Guidance on Surveys for Subsurface Radiological Contaminants

Draft Technical Letter Report

EXECUTIVE SUMMARY

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Prepared for
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CONTENTS

ACRONYMS

ANSI	American National Standards Institute
CCM	contamination concern map
DCGL	derived concentration guideline level
$DCGL_{EMC}$	Derived Concentration Guideline Levels for Elevated Measurement Comparison
$DCGL_V$	derived concentration guideline designed for subsurface soil volumes
$DCGL_W$	derived concentration guideline designed for wide area surface soil
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FSS	final status survey
GSLIB	Geostatistical Software Library
GUM	"Guide to the Expression of Uncertainty in Measurement"
ISO	International Organization for Standardization
LTR	License Termination Rule
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
RESRAD	Residual Radioactive in Soils software
RSSI	Radiation Survey and Site Investigation
SADA	Spatial Analysis and Decision Assistance
SAFSTOR	long-term storage before decommissioning
TLR	technical letter report
VSP	Visual Sampling Plan, a software package
2D	two-dimensional—area
3D	three-dimensional—volume

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) provides guidance for characterization and final status surveys (FSSs) of residual radioactive material at surfaces of soils and structures in NUREG-1575, "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," Revision 1, issued August 2000 (NRC 2000)[1], and in NUREG-1757, Volume 2, Revision 1, "Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria" (NRC, 2006). NUREG-1757, Volume 2, Revision 2 has been issued as a draft report for comment (NRC 2020c) and is available for use by NRC licensees, although the final version of the guidance document will not be available until sometime in 2022. MARSSIM guidance covers contaminants in surficial materials (i.e., around the top 15 centimeters of soils); subsurface contamination is specifically out of scope. NUREG-1757, Volume 2, Revision 2, references MARSSIM guidance for surficial residual radioactivity but also provides limited guidance on subsurface or buried radioactive material, including dose scenarios that could bring residual radioactivity to the surface. An increasing number of complex decommissioning sites are expected to become active soon. Many of these are reactor sites that can be expected to contain areas of residual radioactivity in subsurface soils. Moreover, instead of entering long-term storage before decommissioning (SAFSTOR), some reactor sites are now being decommissioned soon after shutdown. These facilities will need to be surveyed and a determination made as to the need for subsurface remediation.

The NRC intends to develop guidance for the design and implementation of radiological surveys of the subsurface using statistical methods and risk approaches to determine acceptable numbers and distributions of soil samples (or other subsurface media) taken at depth, to maintain appropriate coverage while keeping costs of sampling and analysis reasonable and minimizing environmental impacts. The guidance would help licensees demonstrate the adequacy of site characterization and the FSS for showing compliance with License Termination Rule (LTR)[2] radiological criteria with reasonable assurance, without being overly conservative. The NRC began to address this problem in NUREG/CR-7021, "A Subsurface Decision Model for Supporting Environmental Compliance," issued January 2012 (NRC 2012), which outlines an approach that overcomes obstacles to detailed subsurface surveys.

The NRC is considering use of MARSSIM-like principles for the characterization and FSS of radioactive contaminants in the subsurface, potentially many meters in depth below ground surface. Material developed in this technical letter report and subsequent information that emerges from a public workshop to be held in 2021 on the subject areas described below will be used to produce a NUREG/CR report providing the technical bases for guidance on subsurface contaminants. Invitees to the workshop will include experts from remediation companies, academia, national laboratories, and regulatory agencies.

Specific activities being considered by the NRC to develop this guidance include the following:

- Developing guidance to allow a licensee to implement historical, scoping, and characterization analyses and an FSS that are appropriate for evaluating subsurface

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1 MARSSIM, Revision 2, has been developed and is expected to be issued for public comment in 2021. An advanced copy is available on EPA's Science Advisory Board website: https://yosemite.epa.gov/sab/sabproduct.nsf/RSSRecentAdditionsBOARD/E1D35FEB397932FF8525854D00836CFA

2 The LTR went into effect on July 21, 1997, and is contained in Subpart E, "Radiological Criteria for License Termination," of 10 CFR Part 20, "Standards for protection against radiation").

contamination. The guidance should provide sound decision-making methods, while recognizing the inherent limitations associated with subsurface investigations.

- Developing a statistical approach and methods to determine the necessary sample density, spatial distributions, depths, and volume to achieve a certain level of confidence and limit decision errors for subsurface contaminants during site characterization and especially for the FSS.

- Addressing how subsurface residual radioactivity exposure scenarios differ from those for surface residual radioactivity. For example, given the relative importance of the ground water pathway and intrusion scenarios for subsurface residual radioactivity that involve soil disturbance and mixing, how does the importance of smaller areas of residual radioactivity in the subsurface differ from those at the surface? Integration of dose modeling and radiological surveys is a key aspect of this project.

- Evaluating and implementing the use of geospatial modeling tools and currently available geostatistical software to analyze data and optimize sampling designs. The tools should be able to provide geospatial and statistical evaluation of remediated sites, especially allowing comparison to regulatory criteria. These tools must be able to consider the likelihood of residual radioactivity above levels of concern and uncertainty associated with datasets. New tools may be needed to achieve these objectives.

The work described in this TLR summarizes industry -accepted practices and references for NRC-proposed activities including historic applications, all focused on subsurface soils. This TLR also provides input on potential changes and issues that would be encountered in applying existing approaches to the subsurface. This document is organized by key topics as discussed below. References for this Executive Summary appear at the end of the summary, while references for the TLR as a whole are in Section 13.

SECTION 1—INTRODUCTION

This section captures the intent of the primary international and national standard reference groups and suggested survey design approaches for subsurface soils. This TLR briefly describes key issues concerning contaminants in subsurface soils and how they contrast with surficial MARSSIM-type approaches, and suggests approaches to address survey design, including NUREG/CR-7021, and statistical methods for evaluating contaminants in the subsurface. Section 1 addresses the following:

ISO Standard EN ISO 18557:2020—"Characterization Principles for Soils, Building and Infrastructures Contaminated by Radionuclides for Remediation Purposes." The International Organization for Standardization (ISO) articulates a set of principles for sampling strategy and characterization of soils, buildings, and infrastructures during nuclear site decommissioning, taking into account constraints imposed by operations, budgets, and regulations while respecting as low as reasonably achievable principles. This ISO document is intended to standardize practices and aid users in planning and reporting characterization activities. Of note for this report, the ISO advocates the integration of geostatistical methods for site characterization. The ISO includes an appendix on geostatistical data processing that elaborates on geostatistical concepts, including analysis of spatial structure, conditional simulation, and multivariate geostatistics to combine distinct sources of information. Remediation of volumetric blocks of soil is discussed. (ISO 2020)

ANSI Standard ANSI/ANS-2.17-2010—"Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants."[3] This standard establishes the requirements for evaluating the occurrence and movement of radionuclides in the subsurface resulting from abnormal radionuclide releases at commercial nuclear power plants. This standard applies to the abnormal radionuclide releases that affect ground water, water supplies derived from groundwater, and surface waters affected by subsurface transport, including exposure pathways across the transition zone from groundwater to surface water. (ANS 2010)

NUREG/CR-7021—"A Subsurface Decision Model for Supporting Environmental Compliance." This NUREG/CR describes the software Spatial Analysis and Decision Assistance (SADA). It provides a geospatial modeling and decision framework for conducting a subsurface compliance survey and analysis for sites that have been remediated for radioactive contamination. This framework proposes a method to extend the MARSSIM guidance, which treats only surface surveys, into the subsurface. It combines and organizes survey methods into a highly flexible sampling, modeling, and decision analysis approach that emphasizes the quality of decision making throughout the investigation. (NRC 2012)

SECTION 2—SURVEY APPROACHES FOR DIFFERENT TYPES OF LICENSEES

Compliance assessments for surface and subsurface residual radioactivity have similar objectives; both focus on demonstrating that LTR radiological criteria are met. These criteria consider residual radioactivity (1) averaged over the entire site or survey unit and (2) elevated concentrations in smaller areas of the site or survey unit. However, the subsurface presents substantial challenges that add to the complexity of these surveys. First, access to subsurface soils is limited, and surveying subsurface soils is much more expensive than surveying surface soils. Given limited access to subsurface soils, continuous scanning techniques, which are commonly used to provide fast and detailed surveys of the surface, cannot be used for subsurface soils. Second, subsurface soils can be expected to be heterogeneous in ways that may not be evident. Third, development of derived concentration guideline levels (DCGLs) for subsurface soils is more complex and often involves consideration of various intrusion events that bring subsurface residual radioactivity to the surface, where a receptor could be exposed. In this regard, ground water exposure pathways also appear to be more important for subsurface contaminants than for contaminants found at the surface. For complex sites that operated over extended times, mobile radionuclides may have been transported deep in the vadose zone and into ground water or fractured rock, further adding to the difficulty in characterizing subsurface residual radioactivity. For these reasons, guidance is needed for the design and implementation of radiological surveys of the subsurface with statistical methods to determine acceptable sample distributions in three dimensions. It is hoped that guidance can be developed to demonstrate the adequacy of site characterization and FSSs by providing reasonable assurance of compliance with radiological criteria while limiting overly conservative approaches.

ISO and ANSI standards take into account the regulations covering survey design and summarize the approaches needed for surveys, sampling, and characterization of different types of NRC-licensed sites (e.g., reactors versus materials sites). Section 2 of this TLR describes the applicable regulations, such as the LTR and the U.S. Environmental Protection Agency's (EPA's) drinking water standards and ground water protection rules.

NUREG/CR-7268, "User's Manual for RESRAD-OFFSITE Code Version 4," Volume 1, "Methodology and Models Used in RESRAD-OFFSITE Code," issued February 2020

[3] This standard was reaffirmed March 10, 2016.

(NRC 2020), considers three possible subsurface soil configurations. The three primary configurations are (1) the contaminants are above the water table, (2) a portion of the primary contamination is in the water table, and (3) all of the primary contamination is within the water table. Although RESRAD ONSITE and OFFSITE are able to simulate a portion of the contaminated zone being in the water table, the codes are unable to address existing ground water contamination outside of the source area, and the contribution to dose of any existing ground water plume must be assessed. NUREG-1757, Volume 2, Revision 2, addresses the remaining subsurface contamination in the vadose zone following decommissioning. This guidance includes consideration of intrusion scenarios that may bring residual radioactivity to the surface, which may complicate the development of cleanup criteria. Also, a review of multiple decommissioning sites in Section 10 of this TLR indicates that multiple DCGLs for multiple depths or environmental media could be employed, which would result in a more complex FSS. A MARSSIM-like survey approach to the three configurations of primary contamination and other intrusion scenarios for residual radioactivity left behind in decommissioning might be applied to the subsurface characterization. The approach includes scoping, characterization, remedial, and compliance surveys. Techniques are presented to calculate the total volume required, if any, for removal (remediation) (NRC 2020a).

The MARSSIM Radiation Survey and Site Investigation (RSSI) process as it relates to the subsurface is examined through the NUREG/CR-7021 perspective, which presents a framework focused on development of a conceptual site model referred to as a contamination concern map (CCM). The CCM describes the extent, location, and significance of residual radioactivity relative to the decision criteria. The CCM is developed with the aid of visualization, geographic information system, and geostatistical software and incorporates information from many different sources and types of input.

SECTION 3—DERIVED CONCENTRATION GUIDELINE LEVELS

Dose modeling is used to determine cleanup levels or DCGLs that meet regulatory criteria for license termination (or to demonstrate compliance with LTR criteria based on measurement of final residual radioactivity levels). After remediation has been completed, an FSS needs to be conducted to confirm that residual radioactivity remaining at the site meets the LTR radiological criteria. While procedures for these surveys and the statistical approaches used for their analysis have been available for surficial contamination in MARSSIM, the NRC is considering formulating guidance on these procedures for subsurface contamination.

The following points should be considered in relation to the development of DCGLs for the subsurface:

- Limited guidance is available on distinguishing between the surface $DCGL_W$ (wide area) and a subsurface DCGL (see NUREG-1757, Volume 2, Revision 2, Section 3.6, Appendix G, I and J).

- A surface MARSSIM-based approach may be extended to subsurface planes such as excavation surfaces (see NUREG-1757, Volume 2, Revision 2, Appendix G). Different classes of survey units may apply to the surface of the excavation versus the walls of the excavation or surface soils.

- Multiple DCGLs may be useful depending on the radionuclides present, applicable exposure scenarios, and actual site conditions. It is always acceptable to use the most limiting DCGL; however, in certain cases (e.g., deep subsurface residual radioactivity), it may be beneficial to develop separate DCGLs, because of the importance of the ground water pathway versus surface dose pathways. Multiple DCGLs add complexity to the FSS, which may be an important consideration in the FSS design. Using multiple DCGLs may be more straightforward in cases where different sources are present (e.g., residual radioactivity at the surface versus residual radioactivity associated with buried material or from deep subsurface spills or leaks that may contain mixtures of radionuclides).

- For buried residual radioactivity, most cases will require consideration of potential intrusion scenarios that could bring deep subsurface contamination to the surface, as well as "as is" conditions for residual radioactivity remaining after the intrusion event.

- The MARSSIM application of a "survey unit" may not directly apply to the subsurface.

- A higher level of analytical sensitivity is required for sites with greater numbers of significant radionuclides, which affects statistical testing considerations.

NUREG-1757, Volume 2, Revision 2, presents several scenarios for buried materials, including the following:

- basement excavation (residual radioactivity within 3 meters of the surface considering erosion) and other scenarios if residual radioactivity is found deeper in the subsurface (e.g., well drilling)

- large backfilled subgrade structures (e.g., containment basements, auxiliary building basements, and/or turbine basements at a reactor site), including large-scale excavations

This section of the TLR also summarizes NRC-acceptable computer codes for developing DCGLs.

SECTION 4—IMPLICATIONS OF NUREG-1757, VOLUME 2, REVISION 2

This section explores the importance of (1) the effect of distance between a contaminated layer and the water table on dose, (2) approaches to subsurface assessments, (3) categorization and classification of subsurface soils, and (4) the importance of smaller areas of residual radioactivity in the subsurface. The following are major points in the discussion of subsurface soil in Section 4:

- For surface sources, the dose from the water-independent and water-dependent pathways typically occur at different times. The contribution from water-dependent pathways can be delayed until radionuclides transported by ground water reach a point of water withdrawal (i.e., a well or pond).

- The concentration in ground water generally decreases the farther away it is from its source because of dispersion and may decrease because of dilution following extraction from a well as the result of mixing with clean water.

- NUREG-1757, Volume 2, Revision 2, provides hypothetical examples of intrusion into a buried fill or excavation of a contaminated layer below the surface and how once the material is brought to the surface the RESRAD ONSITE software can be used to determine DCGLs through dose modeling.

- The concept of a highly contaminated small subsurface volume and its impact on the water-dependent pathway is not easily defined. The size of a hypothetical subsurface "hot spot" volume that is applicable to all licensees is also not identified. This analysis is site specific but remains ambiguous, as an instrument scan cannot be performed to determine how big such a hot spot might be and the impact on dose per radionuclide. Instead, information from historical and scoping surveys, professional judgment, geostatistical tools, and dose modeling can be used to determine the volumetric extent and impact of the hot spot, as summarized in Sections 6–8 of this Executive Summary and in the main body of the TLR.

SECTION 5—STAGES OF THE SUBSURFACE DECISION FRAMEWORK

This section discusses methods and considerations for performing various types of subsurface radiological surveys ranging from historical site assessments, scoping, characterization, remedial action, confirmatory, and FSSs. Figure ES-1 shows the general flow of the subsurface decision framework, which is similar to the MARSSIM framework. The different phases depict how the subsurface analysis moves from a very qualitative beginning to a more quantitative conclusion through a series of phases that are identified in the MARSSIM guidance. Each oval represents a major phase in the investigation. These phases are broadly defined to permit the flexibility needed to deal with varying situations. Each arrow shows a potential path through the framework and is annotated by the output content from the previous phase. In turn, this output becomes the input for the next phase. The major theme is to use the historical site assessment to create an initial CCM. Then, the output of each major phase (which serves as input in the next phase) includes the latest CCM update as well as other relevant products. The end result is success in the compliance phase or a return to an interim phase under compliance failure. The framework suggests some methods that may be useful in compliance phase activities (NRC 2012, page 13).

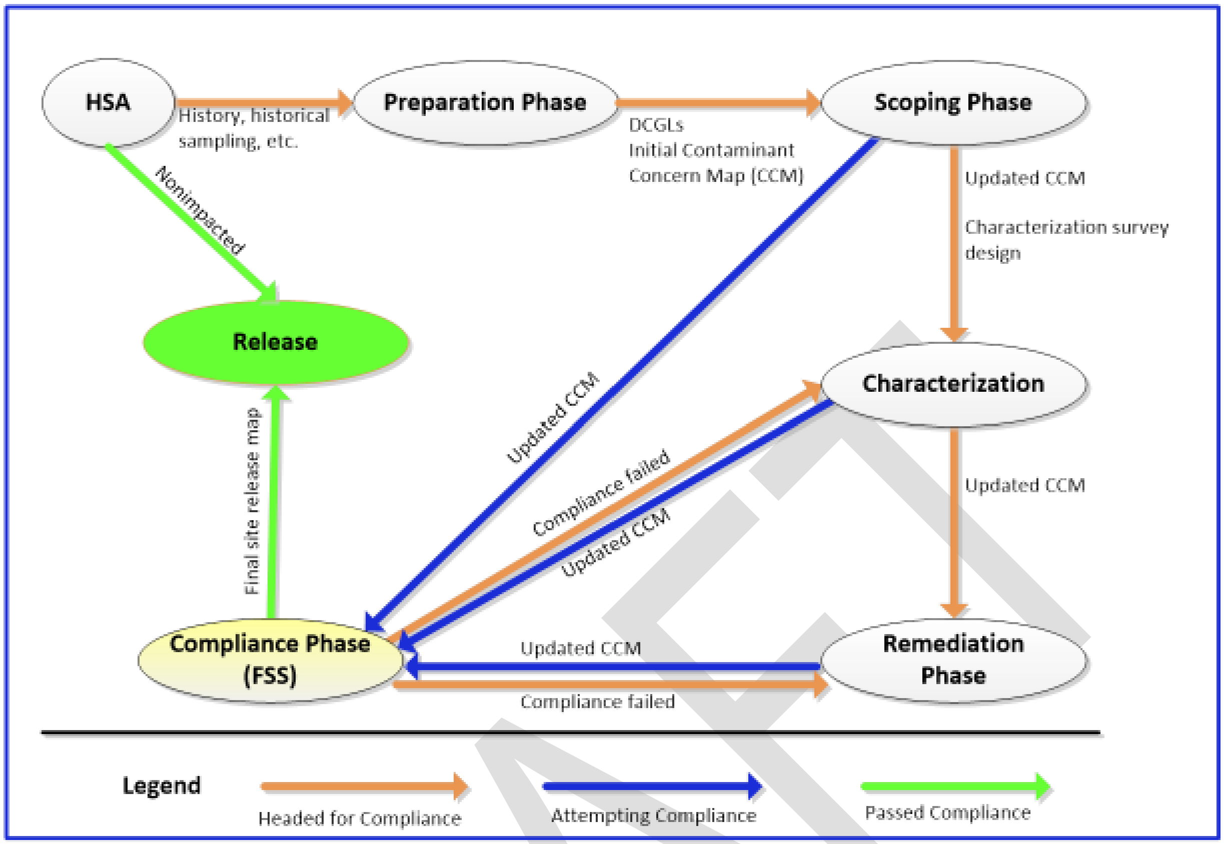

Figure ES-1 Flow diagram for the performance-based subsurface compliance framework
Source: Updated from NUREG/CR-7021, page 13 (NRC 2012)

SECTION 6—GEOSPATIAL MODELING TOOLS

This section describes and evaluates geospatial modeling tools and currently available geostatistical software to analyze data on contaminant distributions and optimize sampling, scanning, or otherwise obtaining information on the subsurface. These tools must be able to consider the likelihood of residual radioactivity above levels of concern and uncertainty associated with a dataset.

The EURATOM work program INSIDER (Improved Nuclear SIte characterization for waste minimization in Decommissioning under constrained EnviRonment) launched in June 2017 (https://insider-h2020.sckcen.be/). The program proposes a strategy for data analysis and sampling design for initial nuclear site characterization based on a statistical approach. It examines several approaches for using geostatistics to aid sample design, especially for secondary sample designs using data from prior surveys.

There are many geospatial modeling tools. The Electric Power Research Institute sponsored a report “Guidance for Using Geostatistics to Develop Site Final Status Survey Program for Plant Decommissioning” (EPRI 2016). The report extensively evaluated 17 2D and three-dimensional (3D) software packages for cost, dimensionality, directed workflow, exploratory data analysis, sample design/optimization, point kriging, block kriging, universal kriging, co-kriging, spatial-temporal kriging, discontinuities or complex geometries, conditional simulation, cross validation, fate and transport modeling, dose assessment, and graphical information system. Of the 3D software packages, SADA is recommended in this TLR because of its use in CCMs, sampling optimization, and remediation cost-benefit analysis, and because it is free. VSP

(Visual Sampling Plan) is another excellent sampling design and data analysis program, also freeware, but it is a 2D package. The EPRI publication extensively reviews both SADA and VSP.

Examples of the types of problems SADA can address include the following:

- calculating the volume or area of contamination above a cleanup threshold and presenting a site map with a map of contamination above a cleanup threshold on top of the site map
- calculating the area or volume requiring cleanup as a function of cleanup level and generating costs for remediation to the different cleanup levels
- selecting optimal sampling locations and placing them on a site map

The SADA software provides *informed* initial design strategies, where the CCM is used to assist in survey design along with the "Check and Cover" strategy (Stewart et al. 2009). As described in NUREG/CR-7021, this sample design seeks to check those locations where contamination is more likely to exist, while at the same time providing some coverage to low-probability areas. Unfortunately, the module to perform the function of "Check and Cover" is not available. A major issue with SADA is that it is not currently supported or maintained, nor has the code been subject to verification and validation studies. It is recommended that the NRC investigate the level of effort and how SADA, or components of SADA, can be used either stand-alone, or in conjunction with other software, such as VSP. Sections 7 and 8 further address SADA and VSP.

SECTION 7—STATISTICAL METHODS AND TESTS

This section presents statistical methods to determine the necessary sample density, spatial distributions, depths, and volume to achieve a certain level of confidence and limit decision errors for subsurface contaminants during characterization surveys. The MARSSIM statistical tests are evaluated for applicability, and alternative methods are proposed. Key points of the section include the following:

- Because sampling the subsurface is costly, the design of subsurface surveys should include some measure of the value added to decision making process for each additional location sampled. The number of samples should be based on a metric that changes as the sample size increases. Therefore, a measure like the statistical power in MARSSIM is desirable. Such a measure is also important to evaluate the adequacy of FSS.
- The most promising methods for designing efficient subsurface surveys appear to be Bayesian Ellipgrid (geometrical) and Markov-Bayes (geostatistical). Both of these methods are implemented in SADA.
- The Historical Site Assessment can provide the prior information needed to use the Bayesian tools, and thus should be as complete and accurate as possible.
- No single software package provides all the tools that would be desirable for subsurface sampling design and data analysis.
- VSP and SADA appear to have the set of features that may be most useful for Radiological Site Surveys and Investigations, although ProUCL also contains useful

features. VSP is supported, maintained, and updated periodically with new features. SADA is available to download, but not currently supported, maintained, or updated.

- It may not be fruitful to spend a great amount of effort in calculating and fitting variograms.

SECTION 8—GEOSPATIAL AND STATISTICAL METHODS

This section reports on the use of geospatial and statistical methods to evaluate remediated sites, especially allowing comparison to regulatory criteria. The section also examines the applicability of MARSSIM statistical tests and possible alternative methods, as appropriate. This includes analysis software that might be used to support a release decision for a subsurface survey unit. This involves the data quality objectives process and limiting decision error rates.

In reviewing available geostatistical software for subsurface FSSs, Section 7 of this report narrowed the recommendations to SADA and VSP. Appendix E to this TLR lists the survey designs in VSP and SADA. The features of these programs are compared:

- The DQO Process is briefly discussed with comments on application to subsurface sampling design, and decision rules.
- The geostatistical tools in both SADA and VSP are based on the FORTRAN code in Geostatistical Software Library (GSLIB).
- VSP supports more classical statistical methods, although it also contains geostatistical methods outside of the MARSSIM module.
- SADA supports more geostatistical methods than classical methods.
- Guidance is needed to define a subsurface survey unit (SSU) or subsurface volume.

This TLR recommends that either VSP or SADA be upgraded to include 3D modules, especially for “Check and Cover.”

SECTION 9—ASSESSING BACKGROUND AND SCENARIO B

This section evaluates the challenges associated with assessing background radionuclide concentrations and disaggregating background radioactivity from residual activity from licensed activities. This section also discusses the applicability of Scenario B[4] for subsurface residual radioactivity and practical approaches for demonstrating indistinguishability from background.

The use of Scenario B is expected only for a small number of facilities, and the considerations for any given facility are expected to be site specific. NUREG-1505, “A Nonparametric

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[4] Licensees must determine whether Scenario A or Scenario B will be used to evaluate the survey unit. Scenario A uses a null hypothesis that assumes the concentration of radioactive material in the survey unit exceeds the DCGLW. Scenario A is sometimes referred to as “presumed not to comply” or “presumed not clean.” Scenario B uses a null hypothesis that assumes the level of concentration of radioactive material in the survey unit is less than or equal to the action level or lower boundary of the grey region. Scenario B is sometimes referred to as “indistinguishable from background” or “presumed clean”

Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys—Interim Draft Report for Comment and Use," Revision 1, issued June 1998, provides an example of the use of Scenario B to demonstrate indistinguishability from background when the residual radioactivity consists of radionuclides that appear in background, and the variability of the background is relatively high (NRC 2006). In a revision to Appendix G to NUREG-1757, Volume 2, the NRC indicates that Scenario B might be used if there is uncertainty as to backfill soils being impacted. Appendix G to NUREG-1757, Volume 2, Revision 2, contains additional information, including 3D data, and other examples for surveys involving Scenario B (NRC 2020c).

SADA does not implement Scenario B (Stewart et al. 2009), although VSP does. VSP is also able to produce retrospective (and prospective power curves) for Scenario B evaluations, which are essential to ensuring that a dirty site is not released due to insufficient power to reject the null hypothesis in Scenario B. Additional features related to Scenario B are currently (fiscal year 2021) being addressed under an NRC contract with Pacific Northwest National Laboratory.

SECTION 10—EVALUATIONS OF LARGE SOIL EXCAVATIONS AND EQUIPMENT

This section describes and evaluates methods to survey large subsurface soil excavations and to survey soils for reuse in large excavations including use of conveyor belts and other soil sorters. Key points identified in this section include the following:

- This section describes how a conveyorized survey machine is used and what soil sorters are available.
- A surface $DCGL_W$ (wide area) has been applied to excavation sides and bottoms in several instances. This section reviews how several sites (including nuclear power plants) developed and implemented DCGLs.
- This TLR suggests that SADA could be used to increase confidence that licensees are correctly identifying all areas that need to be remediated. Only the NRC has actually applied SADA in a site review; the guidance and tools for the industry are yet to be developed.

While multiple lessons can be learned from several sites as summarized in the TLR, excavation experiences across the industry are inconsistent in handling layers and volumes just above the DCGL. Lessons learned include topics for dose modeling, characterization, and remediation. A topical MARSSIM-like roadmap for all licensees needs to be developed to illustrate when remediation is necessary.

SECTION 11—TREATMENT OF UNCERTAINTY AND DATA SUFFICIENCY

This section provides methods of treating uncertainty and data sufficiency.

The statistically rigorous quantitative application of measurement quality objectives plays a central role in the MARSAME (NRC 2009) process. Measurement quality objectives did not appear explicitly in MARSSIM, Revision 1 (NRC 2000), but were subsequently developed for radioanalytical chemistry measurements as part of the "Multi-Agency Radiological Laboratory Analytical Protocols Manual" (MARLAP), issued July 2004 (NRC 2004). However, these concepts apply equally well to field measurements of radiation and radioactivity. The MARSAME process incorporates these ideas and extends them to these measurements.

A major development since the initial publication of MARSSIM was the 1995 release of the *Guide to the Expression of Uncertainty in Measurement*, or "GUM" (ISO 1995). The procedures described in the GUM have become a de facto standard for estimating the uncertainty associated with measurements of any type. The GUM methodology is essential for the assessment of measurement uncertainty but was not previously treated in MARSSIM.

MARLAP recommends that all radioanalytical laboratories adopt the terminology and methods of the GUM (ISO, 1995) for evaluating and reporting measurement uncertainty. The laboratory should report all results, whether positive, negative, or zero, as obtained, together with their uncertainties. This section provides an example of determining uncertainty with the free software GUMCalc, which is user friendly and eliminates the high-level math calculations for field applications. Other available software programs include the National Institute of Standards and Technology Uncertainty Machine and GUM Workbench Version 1.4. This TLR recommends extending MARLAP recommendations to apply to the determination of uncertainty of subsurface sample measurements, whether laboratory or field instrument measurements. Guidance may be developed from the material presented in the TLR.

SECTION 12—ELEVATED AREAS AND HOT SPOTS

This section describes approaches to evaluating elevated areas or hot spots for potential doses to receptors, including the inadvertent intruder. An area of elevated activity is often referred to as a "hot spot." This term was purposefully omitted from MARSSIM because it often has different meanings based on operational or local program concerns. As a result, the MARSSIM authors decided that problems may be associated with defining the term and reeducating MARSSIM users in its proper use. Because these implications are inconsistent with MARSSIM concepts, MARSSIM does not use the term (NRC 2000).

NUREG/CR-7021 provides a geospatial modeling and decision framework for conducting a subsurface compliance survey and analysis for sites that have been remediated for radioactive contamination. The framework presented above proposes a method to extend the MARSSIM guidance into the subsurface. It combines and organizes survey methods into a highly flexible sampling, modeling, and decision analysis approach that emphasizes the quality of decision making throughout the investigation. NUREG/CR-7021 acknowledges the extraordinary costs associated with intense sampling, and in lieu of complete subsurface removal, responds by focusing on the quality of the final compliance decision and the reasonable mitigation of uncertainty (NRC 2012). This TLR explores combining the use of EPA traditional searches for hot spots and the use of geospatial modeling.

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