) from the exterior wall of the building.	
	1 foot (30 cm) below the ceiling.	
	4 inches (10 cm) from other test detectors and objects that are above or to the side of the detector.	
	Exception: Less than 4 inches (10 cm) is permitted for detectors that are not affected by close proximity to other objects. Confirm manufacturer or laboratory requirements or recommendations prior to exercising this exception.	
Side-by-side detectors	Detectors are to be not more than 8 inches (20 cm) from each other whenever seeking to use the average test result of two side-by-side detectors for *mitigation* decisions.	

The adult home occupant will be remotely advised not to move the device, not to tamper with the test, keep all doors and windows closed during the test and keep ventilation pattern normal. They will be supplied with a citizen-level SOP and a phone number to call for questions. In addition, to the extent practicable, Community Leads and UPRM Team can respond remotely to any questions on placing and retrieving devices.

A project modification to the ANSI/AARST standards seeks to ensure quality of measurements by treating the CH devices as if they were devices that perform tests with less precision, such as short-term tests by charcoal canisters, and not as CRMs. The result is that more tests will occur, which helps to ensure accuracy. Therefore, sampling will occur according to ANSI/AARST MAH (ANSI/AARST, 2019), the *Time-Sensitive Testing Protocol* (Figure 4-2) and the *Extending Testing Protocol* (Figure 4-3) for the “short-term test” option depending on the type of test (regular or simultaneous) and depending on the result of the first test (for regular tests).

The two tables shown in Figures 4-2 and 4-3 specify protocols from ANSI/AARST MAH (ANSI/AARST, 2019) when deploying short-term test devices versus CRMs. In this project, for any non-duplicates (non-simultaneous), the CH will be treated as a CRM when the initial test is below the action level, in which case no additional test is called for (Figure 4-2 “continuous monitor”). For simultaneous tests, the CH will be treated as a short-term test device (e.g. charcoal canister), and two devices will be deployed simultaneously (Figure 4-2 “simultaneous testing”). When one CH is deployed, if the first test meets or exceeds the action level, then the test will be immediately followed by another test (Figure 4-3, step 2, retest, second and third lines). This test: one test followed immediately by another test, is considered the “sequential” testing option. The resultant average measurement to be recorded is the average of the two tests when two

tests are performed, otherwise, a single result from the CH will be recorded. Results represent a 7-day average.

Figure 4-2. MAH (ANSI/AARST, 2019)Time-Sensitive Testing Protocol

Table 5.2	Time-Sensitive Testing Protocol (Required Procedure and Summary)	
Step 1 Options	***Simultaneous Testing***	Tests are to be conducted using two short-term test devices at the same time in the same location, 4 to 8 inches (10-20 cm) apart.
	Continuous Monitor	Tests are to be conducted using a monitor that records retrievable hourly measurements.

Figure 4-3. MAH (ANSI/AARST, 2019)Extended Testing Protocol

Table 5.3	Extended Testing Protocol (Required Procedure and Summary)	
Step 1	***Single Short-Term Test***	Testing is conducted using a short-term detector at each test location.
Step 2	***Retest***	locations where the initial short-term tests meet or exceed the *action level*, e.g., 4 pCi/L.
		If the first short-term test is twice the *action level* or greater, a second short-term test is to be conducted without delay. [1]
		If the first short-term test exceeds the *action level* but is less than twice the *action level*, either a second short-term test or a long-term test is to be conducted.

Some home testing will be considered QC testing. At least 10% of tests will be simultaneous tests (duplicates), the rest will follow the sequential test protocol. If after receiving a duplicate or a sequential test, the average level is less than 4 pCi/L (average of the first test plus the second test), no additional test is warranted. However, homes that showed averaged levels at or above 4 pCi/L will be evaluated for retest. If the home already received a duplicate, no retest is necessary; if the home received only one test (this could happen if the immediate retest was not practicable for the home occupant), then a retest will occur with the RAD7 (following the “continuous monitor procedure” in Figure 4-2) or alternate approved device (following the sequential test in Figure 4-3) at a rate of 10%. The result for these QC tested homes will be reported as the 44-48-hour average from the RAD7 or an average of the first and second test with the CH devices if an alternate approved device is used for the second test. In some homes that showed averaged levels at or above 4 pCi/L and have compartmentalized basements, sequential tests will include, to the extent practicable, testing every room on the lowest livable area. See Section 6.2 Quality Control Checks for more information on QA procedures.

If the final test result in a test indicates levels at or above EPA’s action level of 4 pCi/L, a designated project team member will inform the tenant of their options to reduce exposure. Any initial test of 50 pCi/L or above will be followed by a consultation with the adult home occupant and a retest without delay. Once a test is complete, a designated project team member will record the test results. The Community Lead or other designated team member will facilitate the movement of the test device to the next home to begin new testing. See Section 4.1 Site Specific Factors and 4.3 Sample Information for discussion of results recording.

Designated project team member(s) will perform limited temporary interventions for as many homes as practicable that show radon concentrations at or above the action level after testing is completed for each specific home. All homes with interventions will be

tested again, post-intervention, for 44-48 hours with either the RAD7 or 48 hours with an alternate approved device. See Section 3.1 Sampling Design for more information.

4.1 Site-specific Factors

Site-specific factors for sampling include placement of the device, type of home (slab on grade, basement, crawlspace, etc), home-specific pressure field, extent of natural ventilation from outdoors (not from soil pore space), underlying geology, weather, and test duration. Some factors will be known, others observed, some unknown. A form will be developed before testing which includes space to record site-specific factors for each test site and whether the factors are known, measured, assumed, observed, etc. UPRM Team will collect and record the information in Word, RadResponder or another electronic format.

4.2 Sampling Equipment & Calibration

Though the CH devices are not professional devices, the expectation is that the consumer devices will perform within a similar level of quality. The RAD7 meets the AARST-NRPP requirements. Quality assurance guidance is found in the ANSI/AARST standards ANSI/AARST MS-QA (ANSI/AARST, 2019) and ANSI/AARST MS-PC (ANSI/ARST, 2015)). Home radon measurement guidance is found in ANSI/AARST MAH (ANSI/AARST, 2019). In addition, the AARST-NRPP program certifies devices for professional testing but is not fully aligned with ANSI/AARST MS-PC (ANSI/ARST, 2015) device specifications. See Section 9.0 References for a link to access the standards online.

Several types of radon devices are described by the ANSI/AARST MS-PC (ANSI/ARST, 2015). The standard seeks to address needs of measurement professionals, manufacturers, citizens, private proficiency programs, regulators, and anyone concerned with conducting measurements of radon gas. The specifications and practices in the standard can be adopted as requirements for contractual relationships or as recommendations or requirements of a state, country, private proficiency program, or other jurisdiction of authority. The standard describes the Continuous Radon Monitor (CRM), which for all intents and purposes, the CH is most like a CRM than other devices described in the standard in that it continuously monitors radon and can store hourly data. The standard further defines a CRM as follows: *an electronic device that (1) is capable of providing reviewable, numeric measurements of radon concentration averaged over time intervals of 1 hour or less, (2) has a minimum detectable concentration (MDC) of no greater than 148 Bq/m3 (4 pCi/L) for a 1-hour measurement, and (3) has a calibration factor of at least 2 counts per hour per 37 Bq/m3 (0.054 counts per hour [cph] per Bq/m3 or 2 cph per pCi/L)*. To demonstrate meeting all guidance put forth in ANSI/AARST MS-PC (ANSI/ARST, 2015) for a CRM is cost-prohibitive for the 90 consumer devices employed in this project; therefore, five percent of devices will receive enhanced QA (above and beyond what would normally occur with a consumer

device), and all CH devices will receive a comparison check with the enhanced devices prior to deployment. See Section 6.1.2 Precision for details.

4.3 Sample Information

All sample information will be input into a data collection form and must include, but is not limited to, radon level readings, home type/structural design, weather, collection start and end date and time, average geolocation, excluding PII and any other extenuating circumstances that the designated Project Team member has collected by onsite visuals. Average geolocations will be identified with each result ensuring not to collect PII. Residential owner names and addresses will be available to the project team members exclusively, and not to publicly available information releases. The result is an average radon level representing the deployment period. The designated Protect Team member will collect the device, record the readings, upload readings into RadResponder database and transmit results to the Team Leader. The Project Team will collect Site Specific Factors forms to aid in analyzing data. See Section 4.1 Site Specific Factors.

5.0 Analytical Procedures

The Regional RadResponder (Chainbridge Technologies, 2021) Administrator will create new Event in RadResponder. Instrument names along with their serial numbers will be entered into the database and assigned to the Data Collectors. Final radon results as read from devices will be entered into RadResponder by the Project Team's Data Collectors using geolocations.

The RadResponder Network is the national standard and Whole Community solution for the management of radiological data. It is a product of collaboration between Federal Emergency Management Agency (FEMA), Department of Energy (DOE)/National Nuclear Security Administration (NNSA), and the Environmental Protection Agency (EPA), and is provided free of charge to all Federal, state, local, tribal, and territorial response organizations. RadResponder's flexible architecture enables organizations to rapidly and securely record, share, and aggregate large quantities of data while managing their equipment, personnel, interagency partnerships, and multijurisdictional event space. RadResponder can be accessed on smartphones, tablets, and via the web, allowing it to be seamlessly and rapidly employed at all levels of government during a response to a radiological or nuclear emergency or collection of radiological data. Currently a special platform is being developed for indoor radon; however, until such time, the existing platform allows radon entries. Additional information is available on https://www.radresponder.net/ (as accessed on 9/25/2020).

Region 2 RadResponder Administrator and Equipment Coordinator will receive, consider, approve/disapprove Data Collectors' RadResponder account applications, enter qualified equipment models, serial numbers, assign monitors, provide training, monitor data collection and validate or reject uploaded data. All data entries will be verified at 100% with photos and forms by the Administrator and Coordinator.

Each Data Collector will create an account in RadResponder's EPA Region 2 organization. Each Collector will be assigned several radon monitors, the monitor models and serial numbers will be recorded in RadResponder. For data collection, the corresponding event will be created in RadResponder. Data Collectors will install RadResponder app on their mobile devices and/or computers, they will be trained in uploading the data that would include monitor readings, locations, photos, comments and site-specific factors described in Section 4.1. During sampling, Data Collectors will upload collected data into the database directly on-site or, if there is no cellular connection, collected data is automatically saved in the apps. The data will be automatically uploaded once the cellular connection is restored. Alternatively, the data will be uploaded using computer app.

In RadResponder database, only designated EPA persons, such as Regional RadResponder Administrator and Equipment Coordinator, has access to the collected data and only in the specific authorized Regional Events. Individual Data Collectors have authorizations to access only those data that they collected and uploaded personally. Non-authorized personnel and public do not have access to the data in RadResponder. Instruments, serial numbers, maintenance records, specific instrument and task assignments are integral parts of the RadResponder.

5.1 Measurement Methods

Radon measurement will take place according to ANSI/AARST MAH (ANSI/AARST, 2019) and device manufacturer's recommendations for the CH and RAD7 devices except as noted for research modifications in Section 4.0 Sampling Procedures. The consumer device will be left to test radon levels for no less than one week. The professional device (RAD7) provides an accurate measurement within 44-48 hours. The instruments will be placed in areas of the home/building according to Figure 4-1 ANSI/AARST MAH (ANSI/AARST, 2019)Test Locations: at least 50 cm above the floor, 90 cm away from any doors, windows, or ventilation points, 30 cm from exterior walls, and 30 cm below the ceiling. Duplicates (simultaneous testing) will be placed no more than 20 cm apart. Sequential tests will be placed in the same location as the first test. Once placed, the device should not be moved for the duration of the test.

The adult home occupant will be given remotely citizen-level training on radon testing, along with literature in Spanish or English (as needed) which provides additional information at the citizen level for testing and personal safeguarding from radon exposure. The designated Project Team members (i.e., Data Collectors) will collect and disinfect the device, collect and record other site-specific information. Additional project-specific documents (i.e. project-specific sampling SOP, site specific factors and data form) are under development and will be added to a revised QAPP as necessary. Appendix A contains a draft data collection form.

According to previously collected data from USGS described in Section 1.1 Background, approximately 10% of homes in this project's targeted areas were found above the action level, while EPA estimates that approximately six percent of homes in the US have radon levels above the action level (EPA, 2016). The USGS study (USGS, 1995) provided a baseline for understanding the potential of radon risk in PR, but it included far fewer test results than EPA's national study. However, the National Study excluded PR. Thus, it remains a reasonable assumption that the range of test results could fall within 6-10% of tests with levels above 4 pCi/L. Therefore, at least 10% of tests will receive a combination of QC sampling in the form of retests and duplicates. Additional quality assurance is discussed in Section 6.2 Quality Control Checks.

6.0 Quality Assurance and Quality Control (QA/QC)

6.1 Data Quality Indicator (DQI) Goals

Table 6-1 lists the DQI Goals for the critical measurements.

Table 6-1. DQI Goals

Measurement Parameter	Analysis Method	Assessment	Accuracy	Precision
QA Testing in Lab	Device Performance Test (RAD7, Corentium Pro); Approved Alternate Device Performance	Accuracy	25% IRE	
QA Testing in Lab	Device Evaluation Test	Precision (5% CH)		25% RSD
Comparison Test	MS-PC Modified Intercomparison	Remaining 95% CH	25% IPE	15%/25% COV
Field Duplicates and Sequential Tests	MS-QA, MAH	10% of all tests (duplicates), all sequential		25% RPD
Retest	MS-QA, MAH	10% at or above 4 pCi/L, sequential tests not meeting 25% RPD for levels above 2 pCi/L		25% RPD

6.1.1 Accuracy

Accuracy of measurement parameters is determined by comparing a measured value to a known standard. The accuracy statistic is the Individual Relative Error (IRE), which represents the degree from which a single measured value deviates from the conventionally true value. The IRE is calculated using the following equation and accuracy description from the AARST-NRPP DPT protocol in Figure 6-1. To assess accuracy, the RAD7 and 5% of the CH devices (approved alternate devices) will be sent to the laboratory under the AARST-NRPP Device Performance Testing (DPT) protocol. Measurements are expected to fall within the tolerances shown in Table 6-1.

Device Performance Testing is unique in that the analytical service provider is being graded on their ability to produce accurate and reliable radon test results. Although there is knowledge that the tests are taking place, there is no prior knowledge of the radon chamber environment. The results of the performance tests are going to be related to the quality of the calibration and maintenance services, but more importantly, the DPT indicates whether the user knows his/her equipment well enough to produce an accurate assessment of the radon chamber conditions. DPT requires that radon measurement devices be exposed to a known amount of radon gas in a NRPP-approved radon chamber facility. The chamber returns the devices to the company performing the analysis services. The device(s) are analyzed to determine the radon concentrations during their exposure in the radon chamber. The results are then submitted to the chamber that grades the analytical results against the chamber values. Each device must measure within 25% of the chamber value for a passing test result.

If the RAD7 or Corentium Pro fail the DPT, the devices will be inspected and repaired as needed and reevaluated. Because the CH are consumer devices and not expected to adhere to the same device standards as professional devices, any failures or deviations from the criteria in Table 6.1 will be noted and used for data reporting purposes.

Figure 6-1. AARST-NRPP DPT Error Criterion

The radon measurement devices must demonstrate their capability to produce results that have an individual relative error of less than or equal to 25.0% in radon or decay product concentrations that are near the U.S. EPA action level. The total error criterion is consistent with the Individual Relative Error statistic used to evaluate proficiency in AARST-NRPP™ performance tests conducted by individuals desiring certification with the device. The statistic is calculated as follows:

IRE = abs val(MV-RV)/RV * 100%

where:

IRE = the absolute value of the individual relative error for the measurement result, in percent
abs val = the absolute value of the following expression
MV = the measured value, as reported by the participant's system
RV = the reference value, as measured by the chamber facility

The measurement results provided by manufacturers must meet this criterion. This criterion is also used for the results of the U.S EPA exposures for the DEP tests. Note that this criterion is applied to individual measurement results.

The devices for this project will be sent to the KSU (KSU, 2021) Radon Chamber for DPT or spiking. The procedure is spelled out here:

- All devices will be exposed for number of hours indicated in the request (RAD7: two days, CH: seven days).
- For devices requiring a 48-hour to seven-day exposure, a minimum constant radon concentration of 4 pCi/L or higher will be used.
- The radon will be kept at a constant value (within 10% COV) during the exposure. The radon concentration will be verified at the beginning of exposure and at the end of exposure (and every 72 hours during exposure) by a pair of grab samples read with an EPA inter-compared measuring system
- The chamber temperature will be held to a constant 72 degrees (+/- one degree) and the humidity will be held between 20 % and 50% RH.
- At the end of the exposure period, the device(s) will be shipped back to you for your analysis and reading using the shipping method you pre-paid and supplied.
- The final report includes the temperature, barometric pressure and average humidity information appropriate to your exposure period.

6.1.2 Precision

Precision is evaluated by making replicate measurements of the same parameter and assessing the variation of the results. Precision is assessed in terms of relative standard deviation (RSD) for device evaluation testing and comparison testing of the CH devices, while relative percent difference (RPD) is used for duplicates and sequential tests in this project. RPD is described in Section 6.2 Quality Control Checks. Measurements are expected to fall within the tolerances shown in 6.1.

RSD for Device Evaluation Testing—The six CH devices (approved alternate devices) will be tested in the KSU laboratory by radon spiking. Results of spiking will be evaluated for precision by RSD in a Device Evaluation Test, which is described in Figure 6-2a. Sample standard deviation "s" for the RSD calculation is shown in Figure 6-2b. where "s" equals the sample standard deviation, "x1…x2…xN" are observed values of the sample items, "x-bar" is the mean value of observations and "N" is the number of observations in the sample. The expected RSD is 5% according to ANSI/AARST MS-PC (ANSI/ARST, 2015), but the adopted criterion is 25% according to AARST-NRPP Device Evaluation Testing Protocol. While the devices are not evaluated on this statistic for the DPT, the results will be recorded and considered when evaluating sample data.

Figure 6-2a AARST-NRPP Device Evaluation Error Criterion

The radon measurement systems must demonstrate their capability to produce results that have a precision error less than or equal to 25.0%, as measured using a relative standard deviation of at least four simultaneous measurements in a radon or radon decay product concentration that is near the action level. The statistic of relative standard deviation is calculated as follows:

RSD = (s/avg) * 100%

where:

RSD	=	relative standard deviation
s	=	the sample standard deviation of a set of n simultaneous measurements in the same environment
avg	=	the mean of the n measurements

The precision criterion is designed to assess the capability of the measurement system to produce multiple, consistent results. It is applied to both the data supplied by the manufacturer as well as to the results of sets of measurements made in the U.S. EPA chamber for the DEP test.

Figure 6-2b Sample Standard Deviation

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

RSD for Comparison Testing—The remaining 95% of CH devices that were not evaluated by DPT will undergo a modified comparison check prior to deployment utilizing the requirements in ANSI/AARST MS-PC (ANSI/ARST, 2015) as a guide. The devices will then be compared against the 5% of devices that were analyzed in a DPT. The devices will be placed in a home, along with the reference device (approved alternate device), and each device readout will be mathematically compared against the reference. ANSI/AARST MS-PC (ANSI/ARST, 2015) notes the guidance of COV of less than or equal to 15%; and that individual devices must demonstrate an individual percent error (IPE) within ±25% at 6-15 pCi/L. Currently, the NRPP certification program has not adopted the most stringent standards put forth in ANSI/AARST MS-PC (ANSI/ARST, 2015), so devices sent for certification are required to meet 25% RSD (COV) and IRE (IPE).

The modified-comparison test will proceed as follows:

- Five groups of 20 devices will be deployed in residential environments for seven-day tests.
- Each group will contain one device that underwent professional testing (approved alternative device).
- The 20 devices will be deployed in homes according to Section 5.1.
- RSD of 19 devices will be compared to known value as read from the CH approved alternate device.

The RSD of the 19 devices will ideally meet the same as professional devices according to ANSI/AARST MS-PC (ANSI/ARST, 2015) of less than or equal to 15% and IPE within ±25% at 6-15 pCi/L. However, this level of radon is unlikely to be found in many residences; therefore, defaulting to a wider range to meet a COV of 25% is reasonable for levels greater than 2 pCi/L. If the average of the two measurements is less than 2 pCi/L, the device qualification criterion is met if the absolute value of the difference between the two results is less than 1.0 pCi/L (ANSI/AARST MS-QA (ANSI/AARST, 2019)). As data are collected, a better determination of limits will be evaluated if meters fall outside expected limits.

6.2 Quality Control Checks

Duplicates—Upon deployment, 10% of the home measurements will be duplicated. Approximately 10% of homes are expected to reach this threshold based on the USGS

report (USGS, 1995). For this project, 350 samples are expected to be collected, so at least 36 will have received duplicates.

Duplicates will be performed according to ANSI/AARST MAH (ANSI/AARST, 2019) (Figure 4-2) and as described under ANSI/AARST MS-QA (ANSI/AARST, 2019), Section 5.4 Field Operations (2019) as shown in Figure 6-3a. The requirement to send duplicates to the laboratory is moot since the devices read out electronically. The test statistic for duplicates is the Relative Percent Difference (RPD), which represents imprecision as a percentile of the best-known concentration estimate. Note that the RPD is always positive, as the smaller measurement result is subtracted from the larger measurement result. The average of the two detectors is used in the denominator because the best estimate of the true concentration is the average of the results; the RPD therefore represents the imprecision as a percentage of the best true concentration estimate. The RPD is calculated as follows:

$$RPD = [(A - B) / mean] * 100 \quad (6)$$

where A = the larger result,
B = the smaller result, and
mean = the average of the two results.

EPA will oversee the control charts and validate 100% of duplicate statistics.

Figure 6-3a. MS-QA (ANSI/AARST, 2019) Field Operations Duplicates Procedure

5.4 Field Operations (EIC, ATD, CAD)—Required Duplicates

Informative advisory—Deploying field *duplicates* provides evidence that field transport and handling procedures do not introduce unacceptable errors into the measurement system. These QC checks are very important because they can indicate changes in the system, differences between field operatives' procedures or other contributors to imprecision that occurred during field operations.

5.4.1 *Field Operation Duplicates—Frequency and Procedures*

Field operation *duplicates* are to be deployed in approximately one in 10 measurements, or 10% the time. Large projects involving more than 20 measurements are to include some *duplicates*.

Conducting *duplicates* is to include exposing identical, *collocated* devices (see Definitions) simultaneously for at least 48 hours, submitting them for analysis without identification as *duplicates* (*blind*) and then comparing the two results. The results of each *duplicate* pair are to be recorded and plotted on control charts for evaluation.

Field operation *duplicates* are to be distributed among different environments, operators and projects so that the *duplicate* data reflects the range of environments tested. *Duplicates* are to be deployed in environments greater than 4 pCi/L (150 Bq/m^3), when feasible, because the results from higher concentrations will provide more information for assessing and tracking precision error.

Warning and control limits for duplicates and comparison checks are shown in Figure 6-3b. If any duplicate pair result exceeds these criteria operations will be reviewed for potential field effects (e.g. low battery, damaged device, incorrect placement). If more than 5% of QC checks fall outside warning limits or more than 1% fall outside control limits, an investigation should result in either corrective action or, when applying more stringent limits, regeneration of the limits that reflect actual in-control operations. Duplicates outside the warning limits result in retesting the home with a RAD7 or alternate approved device according to ANSI/AARST MAH (ANSI/AARST, 2019).

Figure 6-3b. MS-QA (ANSI/AARST, 2019) Warning and Control Limits

Average of the two devices	*Warning Limit RPD*	*Control Limit RPD*
≥ 4.0 pCi/L (≥ 150 Bq/m^3)	28.0%	36.0%
< 4.0 and ≥ 2.0 pCi/L (< 148 and ≥ 75 Bq/m^3)	50.0%	67.0%
< 2.0 pCi/L (< 75 Bq/m^3)	n/a	Absolute value of the difference between the devices ≤ 1.0 pCi/L (37 Bq/m^3) or both are reported as less than the MDC

Retesting—Quality control checks will include evaluating homes to be retested, and if more than 10% meet the criteria for retesting, then at least 10% of home tests will be retested. Homes will be evaluated in the following order for the need to be retested:

1. homes that had completed sequential tests above 4 pCi/L with an RPD that exceeds 25%,
2. homes that had initial tests under the sequential test option, but no additional test to complete the sequential test, and the initial test was greater than or equal to the action level,
3. homes that had final tests (sequential or duplicates) showing at or above the action level of 4 pCi/L

Homes will be evaluated by the following evaluation criteria and tested as follows:

- For homes that had completed sequential tests above 4 pCi/L with an RPD that exceeds 25%, retest 10% of those homes. Retest will occur with the RAD7 (following the “continuous monitor procedure” in Figure 4-1) or alternate approved device (following the sequential test in Figure 4-2).
- If less than 10% of homes need to be retested due to not having met the RPD criterion, then for homes that had initial tests under the sequential test option, but no additional test to complete the sequential test, and the initial test was greater

than or equal to the action level, then the home will be retested. Retest may occur with the same initial CH device used if the test is started within two days of the ending of the initial test, otherwise, the RAD7 or alternate approved device will be used.

- If less than 10% of homes need to be retested due to previous criteria, then for homes that had final tests (sequential or duplicates) showing at or above the action level of 4 pCi/L, the home will be retested. Exception: if a home that was found with radon levels at or above the action level was already tested under the simultaneous (duplicate) option, then additional testing is unnecessary and that test will be considered as a contribution to meeting the 10% retest QC requirement.

Test results from retesting will be reported as QC tests and used to qualitatively evaluate data from those homes. The table in Figure 6-3b will guide the evaluation, and for any tests that appear to have disagreeable results compared to the control limits, then the final home result may be left out of final analysis. Sequential QC retests outside the warning limits at the rate described by ANSI/AARST MS-QA (ANSI/AARST, 2019) result in retesting the home with a RAD7 or alternate approved device according to ANSI/AARST MAH (ANSI/AARST, 2019).

If more than 10% of homes are found above the 4 pCi/L threshold, all efforts will be made to provide a QC retest for all homes above 4 pCi/L. In the situation that more than 10% of homes are found above the action level, this signifies a deeper radon issue in Puerto Rico, and EPA will convene with the PR Department of Health and selected members of the Healthy Buildings Long-term Recovery initiative for a path forward beyond the scope of this project.

7.0 Data Analysis, Interpretation, and Management

7.1 Reduction

Radon readings from the home devices will be recorded after the initial seven-day test period. For homes that show readings above 4pci/L, the reading generated from the 44-48-hour RAD7 or Corentium Pro test will supersede that of the home device. All RAD7 and Corentium Pro test results (even those associated with random QA) will replace results generated by the home devices. These test results will be compiled into a GIS dataset to be used in the creation of a project-specific radon map. All data collected, regardless of its inclusion in the reduction process, will be kept for reporting purposes.

7.2 Validation

All recorded data will be validated by trained personnel to ensure that the data were collected and logged appropriately. Validation will consist of Student Leads looking at all data collection forms to ensure completeness and by interview of adult home occupants

to evaluate if the test parameters were maintained during the duration of the test (e.g. devices did not lose power, were not moved, and were not in any other way disturbed during the test period). In addition, test forms and accompanying photos will be verified 100% for accuracy after being entered into the data spreadsheet containing all radon points. Data in RadResponder will be verified 100% for accuracy from data forms to a printout of the RadResponder entries. In addition, the internally stored data from the RAD7 and Corentium Pro will be verified against the inputted data on the data spreadsheet for 100% of the readings above 10 pCi/L. QC test needs and deployment will be monitored by EPA Team with calculations verified at 100%.

7.3 Data Storage Requirements

Data will be stored both electronically and physically. All data will be archived appropriately for future reference. The home-occupant will be given the Citizen's Guide to Radon in English (EPA, 2016) and Spanish (EPA, 2017). Project Team will collect site-specific information on a data collection form (see Appendix A). The form will document the location by general area, time period of measurement, result of measurement, and contact person. In addition, electronic records will be entered in RadResponder by trained Project Team. Appendix B contains a Spanish version of Appendix A and radon background information for homeowners and interested parties.

8.0 Data Reporting

8.1 Reporting Requirements

Reporting requirements for this project include:

- Duration of test (days)
- Radon reading: CH seven-day average reading from the home device. If two devices are placed (duplicates and simultaneous), both results will be reported on forms and data spreadsheet; however, the average of the two readings will serve as the final radon result. If RAD7 or Corentium Pro is used for a home test, the test is 44-48 hours and the test results from the RAD7 or Corentium Pro will supersede CH readings.
- Device Type: CH or RAD7 or Corentium Pro serial number
- Device location within the home (floor/room/position)
- Weather conditions
- Remedial action needed, if any
- Test type (initial: duplicate or sequential, post-intervention)

8.2 Data-Related Deliverables

Data-related deliverables include the following: final activities reporting, data reports, summaries, charts and maps for post-project communication pieces, as well as a final

report of results, lessons learned, and scalability to other communities, and a report of selected policy options to municipalities based on results of sampling:

- Radon level report: This is a preliminary report that will explain a home's radon readings to the occupant. It will include radon levels from either the seven-day average from the home device, or the test results from the RAD7 or Corentium Pro as applicable. Test results will be explained, and remedial action options will be outlined as necessary.
- Post-intervention action assessment: Post-intervention action assessment will discuss the retest of the homes that were recommended to take remedial action. The assessment will show the results of the second test and highlight the overall success of the suggested intervention.
- GIS-based map: The documentation of location, time period of measurement and radon concentration will be recorded in electronic form using RadResponder (Chainbridge Technologies, 2021) by the Project Team. Generalized geolocations, excluding PII, will be utilized in conjunction with radon test results to generate a workable geodatabase for radon levels in seven municipalities of Puerto Rico. RadResponder will export maps in formats compatible with the ArcGIS. This information will be used to create a geospatial map of radon levels for the various communities being tested. An ArcGIS story map will be developed. Story maps use GIS tools to combine geospatial data with photos, video, audio, and text to visualize a theme or sequential events. Story maps are designed for nontechnical audiences; users do not need experience with GIS software to read or use story maps. Maps will be disseminated to appropriate stakeholders and will also be incorporated into the final report of the project assessment. The purpose is to visually represent radon levels in various neighborhoods throughout the communities of Puerto Rico so that stakeholders can have a better understanding of the potential radon risk in their areas.
- RadResponder Database – Cloud-based, official EPA radiological data database. Instrument database. Instrument assignments to Data Collectors (students), radon sampling results with corresponding coordinates, residential addresses, names, photos, comments, observations, maps (non-public access)
- Measurement Requests Database – information listing home address, contact person, phone, status (pending, in-progress, complete, follow-up). Each municipality is listed separately (non-public access)
- Measurement Instrument Log – Instrument measurement performance must be logged, each dual measurement identified and agreement tracked (PC backup to RadResponder), measurements implemented in

professional Radon Report Manager database software Version 3.7.0, already installed and currently in use for E-Perm functionality checks (non-public access).

Table 8-1 lists the data-related deliverables, format of each deliverable, and personnel responsible.

Table 8-1. Data-Related Deliverables

Deliverable	Custodian	Person Delivered to	Format
Radon Levels Report	EPA Team, UPRM Team	UPR-School of Public Health, PR Dept. of Health; Healthy Buildings workgroup; Joint Disaster Recovery Group	Word Document, Personal Communications, and Web
Post-intervention Action Assessment	EPA Team, UPRM Team	UPR-School of Public Health, PR Dept. of Health; Healthy Buildings workgroup; Joint Disaster Recovery Group	Word Document, Personal Communications,
GIS-based Map and Story Map	Technician	EPA, Healthy Buildings Long-term Recovery Work Group	GIS Map and Word Document

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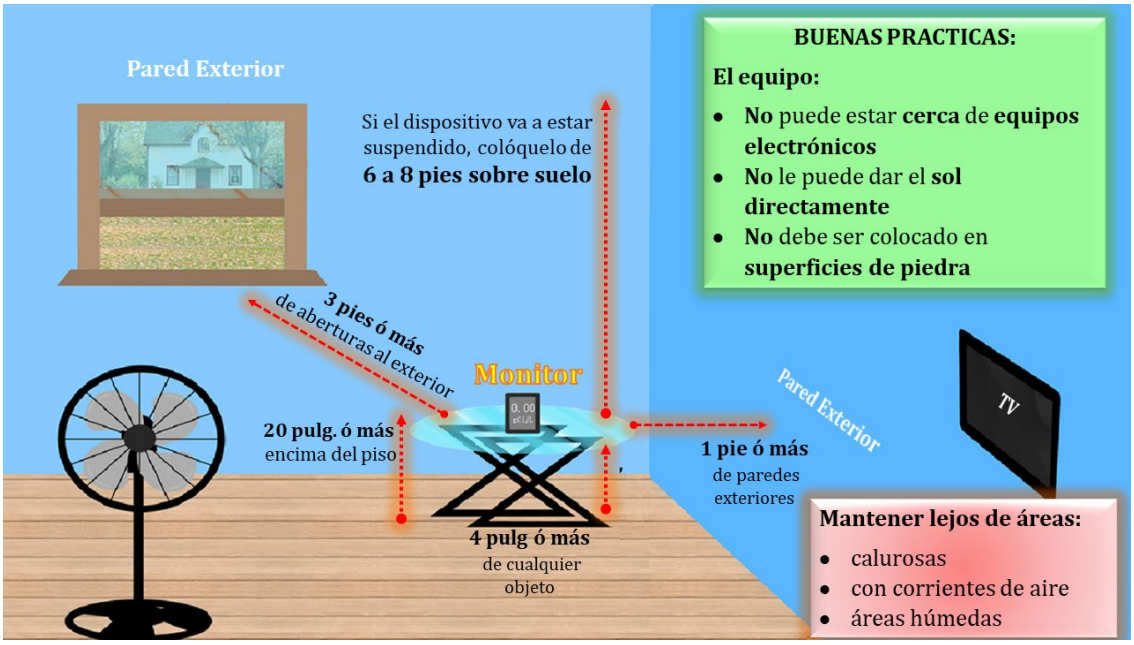
Appendix A

Instructions for Testing Residence for Radon Using "Corentium Home" Radon Monitor

Radon is colorless, odorless radioactive gas that comes from the natural decay of uranium that is found in nearly all soils. It typically moves up through the ground to the air above and into your home through cracks and openings in the foundation. For more information about radon, visit www.epa.gov/radon. You can't see radon, but you can find out the level of radon in your home. Please follow the instructions below.

1. You will be using Corentium Home monitor, manufactured by AIRTHINGS, Inc. (https://www.airthings.com/home). Familiarize yourself with the monitor using attached monitor's User Manual and online description.
2. Disinfect the monitor before and after each test by lightly wiping it off with the paper napkin moistened by provided disinfectant. Do not spray any liquid on the monitor. Do not apply an excessive amount of moisture on the monitor.
3. Look at the screen, it should display various sets of letters and numbers.
    a. If the screen is blank or flashing, check that the batteries are installed correctly.
    b. If the low battery level indicator icon appears in the upper left corner change batteries as soon as possible.
4. Find a proper Test Location:
    a. Choose a lowest livable room such as the living room, office or bedroom where no cooking, showering, excessive ventilation, open windows, or laundering takes place.
    b. Choose a place to set down the monitor that is inaccessible to small children.
    Place the monitor about waist high, more than three feet from any doors to the outside, windows, or ventilation points, and more than one foot from exterior walls. Place monitor at least four inches from other objects and, if possible, away from the house wall that is heated by sun during the day. Follow the picture below for placement instructions.

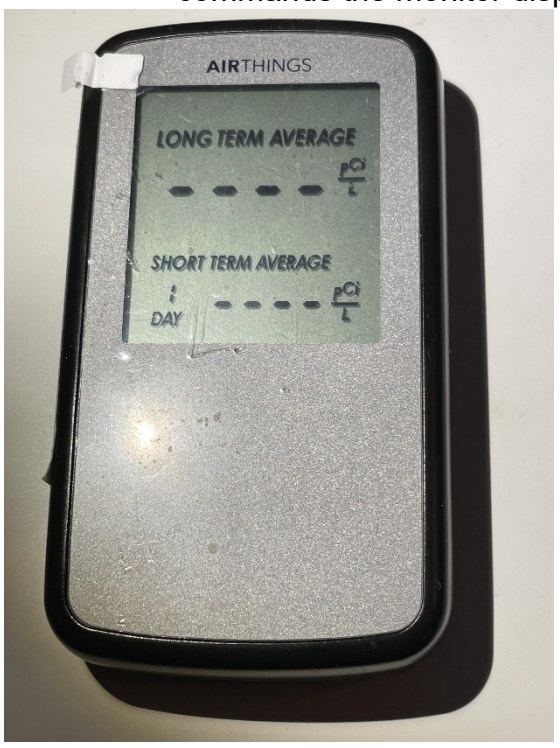


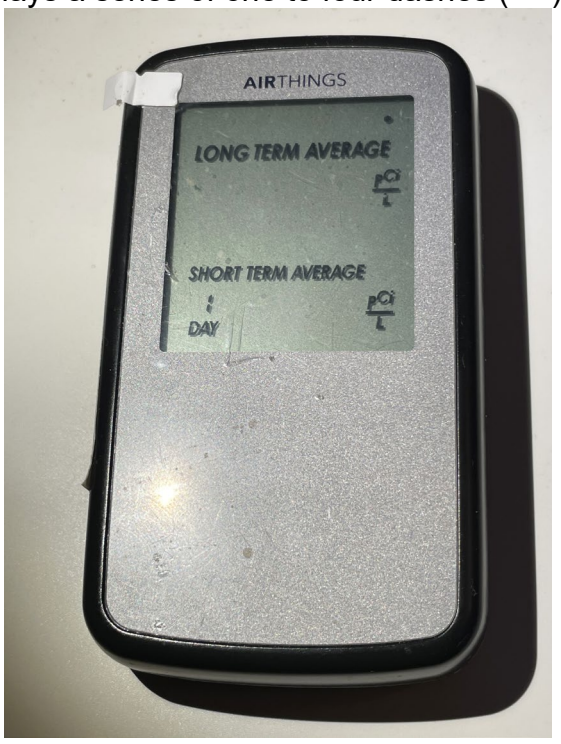
5. Reset the monitor to begin a new measurement cycle:

Screen appearance after initial reset

a. With the end of a paper clip or pen, reset the radon monitor by placing the end of the paper clip in the reset button in the back of the monitor, lightly press & release.

b. Ensure that after series of internal commands the monitor displays a series of one to four dashes (----) as



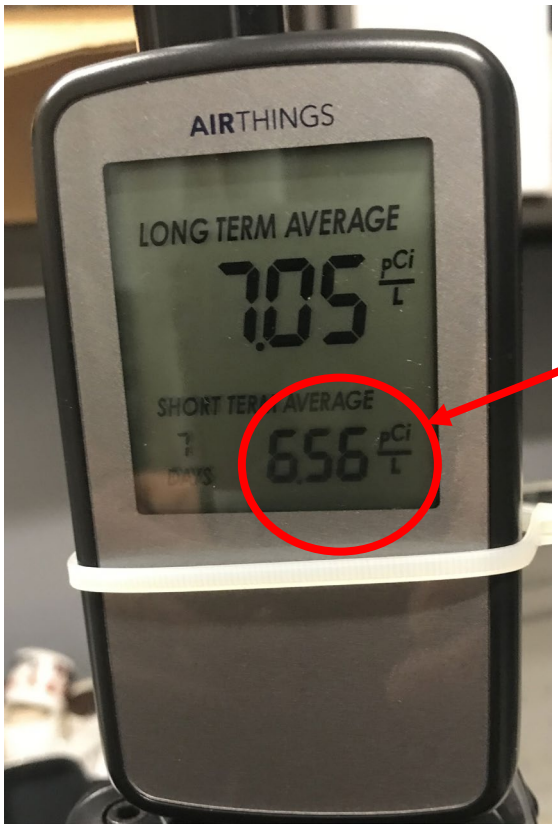


in the figure on the left. The indicator on top right of the screen flashes when instrument is active as in the figure on the right. These two screens would alternate after reset. If not, reset again.

c. Set down the device, screen up, and leave it in place for seven days.
d. Monitor will collect data for some time and will begin displaying some readings after 6-24 hours depending on the level of radon in home.
e. Some homes will receive two monitors; set them side-by-side but at least 4 inches apart and begin the tests at about the same time.

6. Record Information:
   a. Fill in address, phone, test location, and start date and time below.
   b. Take photo of the monitor in place.
   c. After seven days, write the end date and time, and the final test result, which is displayed in small numbers on the bottom of the screen. Note that the readings on the bottom alternate every second between "1-DAY" and "7-DAYS" measurements. Record "7-DAYS" reading. See location of the required reading in the figure below. Do not record large numbers at the top of the screen.

Screen appearance after seven days have passed after reset



This "7-DAYS" reading needs to be recorded

d. Enter any comments (e.g. rainstorm for two days, window open on day five, exposure to direct sunlight, monitor was dropped, exposed to water etc.)
e. If “7-DAYS” reading is not displayed after seven days, and only “1-DAY” is displayed, wait for two more days and check the screen again. Monitor may reset itself during test. Monitor may reset itself if dropped. If that happens, wait for seven more days again after reset. If “7-DAYS” reading is still not displayed, contact UPRM.

7. Send Photo of Final Test Result, and the Form below:
    a. Take a photo of the screen face after seven days of testing. Note that the readings on the bottom alternate every second between “1-DAY” and “7-DAYS” values. Make sure “7-DAYS” is displayed on the left bottom corner of the screen.
    b. After recording all information on this form, take a photo.
    c. Send the two photos to the UPRM contact.
    d. Send the UPRM contact any questions/concerns you have about your radon test.
8. Upload results, photos and observations into RadResponder database.

Address:_____
Name &
Phone:_____

Test Location:

_____

Start Date and Time:

_____

End Date and Time:

_____

Test Result (pCi/L): _____

COMMENTS:_____

SEND PHOTO OF DEVICE’S FINAL READING AND A PHOTO OF THIS FORM

Appendix B

Instrucciones para hacer la prueba de radón en su hogar usando el monitor "Corentium Home"

El radón es un gas radiactivo sin color ni olor que proviene de la descomposición natural del uranio que se encuentra en casi todos los suelos. Por lo general, este gas fluye a través del suelo al aire y entra a su hogar a través de las grietas y aberturas en los cimientos. Para obtener más información sobre el radón, visite la página web https://espanol.epa.gov/cai/acerca-del-radon o en inglés www.epa.gov/radon. Usted no se puede ver el radón, pero sí puede determinar cuál es el nivel de radón en su hogar. Por favor, siga las siguientes instrucciones.

1. Usted utilizará el monitor "Corentium Home" fabricado por AIRTHINGS, Inc. (https://www.airthings.com/home). Familiarícese con el monitor utilizando el manual de usuario del monitor adjunto y la descripción en línea.
2. Desinfecte el monitor antes y después de cada prueba limpiándolo con la servilleta de papel humedecida con el desinfectante provisto. No rocíe ningún líquido sobre el monitor. No humedezca excesivamente el monitor
3. Mire la pantalla, la misma debe mostrar various conjuntos de números.
    a. Si la pantalla está en blanco o parpadea, verifique que las baterías estén instaladas correctamente.
    b. Si el indicador de batería aparece en la esquina superior izquierda, cambie las baterías lo antes posible.
4. Encuentre una ubicación adecuado para la prueba.
    a. Elija una habitación como la sala o el dormitorio, donde no se cocine, se duche, no haya ventilación excesiva, ventanas abiertas o donde se lave ropa.
    b. Elija un lugar para colocar el monitor que sea inaccesible para los niños pequeños.
    c. Coloque el monitor a la altura de la cintura, a más de 3 pies de cualquier puerta que abra hacia el exterior, ventanas o puntos de ventilación, y a más de 1 pie de las paredes exteriores. Coloque el monitor al menos a 4 pulgadas de otros objetos y, si es posible, lejos de la pared de la casa que se calienta con el sol durante el día. Siga la imagen a continuación para ver instrucciones de ubicación.
5. Reinicie el monitor para comenzar un nuevo ciclo de medición.
    a. Con la punta de un clip o bolígrafo, reinicie el monitor de radón colocando la punta del clip en el botón de reinicio en la parte posterior del monitor, presione y suelte ligeramente.
    b. Asegúrese de que después de una serie de comandos internos, el monitor muestre una serie de hasta 4 guiones (----) como en la figura de la izquierda. El indicador en la parte superior derecha de la pantalla

parpadea cuando el instrumento está activo como en la figura de la derecha. Estas dos pantallas se alterarían después del reinicio. Si no es así, reinicie nuevamente.

c. Coloque el monitor con la pantalla hacia arriba y déjelo en el lugar durante 7 días.
d. El monitor recopilará datos durante algún tiempo y comenzará a mostrar algunas lecturas después de 6 a 24 horas, según el nivel de radón en el hogar.
e. Algunos hogares recibirán dos monitores por razones comparativas o para confirmar la medición. Colóquelos uno al lado del otro pero al menos a 4 pulgadas de distancia y comience las pruebas aproximadamente al mismo tiempo.

6. Registre la Información:
   a. Escriba la dirección, el teléfono, la ubicación de la prueba y la fecha y hora de inicio a continuación.
   b. Tome una foto del monitor ya en su lugar.
   c. Después de 7 días, escriba la fecha y hora de finalización y el resultado final de la prueba, que se muestra en pequeños números en la parte inferior de la pantalla. Tenga en cuenta que las lecturas en la parte inferior alternan cada segundo entre las mediciones de"1 día" y "7 días". Registre la lectura de "7 días". Vea la ubicación de la lectura requerida en la figura siguiente. No registre números granes en la parte superior de la pantalla.
   d. Ingrese cualquier comentario (por ejemplo, tormenta de lluvia durante dos días, ventana abierta el quinto día, exposición a la luz solar directa, el monitor se cayó, se expuso al agua, etc.)
   e. Si la lectura de "7 días" no se muestra después de los 7 días, y solo se muestra "1 día", espere 2 días más y revise la pantalla nuevamente. El monitor puede reiniciarse si se cae. Si eso sucede, espere 7 días más nuevamente después del reinicio. Si aún no se muestra la lectura de "7 días", comuníquese con UPRM.
7. Envíe una foto del resultado final de la prueba y el siguiente formulario:
   a. Tome una foto del frente de la pantalla después de 7 días de prueba. Tenga en cuenta que las lecturas en la parte inferior alternan cada segundo entre los valores de "1 día" y "7 días". Asegúrese de que muestre "7 días" en la esquina inferior izquierda de la pantalla.
   b. Después de registrar toda la información en este formulario, tome una foto.
   c. Envíe las dos fotos al contacto de la UPRM.
   d. Envíe cualquier pregunta o inquietud que tenga sobre su prueba de radón al contacto de la UPRM.
   e. Escriba los resultados, la dirección, las fotos y las observaciones en la base de datos de "RadResponder"

Dirección:
_____

Nombre y teléfono:
_____

Lugar de la prueba:
_____

Fecha y hora de inicio:
_____

Fecha y hora de conclusión:
_____

Resultado de la prueba (pCi/L):
_____

Comentarios:
_____

Envíe una foto de la lectura final que aparece en el monitor y una foto de este formulario a:

Attachment:
Corentium Home User Manual

Attachment:
E-Perm® System User's Manual