WM2008 Conference, February 24 – 28, 2008, Phoenix, AZ
Abstract #8262

USACE FUSRAP Maywood Team Develops a Mechanism to Evaluate Residual Radon Exposure Potential at Vicinity Properties Where Remediation of Accessible Contamination has been Completed

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ABSTRACT

The Maywood FUSRAP Team is obligated, under its approved remedy selection decision document, to demonstrate substantive compliance with New Jersey Administrative Code 7:28-12(a)2, establishing an indoor limit of three PicoCuries per liter above background for radon-222 (Rn-222). The Maywood Team explores various avenues for dealing with the radon issue and provides an alternative for demonstrating substantive compliance with the radon remediation standard by answering the question: "In certain conservative situations, can compliance with the radon standard be demonstrated without performing monitoring?" While monitoring may be the most definitive method for demonstrating compliance, a logical argument can be made that when radiological remediation removes the potential source for Rn-222 above background, monitoring is unnecessary. This position is defended through the use of historical physical radon measurements which illustrate that indoor radon was not a pre-remediation problem, and post-remediation soil sampling data which demonstrate that the source of the potentially elevated Rn-222 levels have been successfully mitigated. Monitoring recommendations are made for situations where insufficient data exists to make definitive determinations or when unremediated sources affecting habitable structures remain on a given property. Additional information regarding recommended techniques and references for effective monitoring of indoor radon are included in this paper. This paper may benefit teams that have similar regulatory commitments and/or have need to make assessments of radon exposure potential based upon historical monitoring data and available soils concentration data.

INTRODUCTION

The United States Army Corps of Engineers (USACE) has contracted Shaw Environmental, Inc. (Shaw) to remediate Phase II of the Formerly Utilized Sites Remedial Action Program (FUSRAP) Maywood Superfund Site (FMSS). Rare earth and thorium processing operations at the site during the first half of the last century created wastes containing thorium, radium, and uranium which contaminated the environment primarily as burial pits and secondarily through transport via surface/storm water and use of the material as fill. Phase II includes remediation of the remaining FMSS commercial and governmental properties

The gaseous decay products of the primordial radionuclides present in Maywood FUSRAP soils are routinely evaluated to assess outdoor environmental levels. They have also been evaluated in the past to assess indoor exposure levels to members of the public who work/visit commercial buildings that in some cases were constructed above or in the immediate vicinity of FUSRAP radioactive waste. The Maywood Team is currently evaluating residual radon risk at properties where, to the extent practicable, contaminated soil removal actions have been completed. This paper discusses the elements of the evaluation process and the decision making tools used by the Team to make protective determinations for properties in the current remedial phase of the project (Phase II-Commercial & Governmental Properties).

The FMSS Phase II remedial actions are being executed in accordance with the *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* (ROD) [1], which has identified the New Jersey Rule *N.J.A.C 7:28-12 Soil Remediation Standards for Radioactive Materials* [2]as an applicable or relevant and appropriate requirement (ARAR). The ROD states the following regarding Rn-222:

> "Indoor radon air concentrations will meet the 3 PicoCuries per liter (pCi/l) radon-222 (Rn-222) limit specified in the NJAC 7:28-12.8(a)2 at all properties addressed in this ROD." [1]

New Jersey Administrative Code (NJAC) states the following:

> "7:28-12.8 Radiation dose standards applicable to remediation of radioactive contamination of all real property
>
> (a) Sites shall be remediated so that the incremental radiation dose to any person from any residual radioactive contamination at the site above that due to natural background radionuclide concentration, under either an unrestricted use remedial action, limited restricted use remedial action, or a restricted use remedial action, shall be as specified below:
>
> 1. For the sum of annual external gamma radiation dose (in effective dose equivalent) and intake dose (in committed effective dose equivalent)*, including the groundwater pathway*: 15 millirem (0.15 milliSievert) total annual effective dose equivalent (15 mrem/yr TEDE)**.**

2. For radon*-222*: three picocuries per liter (pCi/L) of radon gas (111 Bq/m3).” [2]

In order to logically assess the real potential for properties with/without residual radioactive soils contamination to exceed the ROD criteria for Rn-222 it is necessary to answer several basic questions:

- Is there historical evidence that Rn-222 levels in habitable structures, prior to remediation, exceeded ROD criteria?
- Is there evidence of residual radioactive contamination under or immediately adjacent to a habitable structure? If so, how will the residual risk be evaluated?
- Using a set of conservative assumptions, can post-remediation final status survey (FSS) soil sampling data for radium-226 (Ra-226) be used to definitively assert that indoor Rn-222 concentrations would be below ROD criteria?
- What situations would be appropriate / inappropriate for application of this methodology?

Once a determination is made regarding the necessity of physical monitoring to demonstrate compliance with accepted standards, a remediation team can move forward. The final section of the paper introduces readers to a selection of the fundamental guidance/requirements for an effective indoor radon monitoring regime.

DISCUSSION

Evaluating Historical Radon Monitoring Data to Assess Residual Radon Exposure Potential

Is there historical evidence that Rn-222 levels in the occupied facilities, prior to remediation, exceeded ROD criteria? The simple answer is “no.” The most comprehensive evaluation to date of indoor radon levels at Maywood site properties was conducted by the U.S. Department of Energy (DOE) in 1994. The report, titled *Results of Radon and Gamma Radiation Measurements at 19 Commercial and Governmental Properties of the Maywood Site* [3], is included as part of the Maywood Soils Feasibility Study [4]. The report presented the results of activated charcoal canister sampling conducted in commercial/government vicinity property buildings at the FUSRAP Maywood Site. The study was thorough and performed with an acceptable level of data quality. The only notable limitation is that the duration of sampling (i.e., seven days) would fail to capture seasonal variability and its effect on building radon levels. **Table I** presents the results for radon/thoron monitoring from the 1994 DOE Study [3].

Table I. Historical Indoor Radon Monitoring Results from FMSS Phase II (Commercial & Governmental) Properties

Property	Phase II Property ID#	Gross Rn-222 Results (pCi/l)	Gross Rn-220 Results (pCi/l)
160/174 Essex Street	4A	0.2 to 0.3	[a]
113 Essex Street	5B	0.2 to 0.6	< 1.0
85 N. NJ State Route 17	6A	0.2 to 0.3	[a]
87 N. NJ State Route 17	6A	0.2 to 0.4	[a]
99 N. NJ State Route 17	6A	0.2 to 0.4	[a]
239 State Rt. 17 (office)	6D	1.3	< 2.0
239 State Rt. 17 (storage)	6D	1.0	[a]
100 W. Hunter Ave. (Stepan)	10A	0.2 to 3.4	< 2.0
167 State Rt. 17	6C	0.2 to <0.3	< 1.0
137 State Rt. 17	6B	0.2 to 0.3	[a]
80 Industrial Road	2C	0.3 to 0.5	< 1.0
170 Gregg Street	3A	0.2 to 0.4	[a]
80 Hancock Street	2B	0.2 to 0.4	< 2.0
100 Hancock Street	2A	0.4 to 0.5	< 1.0
23 West Howcroft Road	8A	0.2 to 0.4	< 0.8
72 Sidney/88 Money Street	1A	0.3 to 0.4	[a]
200 State Rt. 17	5C	0.3 to 0.4	< 1.0
149-151 Maywood Avenue	9A	0.4 or less	< 2.0
205 Maywood Avenue	11A	0.4 to 1.7	< 0.7
8 Mill Street, Lodi NJ	2D	0.3 to 0.6	[a]

[a] Thoron analysis of charcoal canisters not conducted for this building

The results of the 1994 radon study identified no buildings that exceeded an action level. The DOE used the action level of three pCi/l above background for both Rn-222 and radon-220 (Rn-220) (evaluated separately). The maximum result, uncorrected for background, was identified in Building 3 on the Stepan Company Property (3.4 pCi/l for Rn-222, <2 pCi/l for Rn-220). Stepan Building 3 can be reasonably considered a "worst-case" scenario from a potential source standpoint since it was the only habitable structure built directly above one of three licensed radioactive waste burial pits on the site. Other structures on the FMSS that are known or suspected to have residual radioactivity directly below them were constructed above alluvial deposition areas or above areas backfilled with fill containing waste materials blended with regular soils. Furthermore, the lens thickness of contaminated soils under the Building 3 foundation is believed to be greater than under any other structure where contamination is known or suspected to be present (i.e., 12 or more feet in thickness). It should be noted that Building 3 was demolished to the foundation level in 2007 by the Stepan Company in advance of upcoming soils remediation by the Maywood Team and is no longer considered a habitable structure.

Evaluating Indoor Rn-222 Exposure Potential Based on Residual Outdoor Radium-226 Concentrations in Soil

In order to assess radon potential from residual soils after remediation, there must be a reasonable mechanism for accomplishing the following:

- Implementing a reasonable process by which residual Ra-226 soil concentrations in pCi/g can be related to expected Rn-222 concentrations in indoor air in order to assess an action level corresponding to the accepted limit of three pCi/l above background for Rn-222; and

- Quantifying residual soil concentration averages and confidence intervals of Ra-226 (the parent radionuclide to Rn-222 and a Maywood Radionuclide of Concern) on the property.

Several studies have suggested a correlation between radium in soil and indoor radon concentrations [5, 6, 7]; while there is no absolute correlation due to the myriad of factors which contribute to indoor radon concentrations, the conclusion can be made based on these studies that indoor radon potential can be reasonably estimated based upon the radium in soil content.

In the *Development of Generic Standards for Remediation of Radioactively Contaminated Soils* [4], New Jersey suggests a conservative ratio of indoor radon to radium in soil of 1.5 pCi/l radon per pCi/g radium. This ratio was developed by taking the geometric mean for indoor radon in New Jersey homes and comparing it to the statewide average radium in soil content. The New Jersey value, with which the Maywood Team concurs, is supported by an Environmental Protection Agency (EPA) study [6] which found that the ratio of Rn-222 (pCi/l) to Ra-226 (pCi/g) varied based on soil types between 0.2 and 2.4 pCi/l per pCi/g, with an average ratio of 1.1 pCi/l per pCi/g. The New Jersey ratio is more conservative then the average ratio from the EPA study and is therefore used for the purposes of this paper.

Regional Background

Prior to any discussion regarding compliance with remediation standards, it is imperative that background levels of radionuclides are established, for both soil (Ra-226 & Th-232) and air (Rn-220 & Rn-222). This is necessary because all remediation standards are presented as allowable increments above background.

Prior to the ROD-driven remediation of FMSS properties, a Background Investigation Report [8] was prepared for the USACE by Shaw with the intent of establishing regional background values for radionuclide(s) of concern. Results from this regional study established the average background concentration of radium in soil as 0.90 +/- 0.45 pCi/g (1σ). The average background concentration of Th-232 was established as 0.71 +/- 0.30 pCi/g (1σ). These values were derived specifically for the FMSS in accordance with the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) [9] guidance for determining regional background, and as such will be used as appropriate background values for the purposes of this paper.

Establishing a Conservative Soils Ra-226 Action Level

The Technical Basis Document for N.J.A.C. 7:28-12 [4] provides technical justification and assumptions to establish an indoor radon to soil radium ratio (RRR) of 1.5 pCi/l. This is the most conservative ratio considered in the document [4] and gives no consideration to either the vertical extent of the Ra-226 contamination, or to any "clean layer" which might exist between the slab on grade/basement and the Ra-226 layer. Using this ratio provides an allowable concentration of Ra-226 in soil in order to control the indoor Rn-222 concentration to less than 3.0 pCi/l. Since the Rn-222 cleanup criteria presented in the ROD is 3 pCi/l above background, an appropriate value for regional Rn-222 background is added. Regional background concentration for indoor radon in New Jersey homes is 1.35 pCi/l. Application of the RRR to the radon remediation standard of 3.0 pCi/l above background yields the allowable Ra-226 concentration in soil:

$$Ra\text{-}226_{(\text{allowable [soil]})} = (Rn\text{-}222_{(\text{allowable})} + Rn\text{-}222_{(\text{background})}) / (RRR)$$

$$Ra\text{-}226_{(\text{allowable [soil]})} = (3.0\ pCi/l + 1.35\ pCi/l) / (1.5\ pCi/l\ \text{per}\ pCi/g)$$

$$Ra\text{-}226_{(\text{allowable [soil]})} = (4.35\ pCi/l) / (1.5\ pCi/l\ \text{per}\ pCi/g)$$

$$Ra\text{-}226_{(\text{allowable [soil]})} = 2.9\ pCi/g$$

Based on the aforementioned correlation ratio between radium in soil and radon, as well as the acceptable background and allowable increment of radon in air, the action level for Ra-226 in soil is established as 2.9 pCi/g. In terms of radon, it is evident from the above discussion that the radon remedial action objective is 4.35 pCi/l.

Quantifying Residual Soil Concentration Averages and Confidence Intervals for Ra-226

The Maywood Team has selected post-remediation FSS systematic sampling data (all results, regardless of depth) for use in determining residual Ra-226 concentrations in Phase II Property soils. Systematic sample results are collected in a triangular grid pattern with a random starting point, on a survey unit by survey unit basis, as recommended by the MARSSIM. Although FSS soil samples are collected to determine compliance with ROD soils cleanup criteria, their unbiased nature and reasonable frequency of collection are suitable for use in this application.

A descriptive statistical data evaluation of the data collected is made up of the following elements:

- **Table II** presents property-specific data and summary statistics for Ra-226 from all systematic sample location results (excluding quality control results) collected from MARSSIM Class I/II FSS survey units successfully remediated to the ROD Unrestricted Use Soils Cleanup Criteria (i.e., 5 pCi/g above background for the sum of Ra-226 and Th-232 and 100 pCi/g Total Uranium). The mean, median, maximum, standard deviation, and upper 95% confidence interval (UCI95) of the mean is determined for each Phase II property and for the overall dataset. For this application the UCI95 for the

datasets are calculated by added the 2σ dataset uncertainty to the higher of the mean or median values.

Table II. Summary Statistics for FSS Systematic Sampling Results from Unrestricted Use Survey Units within the FMSS (Phase II)

Property ID	Total # of Systematic FSS Samples	Median Ra-226 (pCi/g)	Mean Ra-226 (pCi/g)	1σ Uncertainty (pCi/g)	Maximum Ra-226 (pCi/g)	UCI 95% Ra-226 (pCi/g)
1A	77	0.575	0.612	0.276	1.890	1.154
2A	111	0.910	0.915	0.241	1.710	1.387
2B	137	0.980	0.998	0.220	1.820	1.430
2C	175	0.856	0.852	0.184	1.718	1.213
2D	398	0.721	0.784	0.328	2.831	1.441
3A	63	1.110	1.168	0.385	2.290	1.923
4A	192	0.750	0.780	0.344	3.580	1.455
4B	113	0.670	0.723	0.335	2.030	1.381
4C	23	0.630	0.617	0.214	1.150	1.036
5B	54	0.867	0.899	0.316	2.153	1.518
5C	37	0.932	0.928	0.224	1.332	1.367
6A	69	0.989	1.024	0.293	2.361	1.599
6B	102	0.914	0.933	0.243	2.034	1.419
6C	190	0.880	0.893	0.343	1.819	1.580
6D	10	1.102	1.060	0.148	1.231	1.397
8A	126	0.649	0.656	0.199	1.439	1.046
Total	1874	0.825	0.841	0.316	3.580	1.473

- **Figure 1** presents a graphical plot of the data presented in **Table II** in relation to both the regional background range (UCI95) for the FMSS [7] and the derived action level of 2.9 pCi/g.

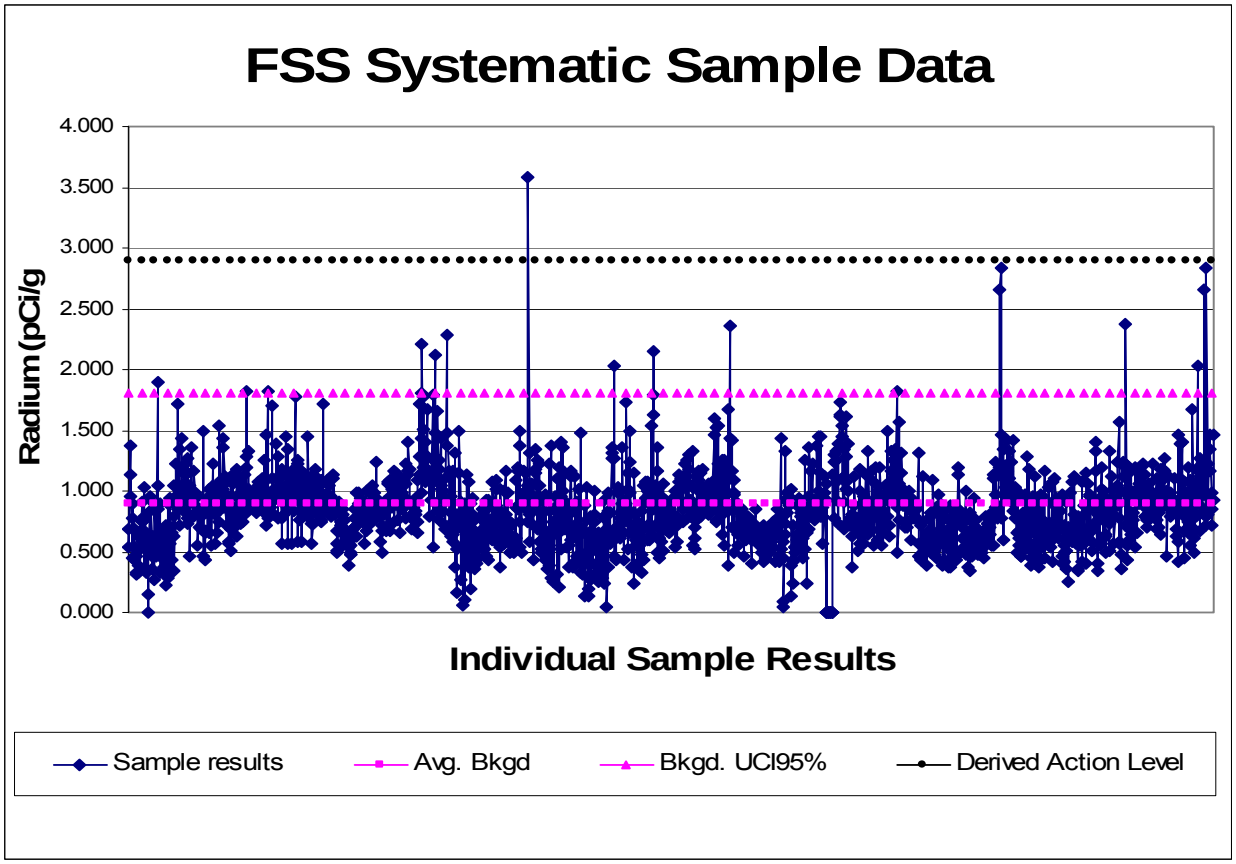

Fig. 1. Comparison of Radium in Soil Results to Background and Radon Potential Action Level

Evaluating Descriptive Soil Data Statistics and Associated Indoor Radon Exposure Potential

Considering that the UCI95 of each property's Ra-226 dataset falls below the trigger limit of 2.9 pCi/g, high statistical confidence exists that indoor radon levels in associated habitable structures would be below the 4.35 pCi/l background adjusted limit for Rn-222. In addition, of the 1,874 FSS systematic samples presented in this study, greater than 99% of the results fell within the upper 95% confidence interval of regional Ra-226 background (1.8 pCi/g) and only a single result exceeded the 2.9 pCi/g Ra-226 trigger limit.

Based on the definitive evidence of limited residual Ra-226 potential in survey units[1] remediated to the unrestricted use soils cleanup criteria, the Maywood Team asserts that no supplemental indoor compliance monitoring for Rn-222 is necessary in survey units successfully remediated to the ROD Unrestricted Use Soils Cleanup Criteria. (i.e., "clean"). This stated position applies to any habitable structure that currently exists within clean survey units or one that is constructed

[1] Survey Units refer to the basic division used for determining regulatory release status via Final Status Survey.

in the future above a clean survey unit, and is in effect regardless of the overall property status (i.e., unrestricted/restricted use).

Evaluating Residual Inaccessible Contamination and other Restricted Use Scenarios to Assess Residual Rn-222 Exposure Potential and Establish an Appropriate Monitoring Regime

Considering that the primary indoor radon potential comes the soils directly under or adjacent to a structure, indoor radon monitoring should not be required in a habitable building surrounded by clean survey units and built upon non-radiologically impacted soils, just because an area of "Restricted Use" (i.e., cleanup to Restricted Use limits or residual inaccessible areas of contamination) exists somewhere on the property. An example would be an inaccessible utility corridor that passes through a property via an easement and is contaminated in the subsurface. If habitable structures are not constructed or present over the contaminated utility corridor AND survey units affiliated with a structure meet the unrestricted use criteria, indoor radon monitoring is not required.

The Maywood Team makes no assertion that survey units remediated to the ROD Restricted Use Cleanup Criteria exhibit a residual Rn-222 hazard potential. It is merely the position of the Maywood Team that insufficient data exists to definitively support the position that survey units remediated to restricted use levels retain no residual radon exposure potential. The Restricted Use Cleanup Criteria differs from the Unrestricted Use Cleanup Criteria only in that residual radioactivity below a depth of 15 centimeters may be as high as 15 pCi/g above background for the sum of Ra-226 and Th-232, provided a minimum of one foot of clean fill cap is placed over the residual radioactivity. However, it is assumed that a higher percentage of systematic sample results exceeding 2.9 pCi/g would be present in survey units remediated to the Restricted Use Criteria. Because of the lack of definitive data evaluation for all Restricted Use survey units, a unit-specific RRR evaluation which considers the characteristics of the residual radioactive lens and the clean layer thickness for establishing correction factors is needed to more fairly assess the indoor radon potential. The correction factors are applied to the 1.5 pCi/l per pCi/g ratio and essentially lower this ratio based upon the thickness of the clean layer of backfill as well as the vertical extent of residual radioactive contamination. Applying this property-specific ratio to the residual Ra-226 concentration yields an appropriate value for indoor radon potential in pCi/l. Comparison of this value to the remedial action objective of 4.35 pCi/l for Rn-222 would be used to determine whether radon monitoring is warranted for affected structures. A survey unit-specific analysis could be supported by one or more rounds of physical radon monitoring of existing structures, if necessary. Subsequent evaluation of the radon exposure potential from survey units remediated to the ROD Restricted Use Soils Cleanup Criteria is likely to be performed by the Maywood Team in the future, as additional FSS data becomes available.

The ROD at Section M.2 includes the following requirement under the "Description of the Selected Remedy":

"Periodic Rn-222 Monitoring of structures over inaccessible soils to ensure that the structure continues to provide adequate protection from these soils; mitigation of Rn-222 (e.g., sealing foundation cracks, supplementing existing ventilation systems, etc.) would be performed if indoor air levels exceed 3 pCi/l above background)." [1]

The Maywood Team amplifies the ROD text with the understanding that if residual contamination above the property-specific soils clean-up criteria remains under the foundation of a habitable structure or in direct contact with an exterior wall, periodic monitoring should be conducted to assess on-going radon risk potential. A round of monitoring is currently being planned for those properties where remediation of accessible soils has been completed and inaccessible contamination remains as previously described. Given the historical data collected and the subsequent removal of significant source term in nearby accessible soils, it is not expected that monitoring results will exceed the limits established in the ROD; however, appropriate mitigating actions will be undertaken in the event that results exceed criteria. Any likely change to indoor radon levels would most likely be attributable to some change or degradation of the foundation or exterior sub-grade wall allowing for easier penetration of Rn-222 into the structure.

SUMMARY

The evaluation of historical Rn-222 monitoring data and systematic FSS sample results, coupled with a reasonable assessment of radon exposure potential from residual soil Ra-226 concentrations leads to the following conclusions:

- Regardless of the overall property status, habitable structures (current and future) within survey units remediated to Unrestricted Use Criteria retain insignificant residual indoor Rn-222 exposure risk and require no further monitoring.

- Habitable structures (current and future) within survey units remediated to Restricted Use Criteria may retain residual indoor Rn-222 exposure risk. Monitoring, or a more detailed analysis which considers application of correction factors based on the characteristics of the residual radioactivity in soils, is necessary to effectively measure exposure risk potential.

- Habitable structures (current and future) above known areas of inaccessible residual contamination in excess of the property-specific ROD soils cleanup criteria should be monitored for Rn-222 to confirm historical data and assess potential impact caused by structural changes and time degradation of the facility.

Additional data collection efforts are planned for habitable structures of the FMSS as remediation efforts are completed.

The demonstration of compliance with radon remediation standards can be accomplished through an analysis of residual Ra-226 concentrations in soil provided that enough soil data exists, such as the case with FUSRAP and other Superfund cleanup sites using MARSSIM-based Final Status Survey. The use of soil analysis may result in cost savings, time savings, and is preferential in the event site personnel are unable to gain property access. In some cases radon measurements or monitoring may be recommended or required. Considering the relatively small cost of indoor radon monitoring, potentially habitable structures should be monitored where

there is greater uncertainty regarding residual radon. The frequency of subsequent monitoring evolutions (e.g. one-time, annually, etc.) is left to agencies responsible for the monitoring and associated stakeholders (i.e., regulators and property owners).

DISCLAIMERS

- Beyond the post-remediation round of radon monitoring, decisions related to subsequent monitoring frequencies are left to the agency responsible for long-term stewardship of the Maywood site and are not addressed by this paper.

- The mission of the Maywood Team is to meet the remedial action objectives established in the *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* (ROD) [1]. The complex scientific studies and evaluations necessary to fully understand the mechanics of gaseous decay product transport in the regional environment are beyond the scope of this mission and as such, this paper. The goals of this paper are to communicate the Maywood Teams understanding of the radionuclides present on site and how that information is used to make logical assessments regarding residual radon exposure potential at properties where, to the extent practicable, the remedial action objectives have been achieved.

- There is no applicable remediation standard under the FUSRAP Maywood Site Soils ROD for Rn-220 (i.e., thoron). Discussions and data related to Th-232 and its gaseous decay progeny, Rn-220, are included to provide additional information to the reader.

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