Determining Acceptable Protocols for Periodic Radon Monitoring in Structures over Inaccessible Contamination on the Maywood Superfund Site – 11428

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ABSTRACT

The *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* requires periodic radon monitoring in structures that have inaccessible soil beneath them, but does not impose any additional requirements or stipulations related to the quantification of radon concentrations. Recently, the first round of indoor radon monitoring was completed in conjunction with a *Comprehensive Environmental Response, Compensation, and Liability Act*-required five-year review. Radon measurements were made in accordance with U.S. Environmental Protection Agency guidance. The gathered data are used along with EPA guidance and the *Multi-Agency Radiation Survey and Site Investigation Manual* to develop a long-term monitoring strategy and a defensible indoor radon survey design for future periodic radon monitoring on the Maywood Superfund Site.

INTRODUCTION

The selected remedy in the *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* [1] distinguishes between accessible and inaccessible soils. Soils identified as inaccessible may remain in-place on a property if their removal would compromise the integrity of a permanent structure such as a building's foundation. The *Record of Decision* (ROD) requirement for performing periodic indoor Rn-222 (radon) monitoring is corollary to this allowance for inaccessible contamination to remain underneath a building. The purpose of periodically measuring indoor radon is to ensure that structures continue to provide adequate protection from the inaccessible contamination. "Adequate protection" is synonymous in this application with maintaining indoor radon concentrations below the 111 Bq/m^3 (3 pCi/L) above background radon limit specified in the New Jersey Administrative Code (NJAC) 7:28-12 *Soil Remediation Standards for Radioactive Materials* [2]. Subpart NJAC 7:28-12.8(a)2 specifies the radon limit and is identified as an applicable or relevant and appropriate requirement (ARAR) in the ROD. This limit (3 pCi/L above background) will be referred to in this paper as the action level for radon on the FMSS.

In conjunction with a *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) five-year review, initial post-ROD [1] radon measurements were collected between October 2008 and January 2009 (2009 radon monitoring). Five buildings with inaccessible contamination beneath them were identified for monitoring and measurements were made using alpha-track etch detectors deployed in accordance with EPA guidance [4,5,8]. While planning the 2009 monitoring, a noticeable lack of regulations governing the quantification of radon was apparent.

Aside from requiring that periodic radon monitoring be performed and identifying the NJAC 7:28-12.8(a)2 ARAR [2], the ROD [1] does not impose any restrictions or requirements for survey design. The

NJAC 7:28-12 standard does not address survey design considerations. There is only one New Jersey State regulation for radon monitoring: NJAC 7:28-27 *Certification of Radon Testers and Mitigators* [3]. This regulation does not directly impose survey design limitations but does define "authorized measurement protocols" as two EPA documents:

- EPA 402-R-92-003 *Protocols for Radon and Radon Decay Product Measurements in Homes* [4]
- EPA 402-R-92-004 *Indoor Radon and Radon Decay Product Measurement Device Protocols* [5]

Note that these are non-regulatory guidance documents[1] primarily designed to assist homeowners. At the Federal level there are no regulations that stipulate how radon shall be measured, or if there are, they all point to EPA *guidance* for measurement protocols. EPA has published several additional guidance documents, but they too are all non-regulatory.

Strict adherence to EPA guidance for the intended purpose of radon monitoring on the FMSS should not be a foregone conclusion since the guidance is non-regulatory and is not designed to demonstrate compliance. Also, EPA designed the guidance primarily for homes and not for the large manufacturing facilities and warehouses which constitute the buildings of concern on the FMSS.

This is not to say that implementing a survey design based solely on EPA guidance is deficient in any way; indeed, the quality control sections of the *Measurement Device Protocols* [5] are impressively thorough and should be a part of any radon monitoring procedure along with the detector placement recommendations from the *Homes* protocol [4]. But, the EPA guidance does not firmly resolve a few key aspects fundamental to the future of radon monitoring on the FMSS. Therefore, this paper seeks to resolve these aspects and form a concrete monitoring strategy by establishing the following parameters:

1. Duration of monitoring events (i.e., detector deployment period)
2. Frequency of monitoring events (i.e., years between testing)
3. Quantity of sample points (i.e., sampling density)

These design parameters are resolved with a heavy reliance on EPA guidance as well as the recognized authority document on radiation survey design: the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) [6]. Using these resources, and having the benefit of data recently collected in accordance with EPA guidance, a long-term monitoring strategy and a defensible indoor radon survey design are developed.

DURATION OF MONITORING EVENTS AND TEMPORAL ERROR

The duration of the sample collection period is a critical parameter for accurately quantifying indoor radon concentrations at a given sample location [4,5,7,8]. Deployment periods across different devices[2] range from 2 days to 365 days and the selected duration influences results due to temporal error [7,9]. Temporal error arises because radon concentrations fluctuate over time as a result of seasonal influences,

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[1] The web page for EPA 402-R-92-004 (www.epa.gov/radon/pubs/device_protocols.html) includes a disclaimer: "The material and descriptions compiled for these pages are not to be considered Agency guidance, policy, or any part of any rule-making effort but are provided for informational and discussion purposes only."

[2] All discussions in this paper assume that alpha-track etch detectors will be used for future radon monitoring on the FMSS.

barometric variations, and changing ventilation conditions within a building [7]. EPA states that temporal errors are the biggest contributor to the overall error associated with short-term measurements [7].

Short-term measurements are defined as having a sampling duration of 90 days or less, whereas long-term measurements have sample durations exceeding 90 days [4,5,7,8]. EPA concludes that a long-term test is more desirable than a short term test because a long-term test gives a better estimate of the year-round average radon level and is more indicative of annual exposure than are short-term tests [7,9]. Since the goal of FMSS monitoring is to accurately quantify indoor radon concentrations, the EPA conclusions essentially rule out short-term testing as a viable option. In addition, EPA recommends that all short-term testing be conducted under "closed building" conditions [5]. Closed building conditions generally refer to keeping windows, doors, and outside vents closed for the duration of the test [5]. Since the buildings of concern on the FMSS are neither owned nor controlled by the FMSS, maintaining closed building conditions is not feasible. In light of these EPA conclusions and recommendations, short-term testing is not a recommended protocol for use on the FMSS. Therefore, indoor radon monitoring performed on the FMSS for periodically evaluating radon concentrations should use a long-term test.

But even within the long-term testing protocols there exists a significant range of deployment periods (anywhere from 91 to 365 days). Considering that the goal of performing the radon monitoring is to determine compliance by quantifying indoor radon concentrations, a 365-day (12-month) testing duration is recommended for several reasons; chief among them is the elimination of temporal error.

"EPA assumes that the annual average [concentration] is constant, but that within any day, month, or year there will be fluctuations in the radon level [7]." Seasonal radon averages have been shown to reduce temporal error to approximately 25 percent from as high as 76 percent for a short term average; semi-annual averages further reduce the temporal error to 17 percent [9]. EPA also states that the closer a long-term test is to 365 days, the more representative the test will be of average annual radon levels [4,5]. Therefore, since temporal errors are essentially eliminated by implementing a 12-month sampling period, such a test will give greater confidence for determinations of compliance or decisions to mitigate.

Other advantages of a 12-month test include the reduction of bias and the elimination of the need to perform additional testing. Similar to temporal error, bias is certain to be present — either intentionally or unintentionally — in any test lasting less than 12-months. This is true because indoor radon concentrations are predictably higher in the winter months and lower in the summer months meaning that any test shorter than 12 months will be biased higher or lower depending on which months are sampled [7,9]. This bias may result in Type I (false positive) or Type II (false negative) errors. In the *Technical Support Document for the 1992 Citizen's Guide to Radon*, EPA assumes that long-term tests eliminate Type I and Type II errors "because temporal variation is the largest contributor to misclassification rate[3] and for year-long tests, this error term is negligible" [7]. By extension, the effective elimination of Type I and Type II errors obviates the need to perform additional, confirmatory testing.[4]

This level of confidence afforded by a 12-month test benefits a radon-monitoring strategy by simplifying the outcomes of the test. Radon concentrations will either be below the action level, requiring no further

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[3] Misclassification as used by the EPA refers to correctly quantifying indoor radon concentration as above or below the EPA action level of 4 pCi/L [7].

[4] Coincidentally, in the *Technical Support Document* EPA defines a confirmatory test as a long-term test lasting one year [7].

action, or they will exceed the action level, in which case mitigation can begin immediately without the need for additional testing.

A 12-month test further simplifies a monitoring strategy by placing no constraints on when the test must begin or end. This will make planning easier since myriad obstacles such as access rights, procurement, and available resources among other things often combine to result in schedule delays. A 12-month test can absorb any schedule delays without impacting the results of the test. On the other hand, planners will need to consider the length of the test in advance to ensure that acquiring results does not delay preparation of a CERCLA five-year review report.

An additional advantage intrinsic to a 12-month test is the reduced measurement error. This can be illustrated by comparing the minimal detectable concentration (MDC) as reported by the analytical laboratory for different testing durations. For FMSS data, the laboratory has reported MDCs of 0.3 pCi/L, 0.2 pCi/L, and 0.1 pCi/L for testing durations of 3-months, 6-months, and 12-months, respectively.[5] Lower MDCs translate to higher confidence intervals at the action level and are therefore desirable. Note that this consideration is not a determining factor since even a 3-month test yields an MDC less than 10 percent of the action level as recommend in MARSSIM [6].

One final non-technical consideration, but an important one nonetheless, is that there is no cost disadvantage for a 12-month test versus other testing lengths. All other things being equal, the time and materials required to perform the testing and analysis are identical across all testing durations since the tests are passive and do not require attention between deployment and retrieval. Given the level of confidence the 12-month test affords, there may actually be cost savings realized since there will be no need to perform follow-up tests should initial results approximate the action level.

FREQUENCY OF MONITORING EVENTS

The ROD [1] allows for inaccessible soil to remain on a property with the understanding that the soil will be remediated when it is made accessible in the future. Considering that the buildings of concern on the FMSS all house active and continually operating businesses, the soil could remain inaccessible for decades longer. This potentially translates into the need to evaluate indoor radon concentrations for generations to come and underscores the need for a long term strategy. The ROD requires periodic radon monitoring but neither stipulates, recommends, nor defines a specific period be implemented. Therefore, periodicity represents another unresolved parameter for which a suitable design is required.

Evaluating indoor radon potential is a component of CERCLA five-year reviews, but this does not mean that direct measurements must be made in each building every five years. There is no question that initial post-remedial[6] radon measurements should be performed in conjunction with the first CERCLA five-year review following completion of the current remedial action. But beyond the initial test, how frequent should subsequent testing be performed? EPA guidance once again provides a starting point.

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[5] Typical results based on Radon Monitoring Reports for samples collected on the FMSS and analyzed by Landauer, Inc. of Glenwood Illinois.

[6] "post-remedial" as used throughout this document should be read as "post-the current remedial action" since the presence of inaccessible contamination and the need for radon monitoring are corollary to the fact that the entire remedial effort is not complete.

In general there is no time-specific recommendation offered; instead, EPA advises that retesting should be performed as follows:

1. "If the result of the initial measurement is below [the action level], a follow-up test is not necessary. However, since radon levels change over time, the homeowner may want to test again sometime in the future, especially if living patterns change and a lower level of the house becomes occupied or used regularly." [4]
2. "In addition to [initial] measurements, EPA recommends schools retest sometime in the future especially after significant changes to the building structure or the HVAC system." [8]
3. "If no mitigation is required after initial testing (e.g., all rooms were found to have levels below [the action level], retest all frequently-occupied rooms in contact with the ground sometime in the future. As a building ages and settles, radon entry may increase due to cracks in the foundation or other structural changes." [8]
4. "If radon mitigation measures have been implemented in a [building], retest these systems as a periodic check on any implemented radon reduction measures." [8]

These recommendations provide a backdrop for evaluating changing building conditions and determining if a retest is warranted. But if building conditions do not prompt a retest, the recommendations are devoid a maximum allowable period after which retesting should be implemented. Because EPA does not recommend a specific period based on elapsed time alone, it becomes necessary to determine a maximum allowable period to ensure satisfaction of the ROD criterion.

In order to determine an appropriate length of time without being completely arbitrary, historical radon data collected on the FMSS were evaluated. Table I compares results from a 1994 radon study [9] to results from the 2009 radon monitoring [10].

Table I. Comparison of 1994 and 2009 Indoor Radon Concentrations.

Building ID	1994 Average Radon Concentration[a] (pCi/L)[c]	2009 Average Radon Concentration[b] (pCi/L)[c]	Absolute Percent Difference Normalized to action level[d] (%)
02A	0.5	0.7	5
02B	0.3	0.7	9
02C	0.4	0.6	5
08A	0.3	0.5	5
09A	0.4	0.6	5

a Average calculated from reported range of results and rounded to one significant figure [10].
b Average calculated from all sampled locations and rounded to one significant figure [11].
c Results reported as "gross" with no value for background subtracted [10,11].
d The action level equals the allowable increment (3 pCi/L) [2] plus background (1.35 pCi/L) [12, 13].

The 1994 tests were conducted using charcoal canisters deployed for seven (7) days (short-term test). The 2009 tests were conducted using alpha-track etch detectors deployed for a minimum of 91 days (long-term test). At first glance it is apparent that the 2009 results are uniformly higher than the 1994 results. However, as compared to the action level, the differences between the results are trivial as illustrated in Table I. Also, considering that the highest average radon concentration measured (0.7 pCi/L in buildings

02A and 02B) represents only 16 percent of the action level, there is confidence that after 15 years the buildings are still providing adequate protection from the contamination.

The fact that the data indicate no appreciable increase in radon concentration over a 15 year period can be used as a guide for setting a maximum allowable retest period (MARP) between consecutive monitoring events. A 15 year period for these buildings has proven to be acceptable and the period can therefore be extended with reasonable confidence that radon concentrations will remain below the action level barring significant changes to building conditions [7,8,14]. Land use and building conditions are routinely monitored on the FMSS and are somewhat accounted for through the implementation of land use controls and administrative controls. A significant change in building condition at any time in the future would necessitate another radon monitoring event. Based on the current data set and assuming radon measurements will only be performed in conjunction with CERCLA five-year reviews unless prompted by changing conditions, conservatively extending the MARP to 20 years for the Table I buildings is recommended. However, as additional testing is performed this period could be increased or decreased as appropriate based on the available data.

Having established a MARP, and considering EPA recommendations for retesting, independent of elapsed time, a decision tree was created as illustrated in Figure 1.

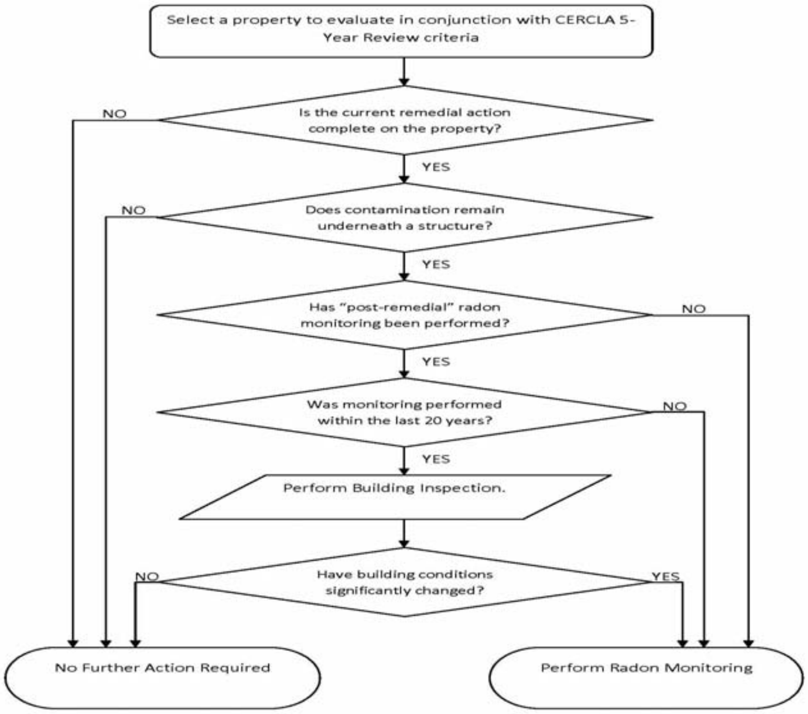

Fig. 1. Example of a decision-making flowchart for determining the appropriate retesting period.

By using a chart similar to Figure 1, an evaluation of indoor radon potential can be made during each CERCLA five-year review. If changing building conditions warrant a retest in accordance with EPA guidance, then a retest should be performed, if building conditions are static then a retest should be performed to coincide with the applicable MARP as determined from the available data set for each building. For the buildings considered in this report, this means that retesting should be performed again no later than 2029, and sooner if building conditions change.

QUANTITY OF SAMPLE POINTS AND SPATIAL ERROR

Having established an appropriate sampling duration as well as a mechanism to implement periodic monitoring, the final parameter needed to complete the radon monitoring strategy is to identify a recommended sampling density that will provide confidence that the collected samples are representative of the actual radon concentrations throughout the entire building. Spatial error[7] is minimized when enough samples are collected to rule out isolated pockets of elevated activity and to conclude with statistical confidence that a building does not have radon concentrations in excess of the action level.

As noted in the introduction, the buildings of concern on the FMSS are large warehouses and manufacturing facilities that the NJ-identified “authorized measurement protocols” do not address [2,4,5]. Therefore, the 2009 radon monitoring effort relied on EPA recommendations from the seemingly appropriate *Radon Measurement In Schools* [8]. In particular, two recommendations pertinent to the quantity of sample points were implemented:

- Measurements were collected in all frequently-occupied rooms in contact with the ground
- Detectors were placed about every 185 m^2 (2,000 ft^2) for larger spaces

EPA research shows that radon concentrations can vary greatly from room to room in the same building; therefore, the only viable approach for adequately quantifying radon concentrations within all rooms is to perform measurements in each room in accordance with EPA guidance [8].

The recommendation for placing detectors every 185 m^2 (2,000 ft^2) in larger spaces is not explained nor was any technical basis for this recommendation found. Therefore, the strength and efficacy of a survey designed based on this recommendation is dubious. Evaluating the 2009 survey design by analyzing sample results through a MARSSIM-based approach will determine the strength and acceptability of the completed survey and may be a useful tool for designing future surveys for large open spaces.

Using one building as an example, the building’s manufacturing area was treated as one survey unit. If this were a final status survey instead of a remedial action support survey, the large space in this example as would be identified as a class 2 survey unit based on the radon-specific historical site assessment (HSA) which follows.

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[7] EPA defines spatial error as the difference between radon concentrations on the level of a home where the tests are made and the overall radon concentration in the whole house [7]. This definition does not strictly apply to the FMSS scenario since the buildings have only one level; therefore, we refer to spatial error in the sense of accurately representing the radon concentration throughout the large manufacturing area (i.e., sampling density).

Historical Site Assessment

Performing an HSA is essential for understanding existing conditions and for assigning a reasonable potential that indoor radon concentrations exceed the action level. The structure used for the example is identified as "Building 08A" and was built in 1961 on a concrete slab with no basement or crawl space. The slab of concrete is at grade on one side of the building, and is above grade on the other side of the building. The only contamination suspected to remain beneath the structure is located along the side of the building where the floor slab is above grade. The large open space for which this evaluation is concerned is primarily a manufacturing area that measures approximately 3,883 m^2 (41,800 ft^2).

Initial Short-term pre-remedial radon measurements were collected within Building 08A in 1994. Building-wide results (0.2 – 0.4 pCi/L) [10] were significantly below the EPA action level of 4 pCi/L [4]. The results were also below the action level, indicating that prior to remediation of accessible soils, indoor radon concentrations were not elevated. "Post-remedial" measurements were also significantly below the action level with the highest result from the manufacturing area measuring 0.9 pCi/L [11]. A building walk-through performed prior to the 2009 radon monitoring inspection found no significant degradation or cracks in the concrete slab. Concurrent interviews with the building owner confirmed that the foundation appears to be structurally sound. These considerations indicate a low potential exists for indoor radon concentrations to exceed the action level (assuming building conditions remain constant).

Data Analysis

MARSSIM promotes the use of statistical tests to evaluate survey unit status. The statistical tests have more power when certain assumptions about the underlying distribution of data are true. When a survey unit meets release criterion based on a simple evaluation of the data as the manufacturing area of Building 08A does (i.e., maximum result of 0.9 pCi/L is less than the action level), a formal statistical evaluation is not needed to demonstrate compliance [6]. Nonetheless, an analysis of the 2009 data distribution can be evaluated against certain assumptions of the statistical tests, and could possibly be used to plan future surveys in large open spaces.

The 2009 data were evaluated by checking the following assumptions: data variance, spatial independence, symmetry, and whether the statistical power is adequate. Again, when a survey unit passes criteria, the power of the test becomes a somewhat moot point [6], but the retrospective power evaluation is performed not only to confirm the strength of the completed survey, but also to evaluate whether designing future surveys based on the 2009 dataset (by estimating the standard deviation of a future dataset) is recommended.

Data Variance

Data variance can be evaluated using basic statistics. Table II summarizes some statistics from the manufacturing area of Building 08A. Note that these statistics are based on the "gross" data set for which a background value has not been subtracted; also note that for the purpose of calculating these statistics, reported non-detect values were assigned a real value based on the linear extrapolation of the number of tracks counted versus reported activity (for all detected values in the analysis batch).

Table II. Statistical Analysis of Building 08A 2009 Radon Monitoring Data.

Statistical Parameter	Value	Evaluation
Mean	0.47	10.8 % of the action level
Standard Deviation	0.18	Small; indicates sufficient number of samples likely collected to achieve desired power of statistical test.
Median	0.45	Approximates the Mean indicating high probability of uniform data distribution.
Data Range	0.2 – 0.9	All data is within 3 standard deviations of the Mean indicating low variability of results.
Maximum Result	0.9	20.7 % of the action level

A few conclusions are readily apparent from these statistics: one, the radon concentration is significantly below the action level; and two, the data appears to be normally distributed (mean nearly identical to median) with low variability (small standard deviation, narrow range of data). Basically the data does not appear to be highly variable which agrees with the data variance assumption of the statistical tests.

Spatial Independence

Spatial independence can be evaluated by plotting the data graphically in order to evaluate any spatial trends that may exist. Figure 2 shows of posting plot of the data [11,15].

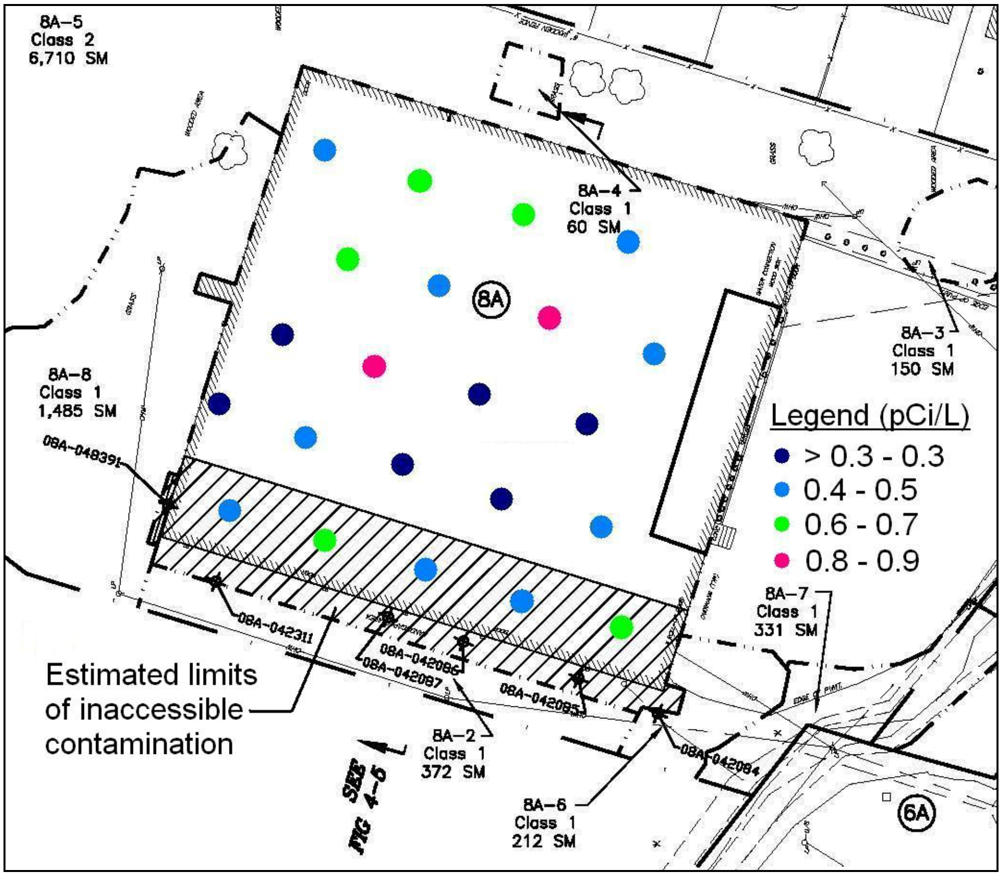

Fig. 2. Posting plot of 2009 radon monitoring data in building 08A.

This posting plot indicates that relatively strong spatial independence exists. Although there appears to be some grouping of low activity data points, the fact that the two highest readings occur adjacent to the lowest readings precludes attributing a trend to the data. Also, the fact that the data directly above and adjacent to the inaccessible contamination shows no upward bias reinforces the spatial independence of the data set, thereby agreeing with the statistical test assumption.

Symmetry

The histogram, or frequency plot, is another data analysis tool which can reveal the general shape of the data distribution. Figure 3 shows the results of the histogram evaluation using two different approaches for dealing with non-detected values.

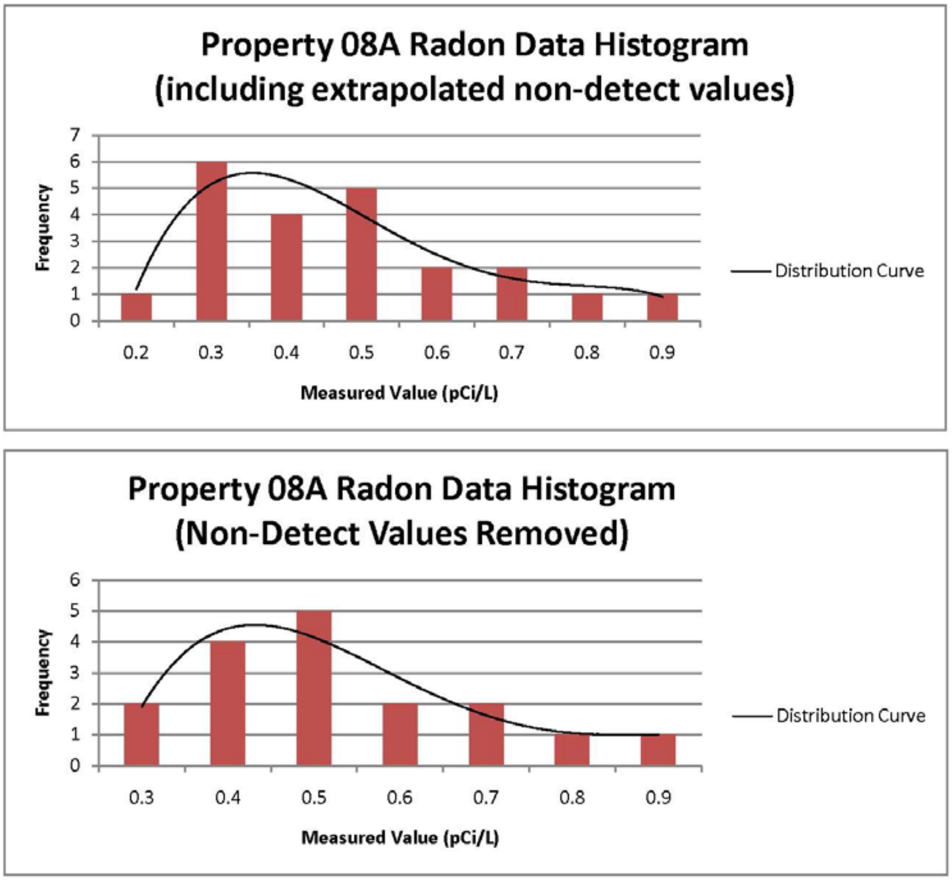

Fig. 3. Histogram of 2009 radon monitoring results for building 08A.

Figure 3 includes the non-detected values as real values which were extrapolated from plotting raw track counts versus reported activity. Although the curve does have a somewhat normal shape, it is skewed towards lower activity. Removing the non-detect values, as in the bottom chart, predictably shifts the curve towards the median yet still indicates that data is distributed with a bias towards the low end. However, the bias is not pronounced and the data appear to be distributed fairly normal. The symmetry may not be ideal for a parametric test, but should be acceptable for the non-parametric tests recommended by MARSSIM [6].

Retrospective Power Evaluation

Thus far the results of the data analysis indicate that the data has a somewhat normal distributed which will allow conclusions to be drawn from the data set with confidence. With no spatial trending, low variability, and an acceptable distribution of data, the stage is set to make a retrospective power evaluation. Table III summarizes the results of the retrospective power analysis assuming error rates of 0.05 (for both Type I and Type II errors).

Table III. Radon Retrospective Power Analysis for Building 08A

Parameter	Value
Standard Deviation	0.18
Action Level	3.00
Median (Lower bound – gray region)	0.45
Shift	2.55
Relative Shift	13.90
Pr (MARSSIM Table 5.1)	1.000000
Required number of samples (N/2)	8
Actual number of samples collected	22

The relative shift value, calculated from the sample results, was used to determine if sufficient power exists in the data set to confidently conclude that the radon concentration within the manufacturing area of Building 08A is below the action level. Based on this evaluation, a total of eight (8) samples were required for sufficient statistical strength. Considering that 22 locations were sampled, it appears that an ample number of discrete sample points were sampled within the manufacturing area of Building 08A to statistically conclude that indoor radon concentrations are below the action level. This is a strong indicator that spatial error is minimized. Whether or not this means that future surveys should be designed using the MARSSIM-based approach of estimating the standard deviations of future data sets will be discussed in the conclusion of this paper.

SUMMARY AND CONCLUSIONS

EPAs *Technical Support Document* [7] identifies three sources of error associated with radon monitoring: measurement, temporal, and spatial. It can be argued that minimizing these errors for radon monitoring on the FMSS is in the best interest of the public and the stakeholders. Setting appropriate parameter values for monitoring duration and sample quantity will effectively minimize these sources of error. Since the data are used to support decisions related to periodicity of monitoring events and mitigation, a higher quality of data will give greater confidence that proper decisions are made for periodic retesting or mitigation. The following summarizes the conclusions for each parameter and gives recommendations for future monitoring efforts on the FMSS.

Duration of Monitoring Events

Implementing a 12-month sample collection period effectively minimizes or eliminates the measurement and temporal sources of error. This fact alone favors a 12-month test and when combined with the other advantages discussed in this paper, a 12-month test seems to be the preferred protocol (with the caveat that planners must be aware of the 12-month duration and plan accordingly). Therefore, it is recommended that all future periodic indoor radon monitoring on the FMSS be conducted using a 12-month test.

Frequency of Monitoring Events

EPA offers several examples of when a building should be retested, particularly as relates to changes in the building structure or ventilation system. EPA does not recommend a specific retesting period based solely on elapsed time. Therefore, historical radon data were used to determine an appropriate maximum allowable period between tests. A maximum retest period combined with EPA recommendations for retesting yielded a decision tree flowchart (Figure 1) which can be used to determine the appropriate frequency of monitoring events. It is recommended that a flowchart similar to Figure 1 be used to evaluate the need to test each building in conjunction with the CERCLA five-year review process.

Quantity of Sample Points

An analysis of the 2009 radon results revealed low variability in the data set and a sufficient quantity of sample points. The evaluation concluded that eight (8) sample points would have provided sufficient statistical strength to determine compliance. Based on these results, the initial temptation is to apply a power curve for planning future radon surveys in accordance with MARSSIM. But there are some inherent differences between a radon survey and a MARSSIM soil or building survey that preclude this approach from being recommended:

1. An integral component of a MARSSIM survey involves scanning all, or a portion of, a survey unit. A feasible or meaningful method of scanning for radon does not currently exist. This means a radon survey does not inherently include a method for identifying small pockets of elevated activity that may exist between sample points. Since decreasing sample density increases the likelihood that pockets of elevated radon concentrations will not be identified, a decreased sample density is not recommended.
2. Another component of a MARSSIM soil or building survey which lends strength to the evaluation is the fact that a random sampling grid is used. Experience from the 2009 radon monitoring illuminated the fact that deploying detectors in a large open warehouse or factory is challenging and the options are limited, meaning that it is unrealistic to plan, or adhere to, a random sampling grid. Removing the random aspect of sample points weakens the strength of the MARSSIM survey unit evaluation meaning that collecting more samples than the minimum determined by the retrospective power evaluation is recommended.
3. There is no real accounting for the variability of radon in a discrete location over time. Whereas a soil survey unit can be assumed to have immutable radionuclide concentrations over time, radon concentrations within a building are in a constant state of flux due to the complex variables that affect radon transport [16]. While these variables are accounted for during a test, accounting for these variables between tests is not possible. A location that has low radon concentrations today could have elevated radon concentrations 5-, 10-, or 20- years from now. The conclusion then is that reducing the number of sample points could lead to an increase in Type II errors (false negatives) despite the results of a retrospective power evaluation.

Given the variability of radon concentrations over time, the inability to implement a random sampling grid, and the absence of a feasible scanning methodology to rule out small areas of elevated activity, determining a future quantity of sampling point based on the expected variability of the dataset is not recommended. A more intensive survey is required because although the 2009 data for Building 08A had a relatively normal distribution, there is no guarantee that future radon concentrations will be similar.

Barring additional guidance, and having just confirmed that the EPA recommended survey design of placing detectors every 185 m^2 yields a statistically strong data set, it is recommended that future radon monitoring be performed in accordance with all EPA guidance for detector deployment. The increased data quality offsets any cost increase[8] associated with the EPAs more rigorous sampling plan. Furthermore, it is recommended that a post-monitoring MARSSIM evaluation be performed on the data to demonstrate confidence in the test results.

DISCLAIMERS

It interesting that there is no time component to the radon remediation standard. This paper assumes that the NJAC 7:28-12.8(a)2 radon criterion [2] should be read as “an annual average concentration of 3 pCi/L above background.” This is consistent with the dose-based criterion and it is also consistent with EPA guidance that identifies the 4 pCi/L limit as applying to the average annual indoor radon concentration [4,5,7].

Recommendations made in this paper are specific to the FMSS periodic radon monitoring program and should not be construed for other purposes.

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[8] The buildings monitored in 2009 required 230 detectors including quality control. If all large spaces were sampled at their retrospective minimum, only 128 detectors would have been required. At $13.50 per detector, this would have translated to a cost savings of $1,377, or, an average cost savings of $230 per building.

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