Application of Soil Segregation Technology: Reducing Uncertainty and Increasing Efficiency at an NRC test reactor Decommissioning site - 11244

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ABSTRACT

During a recent National Aeronautical and Space Administration (NASA) test reactor decommissioning project, including a significant volume of site soil contaminated with mixed fission and activation products, a unique approach to open land area (soil) remedial action design was implemented to effectively manage end-point uncertainty in regards to the characterization of both remediated soil for transportation and disposal offsite and also excavated soil meeting the site unrestricted release criteria. The approach used soil segregation technology to characterize impacted material with precision and accuracy not possible with traditional field scanning coupled with sample and analysis driven soil remediation. Utilizing a soil remediation work plan centered around the auto-segregation of excavated material for determination of status (transport offsite for disposal or stockpiled onsite for use as fill), the impacted footprint of the test reactor site was excavated and 100% assayed via gamma spectroscopy using the soil segregation system. The Nuclear Regulatory Commission (NRC) approved derived concentration guideline values (DCGLs) for the key radionuclides combined with historical site characterization data was used to determine an appropriate segregation threshold for Cesium-137 as a surrogate for the mix of radionuclides present. The segregation process produced separate below and above unrestricted release criteria material stockpiles whose volumes were optimized for maximum refill and minimum waste. The below criteria material was returned to the excavation, while the above criteria material was packaged for offsite disposal. To satisfy the NRC approved decommissioning plan requirements, a quality control sample and analysis program was developed based on the Multi-Agency Radiation Site Survey and Investigation Manual (MARSSIM) guidance. The process of determining which soils were greater than the acceptance criteria (waste) and which were acceptable to use onsite as refill was completed with substantially reduced uncertainty.

The commercially available, in-line gamma spectroscopy system was used to assay greater than 180 million pounds of soil during the project in support of the NRC license termination/decommissioning plan implementation. The major projected benefits of this approach are reviewed as well as the performance of the segregation system and lessons learned including: 1) Total, first-attempt data discovery brought about by simultaneously conducted characterization and final status surveys, 2) Lowered project costs stemming from efficient analysis and abstraction of impacted material and reduced offsite waste disposal volume, 3) Lowered project costs due to increased remediation/construction efficiency and decreased survey and radio-analytical expenses, and 4) Improving the decommissioning experience for both the licensee and the regulatory agency with new regulatory guidance.

INTRODUCTION

The decommissioning process used by the NRC and EPA to evaluate, remediate, and ultimately remove a site from regulatory oversight has flexibility brought about by dose-based acceptance criteria [1, 2, 3, 4, 5, 6, 7 and 8]. The process establishes a radioactivity concentration 'clean' criterion based on site specific parameters and the anticipated as-left condition of the site. Remedial decisions are subsequently made based upon the comparison of site characterization data to the cleanup criterion. When the remedial action ends with the residual concentration below the established cleanup criterion, a final status survey is performed and submitted to regulators to demonstrate compliance.

The entire process ends in final status surveys designed using the guidance of the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), to show compliance with the derived acceptance criteria. Although the acceptance criteria are based on 3-dimensional volumetric models of the site, MARSSIM guidance is based on 2-dimensional survey surfaces [9]. The disconnect between the 3-dimensional model derivation of acceptance criteria and the 2-dimensional final status survey is easily resolved using the soil segregation technology decommissioning strategy.

COMPARISON OF SOIL REMEDIATION APPROACHES

Since the cost of transportation and disposal (T&D) of contaminated material is often the highest relative to the overall decommissioning costs, decommissioning planning centers on technical approaches that minimize waste T&D. This planning must balance activities achieving the dual objectives of minimal waste T&D and acceptable as-left site conditions. The conservative exposure scenarios (e.g., residential farmer) and inputs typically used to establish site acceptance criteria (Derived Concentration Guideline Values, DCGLs) ratchet "acceptable" to a very low threshold. While this ratcheted threshold bounds the uncertainty in the remediated site conditions (and the certainty of regulatory release), it also ensures an increase in T&D activities.

Traditionally, there has been an unfortunate imbalance during planning on the emphasis placed on achieving the dual objectives, resulting in as-left site conditions that are acceptable but at a disproportionate T&D cost. Understandably, the traditional approach was justified because it minimized the impact of uncertainties about the as-left site conditions—a natural risk avoidance measure. In addition, the use of overly conservative assumptions ensures regulatory approval. In contrast, recent developments in automated radiation detection system technology make possible a new approach providing an optimized balance between waste T&D costs and as-left site condition risks. A remarkable feature of the new approach is the cost-favorable reduction in unacceptable risk associated with the as-left site condition. These approaches, the traditional and new 'unique', are discussed below.

Traditional Approach

The hallmark of traditional soil remediation is excavating above-DCGL soil so that only below-DCGL soil remains. The DCGL values are the result of a dose assessment based on the projected as-left condition of the site. Guided by real time remedial action support surveys (RASS) using portable instrumentation, excavation proceeds until surveys indicate the remaining 'bank' soil is below the DCGL values. Next, a final status survey (FSS--full or partial surface scanning and systematic random-start, equal-distance soil sampling/laboratory analysis) is performed and the results evaluated to determine whether additional remediation is necessary or the survey unit meets the acceptance criteria. Many RASS plans include intermediate sampling and preliminary screening of samples to confirm that the survey unit should meet the criteria and is ready for FSS. The RASS/FSS process involves a "hurry up and wait" routine for the construction faction of the project and an intense effort by the health physics crew.

RASS and FSS designs using MARSSIM guidance include calculations of scan Minimum Detectable Concentration (MDC) values usually at the 95% confidence level (CL), depending on the project Data Quality Objectives (DQOs). For sites contaminated with multiple radionuclides, the sum of fractions ("Unity Rule") is used to show compliance. Therefore, scaling factors (SFs) are also calculated at the 95% CL to relate radionuclides that cannot be detected by gamma scans of soils to radionuclides that are easily detected. The SFs reduce the MDC values so that scans can be used to indicate when remediation is complete based on the entire radionuclide mix. The SF-based scan threshold is necessarily at a very small level and results in an unrealistic but conservative guide to remediation.

The result is usually over-remediation to ensure all of the material above the acceptance criteria is removed prior to beginning the final status survey. Over remediation in this case includes sending the excess excavated material off site for disposal, escalating project cost. The as-left condition of the open land area includes areas of excavation to various depths and other areas that have not been excavated. For consistency with dose assessment assumptions, the FSS protocol often interprets the as left radionuclide concentrations as those existing in the top 15 cm (6 in) of soil of the exposed soil bank. However, the detection depth actually varies from area to area corresponding to the extent of remediation in each area. MARSSIM design final status surveys usually characterized only the top 6-inches of soil remaining which may be radically different than the contaminated zone (CZ) used to develop the DCGL values. The consequence is an ill-defined CZ that may or may not reflect the original dose assessment CZ used to derive DCGL values and is difficult to abstract into a forward dose assessment (reassessment).

Traditional Approach Limitations

The principal limitations of the traditional approach to soil remediation are:

- By convention, the interpretation of FSS survey unit scan data is limited to a depth of 15 cm (6 in). While the actual detection capability may be more intrusive than this, this capability is not used to abstract the source term through these deeper layers to refine the site conceptual model in a forward dose assessment. If the contamination zone extends deeper than the MARSSIM-ideal surface 15 cm (6 in), reliance on scan measurements to identify elevated concentrations is severely limited.
- Left imbalanced, the desire to reduce uncertainty in as-left site conditions by incorporating conservatisms during remediation planning (e.g., exposure scenarios, RASS/FSS scan MDC's thresholds) forces a disproportionate escalation in T&D activities.
- The efficiency of physical remediation work is compromised by labor-intensive manual RASS and FSS activities.
- Soil handling throughput and RASS/FSS activities are incompressible tasks in the project schedule. Consequently, the ability to reduce costs by accelerating time-sensitive tasks and reducing the schedule duration is very limited.

Unique Approach

Given the traditional approach limitations listed above, a unique soil remediation and waste minimization strategy was implemented. The unique approach combined a remediation strategy of over-excavation in the impacted area (resulting in improved certainty in compliance with the approved residual radioactivity limits in the as-left site but higher excavated soil volumes), with automatic assay and segregation of excavated material using a gamma spectroscopy soil sorting system mounted above a conveyor belt. The assayed material is separated into two piles (above and below criteria) based on continuously acquired gamma spectra. Because the segregation system offers excellent counting statistics and sensitivity, the below criteria material can immediately be returned to the excavation (survey unit) as backfill. The above criteria material is staged for further segregation/blending (as necessary to satisfy waste acceptance

criteria), packaging and offsite transport to a disposal facility. Depending on regulatory commitments in the decommissioning plan(s), either the below criteria stockpile or the backfilled area may be subject to a confirmatory FSS for as-left dose reassessment purposes.

Elements of a remediation plan may include: impacted area excavation logistics, material segregation, refill construction, segregating/blending above criteria material for packaging and offsite disposal, and placing clean fill cover material to grade. The remediation plan also specifies the performance and operational parameters for the automated segregation system including: the necessary gamma spectrometry data acquisition, management, and software implementation protocols (nuclide sensitivities, uncertainties, segregation setpoints, data manipulation and storage) and logic control interfaces with material handling equipment. The material handling (conveyor) equipment may also include weight and density sensors and programmable logic controllers to dynamically control feed material processing.

The employment of the segregation system and software provided unparalleled counting statistics power. In fact, the system's material handling parameters yield geometrical consistency assuring that virtually 100% of the material being processed is examined by gamma spectrometry. This capability is a critical feature reducing the labor and expense of a remediation project. For example, in a traditional soil remediation project, labor-intensive RSS and FSS crews are deployed to identify remaining elevated areas with follow-on equal distant collection and laboratory analysis of soil samples to determine average radionuclide activity concentrations. If any elevated areas are identified by the FSS, the areas are either remediated again and resurveyed, or an elevated measurement comparison (EMC) is performed that (hopefully) demonstrates compliance. All of these activities are unnecessary (for the excavated volume of impacted material) with the segregation system.

Unique Approach Advantages

The advantages of the unique approach are:

- Data over-sampling to achieve greater than 100% scan/sample coverage of the entire volume of impacted material excavated, i.e., 100% coverage characterization and final status surveys. The coverage afforded by the segregation system is far greater than a walk-over, gross gamma scan of remediated areas and exceeds MARSSIM DQOs developed for the FSS.
- Continuous presentation of laboratory-equivalent FSS scan and discrete sample data (concurrent with material processing).
- Continuous and direct comparison of the processed material radionuclide profile to the backfill acceptance criteria, eliminating the uncertainty associated with estimating the activity concentration of the material based on gross gamma count rate of a portable survey instrument.
- Continuous and direct comparison of the processed material radionuclide profile to disposal facility waste acceptance criteria.
- Remediation (construction) activities uninterrupted by RASS and FSS activities.
- Near extinction of concerns about the adequacy of site characterization in identifying surface or subsurface contaminated zones. All material, regardless of the depth located, is processed through the segregation system.
- Huge cost advantage brought about by a sorting technology allowing tasks to be significantly compressed for diminished project duration. In the decommissioning project presented below that routinely processed over 907 MT/day (1,000 ton/day), it is estimated that total project costs were reduced by approximately $30MM and schedule was reduced by 18 months in comparison to a traditional mass excavation and disposal approach.

DEPLOYMENT OF SOIL SORTING TECHNOLOGY

A former NASA test reactor site undergoing decommissioning recently utilized a unique approach to achieve future unrestricted release. Elevated levels of radioactivity were discovered during decommissioning activities in soil and sediment material in the vicinity of a former NASA nuclear reactor. During the planning phase of the project, consideration of the traditional remediation approach utilizing a residential farmer exposure scenario to derive DCGLs was given. The traditional DCGL value derived for the surrogate radionuclide (Cs-137) was 0.38 Bq/g (10.3 pCi/g). At this cleanup level, the anticipated remedial action would require excavation of approximately 51,700 MTs (57,000 tons) of material slated for disposal offsite. In this way, the traditional approach produced staggering waste volume, and attendant anticipated cost.

Soil segregation was added to the planned soil remediation scope. Prior to soil segregation activities, a field scan threshold was developed to identify in-situ soil with radioactivity significantly greater than the DCGL criteria for the site. This material was excavated and stockpiled for transportation off site for disposal. The remaining soil greater than background but below the high field scan threshold was stockpiled for soil segregation. This volume of soil was the vast majority of soil excavated and exceeded 88,000 MTs (97,000 tons).

Segregation System

The segregation system (Figure 1 through Figure 3) deployed combined gamma scanning (rolling detection; Figure 2) with gamma spectrometry, the two features of MARSSIM-based FSS. The conveyor counter utilized a fixed platform radiation detection system mounted over a rubber belt conveyor. The system contained two large-volume thallium-doped sodium iodide (NaI(Tl)) detectors housed in an environmentally controlled box for temperature stabilization and background radiation reduction. Gamma spectra in pre-defined energy ranges were collected successively over a fixed distance interval (122 cm) using a Multi-Channel Analyzer (MCA). The system was operated from an adjacent mobile trailer. The system included a controller for conveyor belt speed and sensors for conveyed material depth, detector temperatures, belt speed, and reversing belt direction.
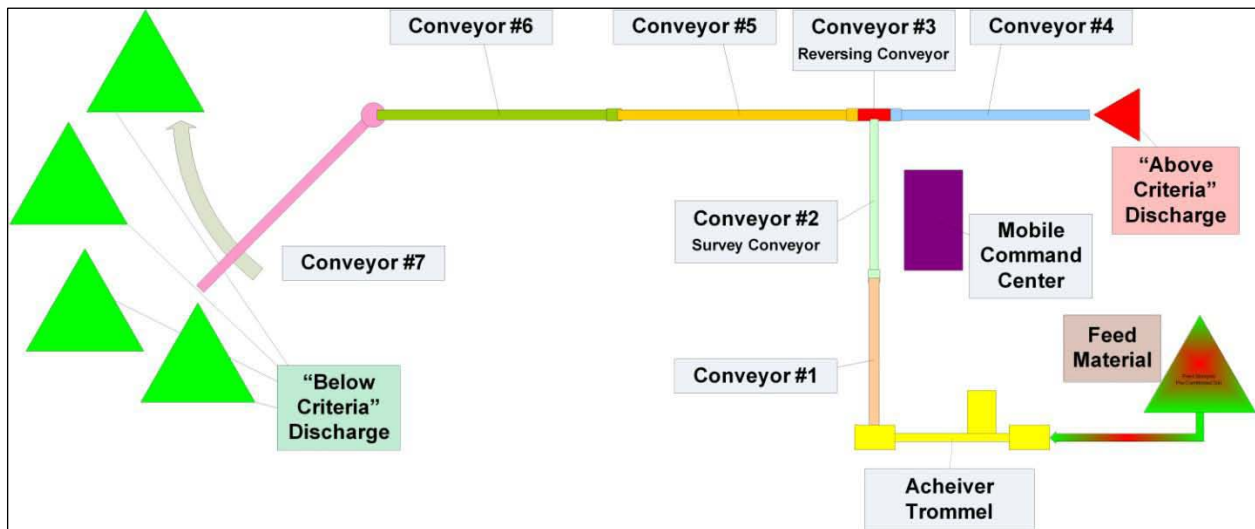

Figure 1Layout of Soil Segregation System View A

Figure 2Survey Conveyor and Environmentally Controlled Detector Box (White)

Calibration

Segregation system calibration to large volumes of soil with known elevated radioactivity concentrations is considered the most accurate method of calibration. Due to the lack of commercially available large volume calibration standards, volumes of soil standard material were collected from the site in areas with measureable Cs-137 activity. The soil volumes were prepared into calibration standards by homogenizing the material and assaying the radiological concentrations using the soil segregation systems' sodium Iodide (NaI) detectors, and by laboratory gamma spectroscopy analysis of a series of representative volumetric samples collected from each calibration reference standard. An unbroken chain of propagated errors tracing the calibration sources back to the National Institute of Standards and Technology (NIST) was established, making the sources NIST-traceable.

Operation of Soil Segregation System

Prior to assay by the soil segregation system, excavated material was pre-conditioned by drying (land farming) material and sizing it through a vibrating screen to remove debris over 10 cm (4 in) in diameter. The tilled and sized feed material was loaded by an excavator into the large hopper of an Achiever trommel. The rotating trommel drum provided a smooth and steady flow of soil material to the survey conveyor where material height was regulated by a "strike-off" bar which maintained a maximum belt fill depth of 15 cm (6 in). Depending on the operating conditions and data requirements, the material traveled at typical conveyor speeds between 30-70 cm/s beneath the suspended NaI detectors. The gamma spectrum was acquired for 122 cm of material, termed an "observation," and isotropically compared to the segregation criteria 0.192 Bq/g (5.2 pCi/g) Cs-137, half of the surrogate DCGL value for Cs-137, in real time. The position of each observation was automatically tracked by the segregation system as it

travelled along the survey conveyor. Once the material reached the end of the survey belt, a proprietary reversing conveyor diverted the material to either the above or below criteria stockpiles depending on its volume-weighted average activity concentration.

The segregation system data is processed with algorithms similar to those developed for sonar. The algorithms greatly reduce the statistical fluctuation normally encountered in scanning detection. During each 122 cm observation (viewing approximately 79 kg (175 lb) of soil), the process computer records the spectra and live time from the multi-channel analyzer (MCA), the conveyor distance traveled, and the average height of the material. While these signals are collected and monitored during operations, the system offers real time, low-level radiation alarming functions based on data analysis.

Figure 3Layout of Soil Segregation System View B

The segregation system data was used to calculate a weighted average activity concentration of the material in both the above and below criteria discharges. Material sent to the below criteria side was discharged into distinct batches and isolated until the confirmatory radiological soil sample measurements verified the segregation system's response. Batch pile size of a nominal 450 MT (500 tons) was implemented as an analogous volume to a MARSSIM Class 1 Survey Unit suggested maximum size [9].

QA/QC

In order to meet the QA/QC requirement to re-survey 5% of the material as required in the site final status survey plan (FSSP), another unique approach was required to minimize the cost and effort to fulfill such a requirement. Traditional approaches would have required the establishment of a laydown area where Radiation Protection Technicians (RPTs) could effectively hand-scan a 6" lift of the assayed material. Instead, an auxiliary detection system was configured and installed to monitor material discharged to the below criteria stockpile. The auxiliary system consisted of two large volume NaI detectors shielded and housed in environmentally controlled boxes similar to the soil segregation detectors. The auxiliary system operated on an identical version of software as the soil segregation system, using the same algorithms to perform real time density corrected gamma spectroscopy. The detectors, sensors, and support electronics were mounted on and around a transfer conveyor (Figure 4) carrying "below criteria" material to the backfill stockpile area (conveyor #6 in Figure 1), such that no additional material handling was required.

Additionally, confirmatory soil samples were collected throughout the project as part of the soil sorting project's internal quality process and FSS requirement. A radiation protection technician (RPT) collected a representative number of samples from each "below criteria" survey unit. Samples were submitted to the onsite radiological assay lab for analysis. Sample results from each survey unit were compared with the results generated by the soil segregation system's software.

Figure 4Auxiliary QA/QC Detection System Mounted on Conveyor #6

Results

Over 88,000 MTs (97,000 tons) of material was sorted during the project. More than 1,636,000 measurements were taken by the segregation system, assaying 211 piles. The data indicates that the 211 piles assayed during the soil sorting campaign had an average Cs-137 concentration only slightly higher than background levels, with a maximum mean pile concentration of 0.0148 Bq/g (0.4 pCi/g). Table 1 lists the segregation system's typical data processing output.

Table 1 Segregation System Batch Output Results

Volumetric Sorting Record
Radioactive Characteristic Profile

Survey Area	Contaminated Stockpile
Survey Unit	0052
Survey Equipment	ORION M302
Survey Date	9/22/2009 6:33:56 AM to 9/22/2009 9:35:55 AM
Survey Operator	Gabe Posner
Material Surveyed	Soil
Criteria	5.2 pCi/g
Number of Measurements	6723
Total Tons Processed	454.61　(909,229lbs)
Number of Diversions	25
Total Tons Diverted	3.85　(7,708lbs)　(0.85 % of Total)

Table 1. Below Criteria Volumetric Concentration Reported in pCi/g

Isotope	Mean ± 95% Confidence	Median	Maximum	Minimum	2-Sigma Population Variance
Net Cs-137	0.1 ± 0.01	0.1	1.9	-2.0	0.9

Table 2. Diverted Volumetric Concentration Reported in pCi/g

Isotope	Mean ± 95% Confidence	Median	Maximum	Minimum	2-Sigma Population Variance
Net Cs-137	0.0 ± 0.06	0.0	1.9	-1.8	0.9

Note: Soil was also diverted for low density, i.e., if soil passing beneath the detectors was not of sufficient density to provide the appropriate counting geometry/statistics, the soil was diverted.

The auxiliary detection system re-assayed over 30,844 MTs (34,300 tons) of material, and collected 1,044,000 measurements. During its operation, the auxiliary system confirmed that no volumes of soil having a mass of 79 kg (175 lbs) or more and a Cs-137 concentration above 0.38 Bq/g (10.3 pCi/g) were discharged to the "below criteria" side. At the completion of the project the auxiliary system ensured compliance with the FSSP requirement of re-surveying at least 5% of the material by assaying over 35% of material.

The data population generated from the segregation system was further compared with the data population of the laboratory results generated from analyses of confirmatory samples of the below criteria

pile. Figure 5 shows the results were remarkably consistent with regard to both precision and accuracy, having an average differential in reported means of approximately 0.0074 Bq/g (0.2 pCi/g).
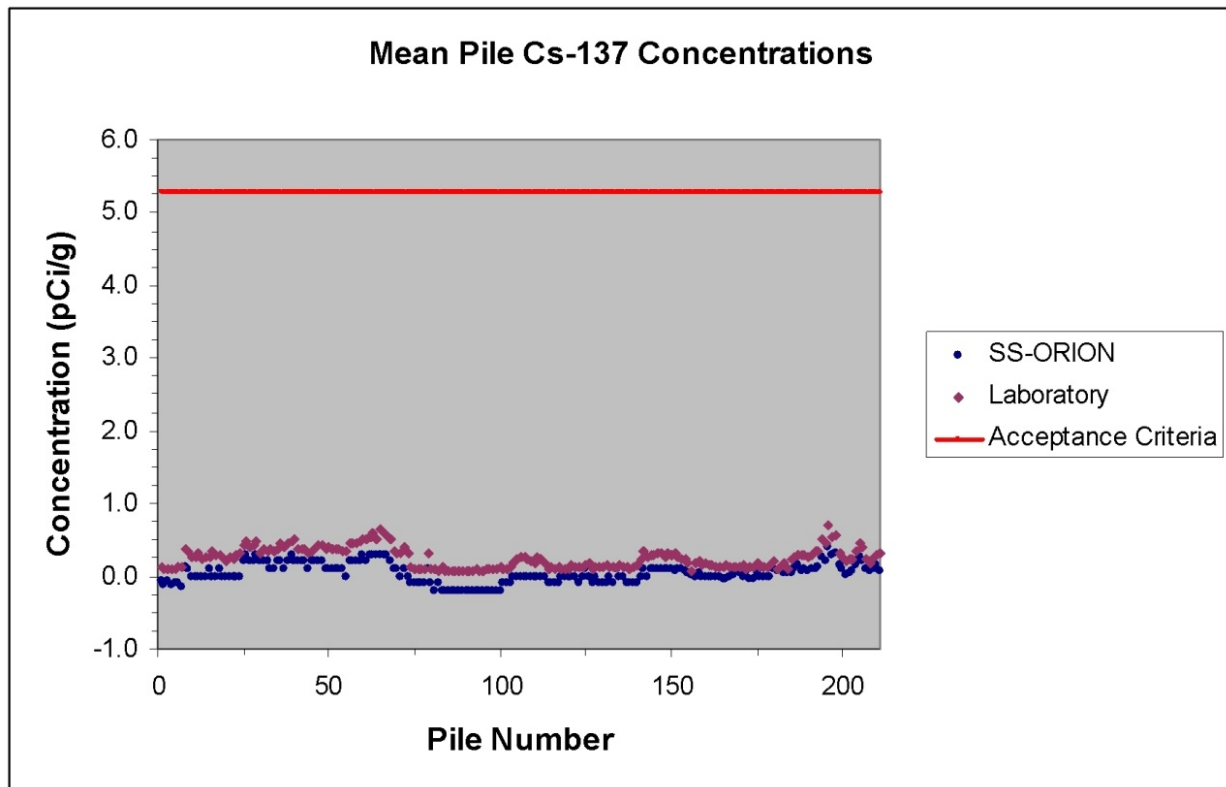

Figure 5Comparison of Reported Mean Pile Cs-137 Concentrations

SUMMARY

The development of site-specific cleanup levels and selection of a transparent site cleanup strategy, responsive to both the provisions of the regulators and project economics, are fundamental outcomes of the decommissioning process. From its earliest beginnings, decommissioning planning must focus upon these outcomes. Development and refinement of a conceptual exposure scenario for the site must factor-in vast amounts of information available from historical site assessments, site characterization events, remedial action support surveys, and final status surveys. No longer is it reasonable to accept that an economic remediation automatically follows from a static review of this information. If a dynamic view of the project is maintained, the site-specific decision on cleanup levels and cleanup strategy must be, and will be, defensible on all accounts and in all forums.

Derivation of contemporary cleanup levels must be performed in accordance with the dose-based criteria stipulated in the project plans. During the planning phase of the decommissioning project, approaches satisfying these criteria should be evaluated exhaustively in tractable dose assessments. The evaluations should rank the merits of the entire range of remediation practices, from exclusive 'hog and haul' through aggressive refill and combinations thereof.

The economics of arbitrary or ill-planned offsite disposal of impacted material are too great to ignore the benefits of dynamic segregation and refill. As discussed in this paper, the unique segregation approach

offers powerful control over refill parameter uncertainty while simultaneously reducing offsite disposal capacity needs and data management loads. In contrast, the traditional remediation approach often encounters difficulty in controlling parameter uncertainty in a uniform manner that often times create regulatory concern.

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