A Case-Study: Implementation of Independent Final Status Survey in Support of Remediation at a FUSRAP Site – 14318

Eric W. Barbour (NAD CX)*, Nicholas M. Berliner**, Scott S. Hay**, Brian P. Hearty (EM CX)*, Michael S. Winters**
*U.S. Army Corps of Engineers
**Cabrera Services Inc., East Hartford, Connecticut

ABSTRACT

The United States Army Corps of Engineers (USACE) Formerly Utilized Sites Remedial Action Program (FUSRAP) addressed an abandoned landfill where widespread dumping of industrial, domestic, and radioactive wastes occurred between the 1940s and 1960s. The FUSRAP mission was to address the remediation of certain residual radioactivity from the Site. The Remediation Team faced numerous challenges which complicated efforts to prove the risk based remedial objectives had been achieved. The challenges were driven by the Site conditions, particularly, a high water table; the presence of low-hanging high voltage utility lines and; the presence of collocated/adjacent chemical contamination in soils requiring special handling. Innovative technical approaches were incorporated into the survey design by the Final Status Survey (FSS) Team to address these challenges in a manner that ensured the 1×10^{-5} Excess Lifetime Cancer Risk (ELCR) Criteria had been achieved for the Site. This case study reviews the technical hurdles and Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [1] - based survey design elements utilized to demonstrate compliance with the ELCR.

INTRODUCTION

Cabrera Services, Inc. (Cabrera) and USACE (collectively the FSS Team) designed and implemented a FSS based on MARSSIM guidance. Final Status Surveys were performed to substantiate that remediation performed by USACE reduced FUSRAP radionuclide concentrations at the Site below site-specific Soil Cleanup Criteria. This case study describes the methodologies and results of site FSS operations, focusing on the technical challenges encountered during implementation and how they were addressed within a broad MARSSIM framework.

DESCRIPTION

Abbreviated Site History

The FUSRAP site was an abandoned landfill where widespread dumping of industrial, domestic, and radioactive wastes occurred between the 1940s and 1960s. Disposal activities at the Site were non-systematic and resulted in random and wide-spread deposition of these waste materials across an area of approximately 40,000 square meters (m^2) (approximately ten acres).

Deposition of Contaminated Materials

Site waste distributions were believed to be the result of initial dumping in a readily accessible area of the Site. The wastes were then relocated to other areas within the Site footprint, and possibly burned as a volume reducing technique.

Waste disposal operations over time yielded a layer of fill that consisted of clayey silt to coarse sand with approximately 15% to 20% broken glass and corroded metal fragments by volume, with occasional clumped white and grey particulate, ash-like material (herein referred to as Site Fill). Site Fill was typically brown with rust-red discoloration in areas above the water table (often sands) and dark grey to black stained with sporadic sheen below the water table (often silts). Site Fill was observed in subsurface lenses up to approximately 2.5 meters (approximately eight feet) in thickness and contained virtually all of the radioactive wastes discovered on site.

Hydrogeologic Setting

The Site has a very shallow water table with seasonal standing water and multiple wetlands identified in low-lying areas forming a swamp encompassing nearly 20% of the Site footprint. This swamp extends beyond the Site footprint to adjoining areas, comprising an area between three and four times the footprint of the Site. A nearby pond several times larger than the Site lies less than 0.3 kilometers (approximately 0.2 miles) away.

Site Use and Abutting Site Use

The Site overhead is traversed by six (6) high-voltage electric lines ranging from 13,800 kilovolt (kV) to 345,000 kV each. Performing remediation in the vicinity of these power lines required careful planning, the use of spotters, and an incremental approach to FSS implementation.

Fourteen (14) utility poles support the high-voltage electric lines that traverse the Site. These locations created unique challenges because they could not be thoroughly excavated without undermining the integrity of the active public utility service. Utility Corridor "right-of-way" excavation restrictions were put in place and adhered to as a means to address the accessible contamination and avoid unnecessary safety risks. Adhering to these imposed restrictions yielded a six-meter (20-foot) diameter cylinder of unexcavated soil around each of the 14 poles. These "right-of-way" restrictions therefore hindered the ability of remedial operations around the poles to chase contamination as necessary and yielded cylinders or "islands" of residual unexcavated soil around each pole.

The Site also shares a property boundary with a former 200,000+ m^2 (50+ acre) municipal landfill. Along the shared property boundary, trash from this adjacent municipal landfill spilled into areas of the Site requiring remediation. Deposits of these non-impacted wastes covered approximately one acre of the Site and were measured at up to approximately 2.7 meters (approximately nine vertical feet) in thickness. This created multiple logistical problems, including that within this portion of the Site, managing this material in the same manner as Site Fill would have greatly increased the volume of material requiring disposal in order to excavate to the below site release criterion.

Radionuclides of Concern

Project-specific risk-based soil cleanup criteria were established for the following radionuclides of concern (ROCs): total uranium, uranium-234 (U-234), uranium-235 (U-235), uranium-238

(U-238), and radium-226 (Ra-226). These ROCs were widespread in surface and subsurface soil as distributed contamination at relatively low concentrations and as discrete sources within the Site footprint prior to remediation and in a limited number of locations beyond the Site footprint.

Mid-way through the course of remediation and FSS, isolated areas of soil containing elevated concentrations of radionuclides from the Thorium Natural Decay Series were identified in some discrete areas of the Site. Actinium-228 (Ac-228, a radioactive decay product of Thorium-232 [Th-232] and member of the thorium natural decay series under assumed secular equilibrium) was noted in on-site gamma spectroscopy lab screening sample results. These isolated areas of elevated Ac-228 concentrations were predominantly collocated with site ROCs in some instances and isolated from other ROCs in other cases.

Non-Radiological Contaminants of Concern

Investigations to address the presence of non-radiological contaminants at the Site identified inorganics, volatile organic compounds semi-volatile organic compounds, polychlorinated biphenyls, pesticides, and dioxins in groundwater, surface water, sediment, surface soil, and subsurface soil. Soils impacted with non-radiological contaminants were carefully removed if they were suspected of being commingled with soils impacted with radiological contaminants. Soils impacted with non-radiological contaminants in excess of Soil Cleanup Criteria went off-site for disposal, while soils impacted with non-radiological contaminants but, below Soil Cleanup Criteria concentrations, were stockpiled on-site for future disposition by other stakeholders. A second remedial effort for non-radiological contaminants at the Site will assume responsibility for stockpiled soils impacted with non-radiological contaminants of concern.

Soil Cleanup Criteria

A decision document was issued for the Site which developed both radiological and non-radiological cleanup criteria based on a site-specific ELCR of no greater than 1×10^{-5}. The radiological cleanup criteria comprised the Site derived concentration guideline levels (DCGLs).

Radionuclide of Concern	Soil Cleanup Levels
Ra-226	120 Bq/kg[a] (3.1 pCi/g[b])
U-234	8,100 Bq/kg (220 pCi/g)
U-235	1,900 Bq/kg (52 pCi/g)
U-238	4,100 Bq/kg (110 pCi/g)
Total Uranium	1,100 ppm[c]

Footnotes:
[a] Bq/kg = becquerels per kilogram
[b] pCi/g = picocuries per gram
[c] ppm = parts per million
Note: The ROC-specific cleanup goals for uranium isotopes met the cleanup goal for total uranium of 1,100 parts per million because the three concentrations of uranium isotopes above collectively equal 347 parts per million.

ROC concentrations were combined for each FSS soil sample by calculating a sum-of-ratios

(SOR) for the ROCs to show compliance with the Soil Cleanup Criteria.

Final Status Survey Design

The FSS was designed to include 100% gamma walkover survey (GWS) coverage in all remediated areas; collection of 24 systematic samples within each remediated survey unit and; collection of biased samples to investigate potentially elevated areas flagged during GWS. All areas where remediation was performed were considered MARSSIM Class 1 areas. The minimum of 24 systematic measurements to be collected for every 2,000 m^2 of excavation area yields 83.3 m^2 grid spacing per 2,000 m^2 MARSSIM Class 1 survey unit (i.e., the MARSSIM maximum size recommendation for a Class 1 outdoor survey unit). Consistent with the design parameters intended by MARSSIM, the FSS was designed to address surficial soils in remediated areas and was not intended to address subsurface soils (i.e., soils greater than 0.15 meters [approximately six inches] in depth). Samples were collected and analyzed from subsurface soils to verify assumptions made during site characterization.

Restrictions for Future Use of the Site

The selected remedy in the decision document requires the implementation of institutional controls to restrict future use of property and groundwater for the Site:

- Restrictions to prevent residential use or other uses that present unacceptable risk in the future.
- Groundwater restrictions for the Site and for nearby residences in the form of deed restrictions.

The site has a chain-link fence around its property line, and has concrete jersey barriers placed inside all of the gates installed in the fence to prevent unauthorized vehicle access to the Site. It should be noted that that for the risk assessment it was determined that on-site residential use of the Site is highly unlikely due to the presence of on-site wetlands, power lines, and the abutting former municipal landfill. The selected remedy allows hazardous substances to remain on-site above levels that allow for unlimited use and unrestricted exposure, and as such constitutes a restricted release. A review is to be conducted within five years after initiation of the remedial action to ensure that the remedy continues to provide adequate protection of human health and the environment.

Concurrent Site Remedial and FSS Operations

Remediation of the Site was to be completed under two separate Federal cleanup programs. USACE (the Remediation Team) was the lead agency responsible for cleanup of the residual radioactivity under FUSRAP. Non-radiological contaminants will be addressed under another Federal program. One decision document was developed to outline the entire remedy for the Site.

Remediation and FSS operations were concurrent at the Site. While logistically possible to implement, these concurrent operations created some challenges, particularly for FSS implementation.

DISCUSSION: CONSTRAINTS AND RESOLUTIONS

Multiple Party Cleanup

Multiple stakeholders retained responsibility for these remediation efforts and were involved throughout the implementation process. During FUSRAP related clean-up activities, USACE concurrently worked to resolve questions and concerns from responsible parties involved with the chemical soils clean-up. Conflicting viewpoints/objectives occasionally complicated certain aspects of cleanup and FSS. The Remediation and FSS Teams established clean and open lines of communication to ensure all parties had the information they needed to satisfy their specific stakeholders without overly impeding the remediation schedule.

Management of Physical Site Constraints

Waste Streams Present On-Site

Conducting screening surveys concurrent with remedial operations was a complex and slow process. Given that the matrix of Site Fill was so variable and therefore gamma instrument response was also variable, screening surveys of Site Fill not often provide clear go/no-go information inputs and therefore complicated real time decisions based on instrument response.
A solution was found in excavating nearly all or all material containing this debris until a layer of native "peat" soil was encountered, which served as an organic confining layer encountered at depth across most of the footprint of the Site. This peat layer produced a predictably and reliably lower gamma instrument response than the debris-laden impacted fill above it. The process change in excavating to this readily visible layer expedited the remediation process and lowered the risk of potentially missing contaminated material that might have remained in residual deposits of fill but were not detectable in the field because of the greater uncertainty in field gamma instrument measurements.

Interference from Power Lines

It would seem obvious that the primary concern from overhead power lines is contacting them with the boom from heavy equipment like an excavator. This case was no different. However, in addition to the standard safe-work considerations, the FSS Team encountered significant radio-frequency interference due to the proximity of the sagging power lines to the GWS field Team.

The safety and radiofrequency concerns were discussed amongst stakeholders and a plan was developed and implemented. A specialty subcontractor was hired to cut the existing, wooden utility poles, and raise the high-voltage electric lines by approximately six meters (20 feet) into a "safe zone". Large brackets were used to secure and stabilize both ends of each pole during/after the cuts were made. Additional pole grounding was also conducted to eliminate detectable voltage leaks into Site trailers.

This approach eliminated multiple safety concerns and significantly improved GPS accuracy and performance.

Shallow Water Table

Throughout remedial operations, groundwater was encountered in excavations at depths shallower than the depth of remediation necessary to achieve radiological cleanup criteria. Dewatering was implemented during remediation to help keep excavations dry, but persistent groundwater infiltration and periods of heavy rainfall complicated the execution of FSS in spite of these efforts. Groundwater infiltrated rapidly into larger excavations, at times requiring hours of continuous in situ dewatering to reduce water levels in excavations sufficiently to allow GWS and soil sampling.

Groundwater infiltration resulted in conditions where 10 to 15% of the excavation floors were covered by standing water greater than approximately 3.8 centimeters (cm, 1.5 inches) depth (i.e., the maximum depth at which the GWS instruments could detect the ROCs at cleanup criteria concentrations in soil underlying water). During the periods of heaviest rainfall, large portions of excavation floors were covered by standing water approximately eight to ten cm (three to four inches) in depth in broad areas, and standing water was noted to be approximately 15 to 20 cm (six to eight inches) in depth in discrete areas under 10 m^2 in area. The Remediation Team installed sheet pile to isolate areas to allow for greater water management during excavation and FSS. Sheet piling was used to isolate areas of approximately 70 to 100 m^2 in portions of the Site where excavation to greater depths (up to approximately five meters or 17 feet depth) was required to chase contamination and release areas used for dewatering sumps.

These conditions complicated FSS implementation as follows:

- Recurrent standing water in excavations prevented implementation of FSS in accordance with design specifications and yielded GWS gaps; GWS was not performed in areas where groundwater accumulated on excavation floors and in sumps at greater than approximately 3.8 cm (1.5 inches) depth
- The influx of groundwater resulted in running sands slumping into excavations and covering portions of the area prior to FSS completion, also yielding GWS gaps
- The separation of remediated areas into discrete enclosures of approximately 70 to 100 m^2 precluded the normal practice of assigning sample locations one SU at a time (with each SU comprising 2,000 m^2)

Addressing GWS Data Gaps

Gamma walkover survey data gaps were addressed by collecting extra biased samples to fill gaps where no scan survey data was collected. The FSS Team designed and implemented a method to determine where additional bias soil samples were required to fill gaps in GWS based on the MARSSIM elevated measurement comparison.

Although actual GWS coverage approached 100% in Class 1 areas, GWS data gaps existed due to temporary or partial loss of GPS satellite reception, lapses in real-time data transfer between radiological and GPS instruments, interferences and, imperfections in GPS data logging capabilities. Other gaps in GWS data were due to site conditions, such as running sands slumping into excavations and covering portions of the area prior to FSS completion and pockets of standing water greater than approximately 3.8 cm (1.5 inches) depth due to groundwater infiltration and collected in sumps that were installed for dewatering purposes.

To address small areas of elevated residual radioactivity that might have been missed due to GWS data gaps, the FSS Team calculated the necessary number of samples to collect from these GWS gap areas to demonstrate compliance with MARSSIM Elevated Measurement Comparison (EMC) criteria. The necessary number of samples was calculated based on area factors established to calculate $DCGL_{EMC}$. To apply area factors based on ROC concentrations, conservative assumptions were made to apply the highest concentrations of the ROCs within any of the FSS samples. This approach was used on a SU by SU basis to assign additional biased sample locations to GWS gaps to reduce the size of areas where samples were not collected. Placement of these additional biased samples was performed using professional judgment.

Streamlining Concurrent Remedial and FSS Operations

Under ideal conditions for implementing final status surveys, an area would be excavated until screening measurements/samples concluded that there was no residual radioactive contamination remaining above the DCGL. Then, the exact footprint of the excavation would be mapped, its exact area calculated, and systematic locations would be plotted to fit that area. At this Site, this approach was not applicable. Once the remedial contractor indicated that the area met screening surveys requirements, the FSS needed to be performed in relatively short order because dewatering operations needed to continue until FSS was complete within each excavation, and remediation in another area while FSS was being conducted was not logistically practical.

Concurrent remedial and FSS operations necessitated that methods be developed to allow FSS performance and associated disposition decisions to proceed quickly to allow backfilling and remediation to proceed in another area of concern. The FSS Team designed and implemented a site-wide systematic grid that dictated where systematic sample locations were to be collected anywhere within the Site footprint where remediation was performed. Final status survey operations began utilizing the planned 24 systematic sample locations per survey unit, but it was determined that remediation in relatively small, non-continuous areas could conceivably yield 2,000 m^2 of discrete excavated areas where much of the excavated area fell between site-wide systematic grid locations. This could hypothetically lead to 2,000 m^2 of post-remediated backfilled area with many fewer than 24 systematic samples collected to substantiate the FSS.

Based on the risk of this potential outcome, the FSS Team adopted a more conservative grid spacing based on 33 systematic sample locations per 2,000 m^2 survey unit (approximately 60 m^2 grid spacing) to mitigate the risk of having too few systematics for any reasonable configuration of discrete excavated areas comprising 2,000 m^2. The denser grid spacing was also implemented to help ensure no sample data gaps resulted post-backfilling, particularly in areas where FSS operations were complicated by the presence of sheet piles.

An on-site laboratory was established and analyzed samples to provide both remedial operations and FSS operations with real time radiological analyses for disposition decisions. Biased samples were collected from locations with the highest field-observed GWS count rates as opposed to locations identified through GWS post-processing. Collecting biased samples in this manner assured that sample results data represented the "worst-case" conditions (i.e., the locations of maximum GWS readings) which could reliably support stakeholder decisions to backfill an open excavation. Biased samples were first analyzed by the on-site gamma spectroscopy laboratory as a screening tool to compare soil concentrations to soil release criteria. These on-site results were used to make real time disposition decisions regarding whether a given excavated area was ready to be backfilled. All soil samples utilized in quantitative FSS decisions were submitted for off-site laboratory analysis. The off-site laboratory data served as the definitive record of release results.

Representativeness of the Off-Site Background Reference Area

A reference area (RA) was established across the street from the Site. This RA was sampled and samples were analyzed for the ROCs (all of which occur in nature). Data from the RA samples were used to establish background values for the each of the four ROCs (based on mean activity concentrations).

Once FSS soil sample data was available, it became evident that approximately two thirds of Ra-226 concentrations from remediated areas were below the concentrations in the RA indicating that the Ra-226 concentration in the RA was not necessarily representative of the distribution of Ra-226 in background throughout the Site.

This development prompted reevaluation of the RA dataset and consideration of an alternative approach. These reevaluations confirmed that all materials within the Site footprint were impacted and could not be utilized to provide non-impacted background data, and that the geology of surrounding potential reference areas were not sufficiently similar to soils within the Site footprint to provide representative reference soil.

A revised alternative approach was utilized to generate reasonably representative background RA data for use during FSS and subsequent evaluations. The strategy was to split the Site into four “quadrants” and determine new radionuclide “background” concentrations for each quadrant. The systematic sample results from each quadrant were then examined during FSS data evaluation.

- If greater than 50% of the sum-of-ratios (SORs) for the systematic sample results within each quadrant were below the SOR of the RA average, new background values were calculated for the ROCs and were applied retroactively to the SUs within each quadrant.
- If greater than 50% of the SORs for the systematic sample results within each quadrant were above the SOR of the RA average, the RA mean activity concentrations were used as background values.

When needed, Quadrant-Specific Background Values were calculated by ranking the systematic sample points within each survey unit by SOR, removing the highest 10% of the SORs, and calculating the mean value of each ROC for the lower 90% of the SORs. The mean average of these lower 90% ROC values for each SU was averaged to compute a reasonably conservative new background value for each quadrant; these newly-calculated background values were only applied in each quadrant if the calculated value was less than the RA mean concentration for each ROC.

Survey Approaches for Areas of Concern Inaccessible via GWS

Routine FSS implementation for land areas involved GWS and soil sampling and analysis at systematic and biased locations. Logistical problems sometimes yield conditions where soils requiring FSS are not directly accessible for surveying (e.g., the area of interest may be overlain by non-impacted material). The simplest method to address area of interest in this setting is the use of heavy machinery to render them accessible (e.g., using excavators to lay these materials into 15 cm (approximately six inch) thick lifts to readily perform GWS). Several areas of concern were not accessible for direct survey via GWS and logistical restrictions precluded the use of heavy machinery to render them accessible.

- Throughout the course of remedial operations, excavations were typically expanded vertically until the peat layer of soil was encountered, which served as a confining layer encountered at depth across most of the footprint of the Site. Peat was typically overlain by Site Fill deposits and Site Fill was therefore the target of remediation operations. In some areas, these fill deposits extended beyond the Site footprint, and survey of these deposits was required to ensure that no residual contamination remained. Yet these Site Fill deposits were overlain by other soil deposits, which were up to approximately three vertical meters (approximately ten vertical feet) thick. These areas were surveyed by means of collecting subsurface samples using a direct push technology probe to sample intervals containing Site Fill material. Samples were collected from Site Fill deposits in areas where excavation did not reach the depth of the peat layer, or where no excavation was performed. If Site Fill deposits were not encountered, samples were then collected from the peat layer.
- One area of the Site is covered by deposits of trash up to approximately 2.7 vertical meters (approximately nine vertical feet) thick from the adjacent municipal landfill, and additional investigation was determined to be prudent in discussions to ensure that no contamination was present within the trash or the soil directly below it. This trash material was easily distinguishable from materials that originated from within the Site footprint because the trash was not burned and combustible materials remained intact within the trash matrix. The FSS Team performed a series of test pits in this area to determine if soil and trash indicated evidence of contamination. Contamination was not evident within the trash, and the area was surveyed by excavating test pits at pre-determined systematic sampling locations, surveying each lift of material as it was excavated using a Field Instrument for Detection of Low Energy Radiation (FIDLER) coupled to a global positioning system (GPS) unit, and collecting samples of soil from below the trash. These test pits typically contained trash fill of varying thicknesses, underlain by a layer of soil with commingled debris (most notably broken glass and corroded metal fragments), which was underlain by the layer of peat. The layer of soil with commingled debris also contained ash deposits and other evidence that the debris was historically burned. This layer of soil was therefore determined to be Site Fill and systematic samples were collected from this material.
- Utility poles utilized by the electric company within the Site footprint incurred excavation restrictions, preventing GWS performance and collection of systematic samples in accordance with the FSS design. The FSS Team designed a supplemental methodology for collecting FSS data around these utility poles to preserve the same basic components for Class 1 areas across the entire Site (i.e., excavated areas). This

supplemental methodology was based on preserving the 100% gamma radioactivity scan coverage of all exposed surfaces and the use of random-start, MARSSIM Class 1 systematic grid sampling locations across the entire Site, and adding at least four additional biased samples per utility pole. This supplemental sampling protocol consisted of breaking the area surrounding each pole into four “quadrants” and collecting one additional biased sample from each quadrant at a stand-off distance of approximately 1.5 meters (approximately five feet) from the pole, plus additional sidewall samples from the sides of each island of residual unexcavated soil. These sidewall samples were intended to avoid leaving a vertical “step” between the edge of unexcavated islands of soil surrounding each utility pole and the surrounding Class 1 surveyed areas. Augmenting the sampling protocol with these additional locations was intended to compensate for the inaccessible “islands” of soils residing within the “right-of-way” perimeters and avoid leaving uncharacterized masses of soil within contaminated and potentially contaminated areas of the Site as additional conservative measures added to further verify that significant elevated areas were not present. Some soil samples did confirm that discrete pockets of contamination do exist around some of these utility poles at concentrations in excess of the Soil Cleanup Criteria. However, the risk presented by this contamination still allows these areas to meet overall site remediation objectives utilizing MARSSIM framework. Despite this, any future remediation operations that disturb residual soils around utility poles or at depth at any location within the footprint of the Site should include analyses for the ROCs to control worker exposures to radioactivity, properly characterize soils removed for waste characterization with respect to known sources of contamination at the Site, and to ensure compliance with the Soil Cleanup Criteria for soils allowed to remain in place.

Accounting for Thorium-232

The on-site lab determined that some screening samples contained Th-232 based on surrogate Ac-228 results under assumed secular equilibrium with the remaining decay series and Th-232 parent. Remediation stakeholders removed soil containing elevated residual Th-232 contamination, predominantly collocated with Site ROC contaminants, based on gamma spectroscopy sample results and gamma walkover survey results. The Chebyshev Upper Confidence Limit (UCL) for Th-232 was calculated using EPA’s ProUCL software [2] for all Ac-228 systematic sample results. The Chebyshev UCL concentration under assumed secular equilibrium was modeled using RESRAD version 6.5 [3] to ensure compliance with the 1×10^{-5} ELCR release criteria. The RESRAD model predicted the maximum dose and maximum ELCR of 2.91×10^{-6} at year zero.

CONCLUSIONS

Results

Data collected during the performance of test pits and collection of subsurface samples at each site-wide systematic grid sampling location, both within the Site footprint and in areas that adjoin the footprint where additional FSS was performed, were compiled to generate a map of residual Site Fill deposits following remediation. These data were adequate to estimate the vertical thickness of these Site Fill deposits throughout the Site footprint and adjoining areas.

These thicknesses were then compared to the thickness used in dose modeling for the site performed to support the establishment of the 1×10^{-5} ELCR release criteria for the ROCs.

Confirmation that the vertical thicknesses of these residual Site Fill deposits were smaller than the modeled thickness, coupled with extensive FSS soil sample data consisting of over 1,000 sample locations, substantiate that ROC concentrations within these residual Site Fill deposits are below those applied in dose modeling (i.e., the soil cleanup criteria values), and provide comprehensive confirmation that remediation objectives were met. Given the volumetric assumptions of modeling used to establish the Site's risk-based cleanup criteria, the volume of the remaining deposits presented less residual risk than the original modeled volume.

All survey units achieved the FSS objectives and meet the 1×10^{-5} ELCR release criteria for restricted site release. An analysis was performed to confirm that Data Quality Objectives were met by recalculating the relative shift for each survey unit using the median and standard deviation of the SOR. All radiological areas of concern have demonstrated compliance with the soil cleanup criteria using a MARSSIM framework and have been released from radiological controls. However, restrictions for future use of the Site remain in place and any future remediation operations that disturb residual soils around utility poles or at depth at any location within the footprint of the Site should include analyses for the ROCs to control worker exposures to radioactivity, properly characterize soils removed for waste characterization with respect to known sources of contamination at the Site, and to ensure compliance with the Soil Cleanup Criteria for soils allowed to remain in place.

Lessons Learned

The following items were demonstrated to be effective methods and are advisable for similar projects:

- Providing an on-site lab to support real-time decision-making
- Assigning systematic locations using a site-wide grid
- Establishing a higher sample density for the site-wide systematic grid than original FSS design

The following items should be considered for planning purposes with similar projects:

- Sites containing varied waste material types and random, wide-spread deposition of contaminants may be more effectively surveyed through inclusion of test pits to complement or replace soil borings
- The use of sample grinders was found to achieve better split sample correlation for certain waste materials
- On projects where concurrent remediation and FSS activities are occurring, it is important to ensure that sufficient communications and protocols are in place between the remedial team and the FSS team, while maintaining the independence of the FSS team

REFERENCES

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