DYNAMIC DOSE MODELING / SOIL SEGREGATION: A METHOD FOR REDUCING UNCERTAINTY AND INCREASING EFFICIENCY DURING RADIOLOGICAL DECOMMISSIONING

Andrew J. Lombardo, Richard F. Orthen, Anita F. Mucha
Civil & Environmental Consultants, Inc.
333 Baldwin Road, Pittsburgh PA 15205

ABSTRACT

The regulatory release of sites and facilities (property) for restricted or unrestricted use has evolved beyond prescribed levels to model-derived dose and risk based limits. Dose models for deriving corresponding soil radionuclide concentration guidelines are necessarily simplified representations of complex processes. It is not practical to obtain data to fully or accurately characterize transport and exposure pathway processes. Similarly, it is not possible to predict future conditions with certainty absent durable land use restrictions. RESRAD incorporates the recommended framework to perform human exposure pathway analyses that support the development of remediation guidelines. The methodology for collecting input data for RESRAD and the ranges and typical values of input parameters are discussed in detail in the RESRAD Data Collection Handbook. The Handbook's RESRAD input data were chosen by its authors to be realistic yet reasonably conservative, thus generating remediation guideline values that should overestimate actual dose. This approach introduced a convenient derived guideline calculation standard (framework and uncertainties) easily adopted by decommissioning project managers. However, this convenience bears a risk that is the project manager's nemesis—excessive remediation. Uncontrolled, this pervasive risk escalates project costs far from its baseline and diminishes the end-state effectiveness.

Because the calculation standard's uncertainties are carried forward in the derived remediation guideline values, Civil and Environmental Consultants, Inc. (CEC) health physicists developed a unique approach to dose modeling and remedial action design to effectively manage end-point uncertainty. This approach uses a dynamic feedback dose model and soil segregation technology to characterize impacted material with precision and accuracy not possible with static control approaches. Utilizing the remedial action goal "over excavation" and subsequent auto-segregation of excavated material for refill, the end-state (as-left conditions of the refilled excavation) RESRAD input parameters are re-entered to assess the final dose. The segregation process produces separate below and above criteria material stockpiles whose volumes are optimized for maximum refill and minimum waste. The below criteria material is returned to the excavation without further analysis, with the above criteria material packaged for offsite disposal.

Using the activity concentration data recorded by the segregation system and the as-left configuration of the refilled excavation, an end state model of the site can be prepared with substantially reduced uncertainty. In conjunction with field controls on remediation work, this approach not only assures that the physical end state and its model are consistent, but also the variability in future dose is reduced by a significant margin. The major benefits of this approach are: 1) Dual 100% characterization and final status survey of impacted area, 2) Increased stakeholder confidence in dose projections brought about by uniquely thorough MARSSIM surveys, 3) Lowered project costs stemming from efficient analysis and abstraction of impacted material and reduced offsite waste disposal volume, and 4) Lowered project costs due to increased remediation/construction efficiency and decreased survey and radio-analytical expenses.

INTRODUCTION

Although there are differences between the processes used by NRC, EPA and DOE to evaluate, remediate, and ultimately remove a site from regulatory oversight (decommission), the conceptual process is the same since the advent of dose based (or risk based) acceptance criteria [1, 2, 3, 4, 5, 6, 7 and 8]. The process involves first establishing a concentration-based cleanup 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 MARSSIM, Multi-Agency Radiation Survey and Site Investigation Manual, 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 dynamic dose modeling/segregation technology decommissioning strategy. To illustrate this and all of the advantages of the dynamic dose modeling/segregation technology approach, the current NRC decommissioning process will be described. Corollaries to the EPA and DOE processes can be easily drawn.

Decommissioning Process

Decommissioning is safely removing a facility from operations and reducing remaining radioactive contamination to levels that permit license termination. On July 21, 1997, NRC published its final rule "Radiological Criteria for License Termination" which was incorporated as Subpart E to 10 CFR Part 20 (the License Termination Rule or "LTR"). The LTR reflects a risk-informed graded approach that includes both restricted and unrestricted options, and additional options for alternate criteria under certain circumstances. The final rule ushered in all pathways dose acceptance criteria to release a site for restricted or unrestricted use. Dose criteria uses site-specific information when determining acceptable concentrations of residual radioactivity at the site using dose models and exposure scenarios that are as realistic as necessary. Previous to the LTR, the NRC staff used the Site Decommissioning Management Program (SDMP) Action Plan criteria which were concentration-based. These criteria were implemented through guidance only and, absent an exemption from the Commission, no option other than unrestricted use was available to licensees.

The NRC staff subsequently developed soil concentration values to support implementation of the license termination rule and to simplify decommissioning in cases where low levels of contamination exist. These values were published in the Federal Register on November 18, 1998, December 7, 1999, and June 13, 2000. The use of the screening values provides reasonable assurance that the 25 mrem Total Effective Dose Equivalent (TEDE) dose criterion in 10 CFR 20.1402 will be met. However, these convenient screening values are necessarily conservative and do not assure cost-effective decommissioning at most contaminated sites. To achieve this assurance, the decommissioning planning process must incorporate site specific information into a dose-based strategy for acceptance criteria development and confirmation. This strategy departs from the screening value approach in the following ways:

- Characterization (location and concentration profiles) of remaining radiological contamination.
- Calculation of radionuclide-specific acceptance criteria (activity concentrations) using abstracted characterization data in conjunction with the projected final condition of the site in a "reverse" dose assessment;
- Designing the interim (remedial action support) and final radiological survey methods demonstrating compliance with NRC approved dose criteria; and
- Following remediation, conducting final status surveys to obtain the data needed to demonstrate compliance with the acceptance criteria for license termination. Alternatively, the final status survey data may be used in a "forward" dose assessment to demonstrate compliance directly with the acceptance criteria for license termination.

Dose Assessment

Dose based limits allow the site and the regulator to take site-specific information into account in determining acceptance criteria for the site using conceptual models of the site and exposure scenarios that are realistic [10, 11, 12, 13, 14 and 15]. There are two methods used to show compliance with dose based limits through dose modeling. First, a dose assessment can be completed to convert the dose (or risk) based limit for release of the site, e.g., 25 mrem/yr TEDE to the critical group over the next 1,000 years, into radionuclide specific soil activity concentrations, e.g., 5 picoCuries/gram (pCi/g) of Th-232. Compliance is then shown by final status survey measurements post remediation compared to the derived acceptance criteria.

An alternate method is to commit to the scenario(s), model(s), and parameters to be used to evaluate compliance with the dose criterion using the final concentrations as measured. This method requires the site to project expected final concentrations to demonstrate reasonable assurance that the dose based limit will be met at the end of site remediation, when the measured conditions are used to calculate dose. Most sites use the first method or a combination of the two so that the derived activity concentrations can also be used to guide remediation in the field, prior to final surveys. Either way, the dose assessment is usually an iterative process since there is a degree of uncertainty in predicting (optimizing) the final conditions of the site.

The key elements of the dose assessment are: 1) source term abstraction, 2) exposure scenario(s) determination, 3) exposure pathway(s) determination, 4) conceptual model of the site development, 5) dose to the critical group calculation.

Going from a conceptual model to a mathematical model involves a number of assumptions and simplifications. RESRAD is the commonly used computer model used to model exposure from residual soil contamination through environmental pathways.

Computer Model (RESRAD)

RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials [16 and 17]. The RESRAD model and computer code was developed as a multifunctional tool to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive materials. RESRAD is used to:

- Compute soil guidelines (concentrations that will comply with dose- or risk based acceptance criteria),
- Compute potential annual doses or lifetime risks to the critical group (workers or members of the public) resulting from exposures to residual radioactive material in soil,
- Compute concentrations of radionuclides in various media (air, surface water, and groundwater) resulting from residual activity in soil, and
- Support ALARA (as low as reasonably achievable) analysis and/or a cost/benefit analysis that can help in the cleanup decision- making process.

Significant exposure pathways for the critical population group modeled by RESRAD in deriving soil acceptance criteria include the following:

- Direct exposure to external radiation from the contaminated soil material;
- Internal dose from inhalation of airborne radionuclides, including radon progeny; and
- Internal dose from ingestion of
    - Plant foods grown in the contaminated soil and irrigated with contaminated water,
    - Meat and milk from livestock fed with contaminated fodder and water,
    - Drinking water from a contaminated well or pond,
    - Fish from a contaminated pond, and

- Contaminated soil.

Final Status Survey Guidance (MARRSIM)
MARSSIM provides a consensus approach to conducting radiation surveys and investigations at sites impacted by radioactive material. The MARSSIM approach is both scientifically rigorous and flexible enough to be applied to a diversity of site cleanup conditions. MARSSIM provides information on planning and conducting surveys, and on investigating (i.e., by gathering data or information) a potentially contaminated site. Decommissioning that follows remediation requires a demonstration to the responsible federal and/or state agency that the cleanup effort was successful and that the release criterion (based on a specific regulatory dose based limit) was met. In MARSSIM, this demonstration is given the name “final status survey.” MARSSIM also serves as a guide to surveys that monitor remediation efforts prior to a release criterion being applied.

This guidance describes a performance-based approach for demonstrating compliance with a dose- or risk-based regulation. This approach includes processes that identify data quality needs stated as Data Quality Objectives (DQOs) and may reveal limitations that enter into conducting a survey. DQOs must be developed on a site-specific basis. However, because of the large variability in the types of radiation sites, it is impossible to provide criteria that apply to every situation. MARSSIM design final surveys are based on application to a standard 2-dimensional area, regardless of the depth of the residual contamination.

COMPARISON OF TRADITIONAL AND DYNAMIC 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. [The USNRC has acknowledged the cost of T&D of soils is so high that removal of additional soils once criteria have been met is not ALARA (As Low As Reasonably Achievable).] 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 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 ‘dynamic’, are discussed below.

Traditional Approach
The hallmark of the traditional soil remediation approach is precision excavation to reduce the activity concentration of the remaining soil to levels less than the approved dose based acceptance criteria (radionuclide specific DCGL values). The DCGL values are the result of a dose assessment based on the projected as-left condition of the site. Areas are targeted for remediation based on historical information and characterization data. 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 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 decision to end remediation and begin FSS must consider the depth distribution of contamination. Surface-based (and some subsurface-based) characterization studies do not always reveal the correct distribution, undermining the decision to proceed with a FSS. In a survey unit contaminated by a surface liquid spill, the soil activity concentration profile is expected to decrease with increasing depth below the soil surface. In this situation, a RASS indication that the acceptance criteria has been reached would be the only justification needed to perform a FSS of the exposed bank soil. However, other survey unit contamination scenarios exist that do not result in a decreasing gradient of soil activity concentration (e.g., burials of contaminated soil or surface contaminated objects). For this increasing concentration gradient situation, proceeding with the FSS based on an acceptable RASS indication will force FSS failure and remediation rework.

The result is usually over-remediation to ensure all of the material below 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 RESRAD assumptions, the FSS protocol often interprets the as left radionuclide concentrations as those existing in the top 6-inches 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. The important consequence is an ill-defined contaminated zone that is difficult to abstract into a forward dose assessment (reassessment).

In summary, the major limitations of the traditional approach to soil remediation are:

- Whereas the FSS provides data confirming average and elevated radionuclide concentrations within a survey unit, it does not validate other parameters of the site conceptual model used to establish DCGLs.

- By convention, the interpretation of FSS survey unit scan data is limited to a depth of 6 inches. 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 6 inches, 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.

Dynamic Approach

This methodology combines a remediation strategy of over excavation of the entire impacted area, combined with real time automatic segregation of excavated material using a gamma spectroscopy system mounted above a conveyor belt. Excavated 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 refill to "construct" the contaminated zone. 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 [18]. Depending on regulatory commitments in the LTP/DP, the refilled contamination zone may be subject to a confirmatory FSS for as-left dose reassessment purposes. The below criteria refill material can then receive a clean fill cover to grade. The clean fill constitutes the cover in the final dose assessment. The refilled contaminated zone and cover construction details, in conjunction with the radioactivity data archived by the segregation system (and the FSS if performed), can then be used as input to a compliance dose reassessment.

To ensure the as left configuration of the contaminated zone and cover will mirror the model used to demonstrate compliance with the dose based criteria, an initial dose assessment is performed during the planning phase of the project to specify its optimum configuration (i.e., refill construction details) and the compatibility with the impacted material to be excavated and reconfigured. The planning dose assessment may include modeling the site in its current configuration and source term abstraction with the logical critical group and exposure scenario (residential farmer, industrial worker, etc.). The planning dose result will necessarily exceed the dose criteria. Next, using characterization data estimates of impacted (greater than preliminary screening values) area size, the contaminated zone is modeled in various refill physical/radiometric configurations to identify successful (below dose criteria) options. To gauge the precision needed during refill construction assuring success, sensitivity analyses of dose assessment parameters that are controllable during refill construction (principally contaminated zone depth intervals) are performed. These initial dose assessment results can then be used with confidence to develop a remediation plan.

Elements of a remediation plan include: impacted area excavation logistics (including excavator-mounted RASS equipment), 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 includes weight and density sensors and programmable logic controllers to dynamically control feed material processing.

The development of the segregation system and software entailed significant development to achieve unparalleled counting statistics power. In fact, the system's data over-sampling capability assures that *greater than 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 with the segregation system.

In summary, the advantages of the dynamic approach are:

- Data over-sampling to achieve greater than 100% scan/sample coverage of the entire impacted area. The coverage afforded a segregation systems 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 (pCi/g) FSS scan and discrete sample data (concurrent with material processing).

- Continuous and direct comparison of the processed material radionuclide profile to the refill 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.

Case Study

CEC is currently supporting an industrial site decommissioning project to achieve unrestricted release using the dynamic soil remediation approach. Approximately 14 acres of the site are impacted by radioactive material (RAM) consisting of three primary naturally occurring radioactive material (NORM) radionuclides having predictable activity concentration relationships. 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 was 3 pCi/g. At this action level, the anticipated remedial action would require precision excavation of the 14 acre parcel to depths of up to 25 feet, producing approximately 5 million ft^3 of material for disposal offsite. In this way, the traditional approach produced staggering waste volume, and attendant anticipated cost.

Additional work resulted in the remedial action being re-engineered consistent with the assumptions and outcomes of dynamically-derived DCGL calculations. This dynamic model approach (also using a residential farmer exposure scenario) resulted in a surrogate radionuclide segregation (for disposal) criteria of approximately 30 pCi/g in conjunction with excavation of the entire 14 acre parcel. This excavation is guided using a sodium iodide detector system mounted on the excavator boom. Another significant improvement was the complete viewing and segregation of all impacted soil (still defined with an activity concentration greater than 3 pCi/g) by a material handling (conveyor) system controlled by gamma counters (near real-time data acquisition). This system is discussed in the next section. The below disposal criteria material (average concentration of approximately 10 pCi/g based on the refill cutoff at 30 pCi/g) is staged as excavation refill. When placed and compacted back in the excavated survey unit, the refill constitutes a contaminated zone approximately 10 feet thick. The dimensions of the contaminated zone achieved during refill are accurately determined using global positioning system (GPS) radionavigation measurements and traditional survey measurements. Prior to backfill with below criteria material the excavation surface is final status surveyed. The FSS is a traditional MARSSIM designed survey including 100% coverage gross gamma scan and equal distant surface sampling for analytical analysis via gamma spectroscopy, to confirm over excavation is complete.

After developing the engineered contaminated zone with refill, an offsite fill cover (also approximately 10 feet thick) is placed over the contaminated zone to achieve the desired surface contour. The reverse dose assessment of the engineered contaminated zone and cover yields a potential annual residential farmer Total Effective Dose Equivalent (TEDE) of approximately 1 mrem in the maximum year. The above criteria (>30 pCi/g) material, approximately 1 million ft^3 averaging about 54 pCi/g, is shipped off site for disposal. This is a significant reduction from the 5 million ft^3 estimated using the traditional remediation approach. It is also important to note that the *entire* impacted area has been characterized by the over-excavation and automated segregation (greater than 100% coverage) approaches.

Segregation System

The segregation system (a photograph is shown below) combines gamma scanning (rolling detection) with gamma spectrometry, the two features of MARSSIM-based FSS. The conveyor counter utilizes a fixed platform radiation detection system mounted over a rubber belt conveyor. The detector is thallium-doped sodium iodide (NaI (Tl)) encased for temperature stabilization and background radiation reduction. Gamma spectra in a pre-defined energy range are collected successively over a fixed time interval (typically 1 second) using a Multi-Channel Analyzer (MCA). The system is operated from an adjacent mobile trailer. The system includes a controller for conveyor belt speed and a sensor for conveyed material depth.

Fig. 1. Segregation System

Conveyor system feed material is prepared by tilling excavated material to a uniform particle size and sizing it through a vibrating screen to remove debris over 6 inches in diameter, the maximum conveyable size. The tilled and sized feed material is loaded on the conveyor and floated to an even height across the conveyor belt width. Traveling at a typical conveyor speed of 120 lbs/s beneath the suspended NaI detector, the gamma spectrum of the material is acquired and automatically compared to the segregation criteria (30 pCi/g). The above and below acceptance criteria material fractions fall through separate “pant leg” chutes based on signals sent from the sorting logic process computer to the chute diversion gate motor. The sorting logic setpoint is the segregation criteria value derated at the 95th percentile confidence interval DQO. Depending on its volume-weighted average activity concentration, the material is diverted and moved to the above and below acceptance criteria stockpiles.

The segregation system collects data over a fixed time period (data acquisition) as the material moves beneath the detector. The data is processed with algorithms similar to those developed for sonar. This algorithm greatly reduces the statistical fluctuation normally encountered in scanning detection. During each acquisition (1 second, an approximate 120 lb-fraction of soil), the process computer records the spectra and live time from the MCA, the conveyor distance traveled, and the average height and density 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. In addition to the 1-second data acquisition interval, an overlapping 12 acquisition (approximately 1,500 lb or 1 m^3 soil fraction) averaging interval is also used to calculate activity concentration. This averaged value, representing the smallest practical modeling volume, determines whether the scanned soil fractions are above or below the segregation criteria. Since the average is re-calculated with every 1 second data acquisition, each 1 second (120 lb) soil fraction is averaged with 12 subsequent 1-second volumes for comparison to the segregation criteria. The practical and powerful benefit of this averaging scheme is that it provides *greater than 100%* MARSSIM coverage.

The following table lists the segregation system’s typical data processing output:

Table I. Segregation System Batch Output Results.

Material Processed (tons)		Activity Concentration (pCi/g)				No. of Data
Below Criteria	***Total***	***Mean***	***Median***	***Maximum***	***Minimum***	**Acquisitions**
33	34	11.3	11.1	30.7	2.8	914
100	102	8.4	8.2	17.7	1.2	2,718
83	83	10.9	10.8	23.9	4.1	2,239
545	728	16.5	16.2	32.1	0.8	11,173
683	833	16.8	16.6	32.0	2.2	13,474
812	880	12.5	12.6	26.8	2.2	19,133
569	632	16.6	16.3	32.0	2.6	10,423
527	575	12.1	12.0	32.2	1.6	10,407
263	271	7.5	7.4	16.2	1.5	5,370
129	141	7.1	7.0	14.6	1.0	2,989

The segregation system data was used to calculate a weighted average activity concentration of the material placed in the first contiguous backfilled survey unit. The result was 11.9 pCi/g. A MARSSIM final survey of the backfilled survey unit was also performed. The FSS included 100% coverage gross gamma surveys of each 2-foot of material placed in the excavation to identify elevated areas and equal distant core samples through the entire depth of below criteria backfill material placed in the excavation. Each core was then gross gamma scanned for uniformity and separated into 1-meter segments for composite sampling and laboratory analysis via gamma spectroscopy. The results of gross gamma scans of each 2-foot of material placed and of the cores revealed no elevated areas, consistent with the results of the segregation system output. The average of the core sample composites was 8.87 pCi/g, confirming the results of the segregation system.

SUMMARY

The development of site-specific cleanup levels and selection of a transparent site cleanup strategy, responsive to both the provisions of the NRC LTR 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 LTR. 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. Parameter sensitivity results should be examined to direct attention to the few parameters significantly controlling dose outcomes. The engineering of the remediation approach must provide assurance that these parameter uncertainties will be controlled consistent with the site's conceptual model framework. The hallmark of the dynamic approach is objectively revealed by a reverse dose assessment showing remarkable agreement with that used to derive the cleanup levels.

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 dynamic 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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ABOUT THE AUTHORS

Andrew J. Lombardo, CHP is a principal of Civil and Environmental Consultants, Inc. He is a Certified Health Physicist, and has over 23 years of experience in health physics and chemistry including radiological engineering and project management. He has significant experience in decommissioning, reactor health physics, regulatory audit and compliance, dose modeling, internal and external dosimetry, and management of radiation protection programs.

Richard F. Orthen is a senior project manager with Civil and Environmental Consultants, Inc. He has over 25 years experience with hazardous and nuclear materials, specializing in occupational and environmental risk control areas. His practice includes National Environmental Policy Act (NEPA) document preparation, multimedia environmental protection regulatory compliance appraisals, transportation incident analysis, radiological engineering, health physics/radiation protection, dose reconstruction, emergency preparedness, and biosphere modeling. He has prepared detailed decommissioning and final status survey plans/reports for materials and utilization licensees; and has conducted dose/risk assessments for facilities contaminated with technologically-enhanced and naturally-occurring radioactive material, byproduct material, activation products, source material, and special nuclear material.

Anita F. Mucha, NRRPT is an associate project manager with Civil and Environmental Consultants, Inc. She has over 19 years experience in health physics including radiological engineering and project management at a Nuclear Regulatory Commission (NRC) licensed facility. She also has significant experience in regulatory auditing and compliance, dose modeling, dosimetry and management of radiation protection programs.

ABOUT CIVIL & ENVIRONMENTAL CONSULTANTS, INC.

Civil & Environmental Consultants, Inc. (CEC) is an engineering consulting firm headquartered in Pittsburgh, Pennsylvania providing civil, environmental, and geotechnical services. CEC is a "C" corporation and was founded in 1989. Fifteen years later, CEC has grown from six employees in one office, to over 260 employees in eight locations. CEC was named one of the top 500 design firms and one of the top 200 environmental firms nationally by *Engineering News-Record*, and was named in the "Pittsburgh 100," a list of Pittsburgh's fastest growing businesses by *The Pittsburgh Business Times* for four consecutive years. CEC ranked fourth in the medium size category as one of the "Best Places to Work in Pennsylvania" in a survey conducted by the *Central Penn Business Journal* in Harrisburg.

CEC performs civil engineering and environmental projects and maintains strong client relationships through high quality performance and the involvement of senior-level staff. CEC serves the environmental, civil/site and solid waste industries. Our primary practice areas include:

- Civil Engineering/Site Development
- Geotechnical Engineering
- Environmental Management, Engineering & Remediation Services
- Waste Management & Landfill Services
- Ecology & Life Sciences
- Water & Wastewater Management
- Surveying (including GIS & GPS Services)
- Quality Assurance & Construction Field Services
- Brownfield Development Services
- Master Planning & Landscape Architecture
- Hydrogeology, Hydrology, Groundwater Monitoring & Remediation Services
- Air Quality & Water Quality Services
- Forensic Engineering
- Knowledge & Database System Development
- Industrial Hygiene
- Health Physics/Radiological Engineering

Our clients include industrial, institutional and commercial industries, including manufacturing, metals, mining, utilities, and waste management, as well as law firms, developers, city and county governments, educational facilities, and architect/engineering firms.

CEC employs a full service civil and environmental staff, including:

- Professional Engineers
- Professional Geologists
- Certified Hazardous Materials Managers
- Registered Land Surveyors
- Registered Landscape Architects
- Hydrologists & Hydrogeologists
- Health Physicists
- Biologists, Ecologists, Wild Life Scientists, Agronomist, GIS Specialist
- CAD Designers
- Construction Managers
- Field Service Technicians
- Industrial Hygienists

CEC health physicists have assisted clients in managing sites with low-level radioactive contamination undergoing decontamination and decommissioning (D&D) including NUREG-1757 based decommissioning plan development, MARSSIM based characterization and final status survey design and implementation, remediation support services, radiological health and safety support, and general radiological engineering support. CEC has successfully developed dose assessments (exposure models) for "open land" areas and structures using various software codes, including RESRAD, RESRAD-Build, DandD, and Microshield, to assist clients pursuing unrestricted release criteria balanced with a cost-effective decommissioning strategy. In addition, we have prepared final status survey reports at the conclusion of remediation activities for submission to the appropriate regulatory oversight agencies. CEC has assisted clients in agency negotiations at both the federal and state levels to ensure timely and appropriate licensed activities. We have also prepared numerous license amendments and decommissioning plans as well as disposal option analyses for a variety of clients.