# US Nuclear Regulatory Commission Decommissioning Guidance and Research Initiatives

Cynthia Barr

US Nuclear Regulatory Commission

Rockville, MD, United States

Email: Cynthia.barr@nrc.gov

Bruce Watson

US Nuclear Regulatory Commission

Rockville, MD, United States

Email: bruce.watson@nrc.gov

Christepher McKenney

US Nuclear Regulatory Commission

Rockville, MD, United States

Email: Christepher.mckenney@nrc.gov

**Abstract**

The United States Nuclear Regulatory Commission (NRC) is actively updating decommissioning guidance and sponsoring related research to support decommissioning of complex materials and reactor sites. Guidance improvements are related to lessons learned from review of decommissioning plans and final status surveys, as well as changes and advances in technology over time. Decommissioning guidance update topics include subsurface investigations (e.g., survey methods for subsurface materials); analysis of continuously collected data using modern data logging systems; and use of cover systems, (e.g., evapotranspiration covers) in site remediation and uranium mill tailings. NRC is also developing a generic communication on methods for prevention and control of discrete radioactive particles (DRPs) at decommissioning sites; and is considering the need for guidance related to survey and dosimetry considerations for DRPs. In addition to the guidance updates, NRC is sponsoring development of subsurface assessment tools. Pacific Northwest National Laboratory’s Visual Sample Plan (VSP) computer code is used to design and analyze data from radiological surveys and is being updated to support NRC’s guidance initiatives with inclusion of new tools to support optimization of survey designs; and data visualization and analysis for the subsurface. VSP is also being updated to allow importation and analysis of continuously collected data. Guidance updates are being conducted with the input of NRC stakeholders as part of the guidance development process. NRC releases its guidance documents for public comment and has hosted a number of public meetings and technical workshops on decommissioning topics of interest to its licensees, stakeholders, agreement states and federal partners. NRC is also providing feedback to industry on development of its own guidance to provide a standard format and content specific to the decommissioning of nuclear reactors in the United States.

## INTRODUCTION

The Nuclear Regulatory Commission (NRC) has been actively updating its guidance to address lessons learned from review of decommissioning and license termination plans and final status surveys to support the release of complex materials and reactor sites. Recent guidance updates have included Revisions to NRC’s *Consolidated Decommissioning Guidance: Characterization, Survey and Determination of Radiological Criteria*, NUREG-1757, Volume 2 (Revision 2) and the *Multi-Agency Radiation Survey and Site Investigation Manual*, MARSSIM, (Revision 2). The final NUREG-1757, Volume 2, Rev. 2 was published in July 2022 after addressing over 200 comments on the draft document. Draft MARSSIM, Rev. 2 was published in June 2021 and the MARSSIM working group is currently addressing United States Environmental Protection Agency (US EPA) Science Advisory Board (SAB) peer review comments on the draft document, along with public comments received on the draft report. The final MARSSIM, Rev. 2, is expected to be published in 2024. Comments received on NUREG-1757, Volume 2, Rev. 2, and MARSSIM, Rev. 2, that were more difficult to address include the need for additional guidance on subsurface radiological surveys (guidance on final status surveys akin to MARSSIM for surveys of surface soils or building surfaces) and the need for guidance on survey and dosimetry considerations for discrete radioactive particles. Additionally, changes in technology over time have necessitated updates to guidance documents. For example, more licensees are turning to radiological surveys conducted without surveyor vigilance and with the aid of global positioning system (GPS) instrumentation and geographic information system (GIS) software with stronger reliance on post-processing of data. Use of more modern data logging systems is an evolution from traditional walk-over surveys (i.e., surveys with a surveyor listening to the audible increase in counts to determine areas for follow-up investigation), which have been increasingly adding technology to assist the surveyors with their surveys. In addition to guidance updates, NRC is working to develop tools to facilitate implementation of proposed methodologies for data evaluation using existing software such as Visual Sample Plan, currently used to design radiological surveys, analyse data, and evaluate compliance with release criteria.

## SUBSURACE GUIDANCE

NRC began to develop subsurface guidance with *A Subsurface Decision Model for Supporting Environmental Compliance* (NUREG/CR-7021) published in January 2012. The technical document walked through the MARSSIM radiation survey and site investigation process from historical site assessment to the compliance phase providing a methodology and recommended tools to facilitate remedial and compliance decision-making when subsurface residual radioactivity is present. Figure 1 shows the steps in the subsurface decision model framework.



*FIG. 1.Flow diagram for the performance based subsurface compliance framework. Image credit: NUREG/CR-7021, Figure 3.3.*

Subsurface investigations represent unique challenges given the potentially large volume of heterogeneous subsurface materials requiring sampling, as well as the inability to rely on relatively cheap field instrumentation to detect areas of elevated activity between sample locations—a tactic used on more accessible surface soils. Inadequate sample size and unclear exposure scenarios for buried residual radioactivity present challenges to risk-informed remedial and final status survey decision-making. In some cases, decommissioning sites resort to extensive soil removal and exhaustive sampling of exposed surfaces during the remediation process to demonstrate compliance with release criteria leading to a potentially inefficient albeit effective approach to remediation and decommissioning. The objective of the subsurface guidance is therefore, to provide licensees the flexibility to leverage and combine various types of survey data and make use of geospatial modeling and simulation as surrogates for surface scanning to increase efficiency and optimize risk reduction across the site.

NRC contracted with SC&A to develop a technical basis to support subsurface survey design and decision-making using NUREG/CR-7021 as a starting point. SC&A published a final white paper in September 2022, recommending a subset of tools available in the Spatial Analysis Decision Assistance (SADA) code (SC&A, 2022). Recommended tools included Bayesian Ellipgrid and Markov Bayes co-kriging. Initial sample sizes would be based on a geometric approach that used Bayesian Ellipgrid for the identification of elevated volumes of concern in the subsurface. The minimum elevated volume of concern could be based on data collected during the historical site assessment, as well as modeling results (e.g., dose modeling could be used to assess the risk-significance of small-elevated volumes in the subsurface). After an initial round of sampling, Markov Bayes was proposed to guide secondary survey design and the collection of additional data to inform the compliance phase.

Pacific Northwest National Laboratory (PNNL) considered the recommendations of SC&A as well as made its own recommendations for tools to be added to the Visual Sample Plan (VSP) software program to enhance its subsurface data analysis capabilities (PNNL, 2022). PNNL produced a scoping report published in November 2022 which proposed several improvements to the VSP code related to (i) data quality/management, (ii) visualization, (iii) geostatistical modeling, and (iv) compliance evaluations. As a first step, three-dimensional capabilities and consideration of anisotropy in variogram fitting is being implemented in Fiscal Year (FY) 2023. Longer term projects include development of multi-variate geostatistical methods to allow data from disparate sources to be combined. Inclusion of multi-variate geostatistical methods will allow leveraging of less accurate field data with higher quality data in favour of higher quality decision data support (recognizing the benefit of more informed decisions versus simply the collection of higher quality, but more expensive data). Machine learning (e.g., few-shot learning) coupled with remote subsurface sensing techniques and high-performance forward modeling is also being evaluated as a potential method for filling in data gaps to make better, more risk-informed subsurface decisions.

NRC plans to publish guidance in two phases. NRC is in the process of publishing interim staff guidance (ISG) on subsurface surveys in Phase 1. Phase 1 guidance topics include extension of MARSSIM to open surfaces (e.g., excavations, sub-structures, and materials planned for onsite reuse) in the subsurface. The ISG will include information on methods to survey hard-to-access locations (embedded piping, sumps, and ducts), and evaluation of the efficacy of in-situ object counting systems (ISCOS) to survey of subsurface substructures and materials given the rather large field of view of ISOCS. Guidance on use of commonly used decommissioning dose modeling codes for calculation of derived concentration guideline levels (or DCGLs) for subsurface materials (e.g., reactor basement substructures located within the saturated zone); assessment of risk from multiple contaminated media, including existing groundwater contamination; groundwater monitoring considerations; and evaluation of uncertainty and support for parameters important to dose from the groundwater pathway will also be included in the ISG. The ISG is expected to be published in late summer 2023. During Phase 2, NRC plans to update NUREG/CR-7021 considering the state-of-the-art in geostatistical methods for subsurface decision support.

## Discrete Radioactive particles

Discrete radioactive particles (DRP) have recently become a concern at some decommissioning sites. In November 2022, NRC held a workshop to discuss technical issues associated with generation, control, survey, and internal dosimetry of DRPs. Because DRPs represent point versus areal or volumetric sources, special considerations apply when attempting to detect DRPs in the field using traditional scanning approaches. Oak Ridge Institute for Science and Education (ORISE)/Oak Ridge Associated Universities (ORAU) was tasked with developing scan minimum detectable activities (MDA) for DRPs as well as identifying good practices for DRP survey design and implementation. ORISE considered 4 radionuclides (Cobalt-60, Cesium-137, Thorium-232, and Americium-241) and various surveyor speeds, detector/source distances and soil depths in assessing scan MDAs. Best- and worst-case scenarios were considered with the detector passing directly over the DRP and the detector located at the furthest distance away from the DRP. The Monte Carlo N-Particle® code (MCNP) was used to calculate detector efficiencies at various points along a hypothetical survey transect. The MCNP results were fit to a log logistic model as a function of offset distance to the DRP for the various distances. Detector response as a function of time was constructed for the two scenarios. When the detector passes over the DRP, a single peak is observed, while two peaks are observed for the scenario when the detector is at its maximum distance from the DRP. The total integrated response for the worst-case scenario was calculated as the area under the peak using the trapezoidal estimation method. Scan MDAs were calculated using a modified version of the scan minimum detectable concentration (MDC) equations in NUREG-1507. Generally, results were as expected with higher scan MDAs for greater detector to ground surface distances, greater depth of DRP below ground surface, faster surveyor velocities, and for the more pessimistic scenario where the detector is the furthest distance from the DRP source. Exceptions are noted including a case where the scan MDAs for ground-to-detector distance of 10 cm is slightly lower than the 7.5 cm under certain pessimistic scenarios and when the DRPs are below the surface. One possible explanation for this non-intuitive result is that there is higher soil attenuation for the 7.5 cm distance under these scenarios given the angle between the source and detector. ORAU published a technical report documenting its findings with respect to survey of DRPs (Altic, 2022).

Because particles are relatively insoluble and tend to be more stationary (due to potential jaggedness and non-uniformity, DRPs can become lodged in the respiratory or gastrointestinal tract), International Commission on Radiation Protection (ICRP) 26/30 biokinetic models do not necessarily represent DRP behaviour in the body. Therefore, NRC also contracted with Renaissance Code Development (RCD) to develop dose conversion factors for DRPs. The focus of the RCD work is on recommended ulceration dose threshold for internal DRPs, and development of dose coefficients or dose conversion factors primarily for stationary DRPs for the skin surface, upper respiratory tract, and small and large intestine. The PIMAL and VARSKIN computer codes were used to support this tasking. A technical report will be published in 2023. RCD’s presentation at the DRP workshop presenting tables of DCFs for various radionuclides and materials is publicly available (RCD, 2022).

NRC plans to develop a generic communication to address issues associated with control of DRPs during decommissioning activities (e.g., ventilation, containment, tenting, filtering, and other controls to prevent the release of DRPs into the environment), as well as proper documentation/reporting and survey following risk-significant decommissioning activities that have the potential to release radioactivity to the environment. The intent of the generic communication is to inform licensees about how particles can be generated and become an issue, including experiences from recent power reactor decommissioning projects. Additionally, the communication will reinforce the importance of good housekeeping techniques to reduce DRPs and keep them localized during waste packaging, reactor vessel segmentation, and other risk-significant decommissioning activities which will mitigate future DRP issues at decommissioning sites. The generic communication is planned to be issued in late-2023. The need for guidance on survey and internal dosimetry associated with DRPs in decommissioning is also being considered.

## continuOUsly collected data

Owing to significant technological advancements over the past two decades, NRC licensees have increasingly used more modern survey instrumentation and data capture tools, including GPS and GIS technologies. Newer scanning instruments and mobile systems represent attractive options for radiological assessment. In its peer review of draft MARSSIM, Rev. 2, EPA’s SAB noted that “to be technically appropriate and useful for performing environmental radiological surveys, statistical and uncertainty methodologies should be updated for modern detection systems with data logging.”

NRC contracted with ORAU to develop methods for evaluation of continuously collected survey data without surveyor vigilance in NUREG-1507, Rev. 1, *Minimum Detectable Concentrations with Typical Radiation Survey for Instruments for Various Contaminants and Field Conditions*. NUREG-1507, Rev. 0, developed a methodology for calculation of scan MDCs for surveys conducted with surveyor vigilance--that is surveys conducted with the surveyor listening to the audible response of a detector with the surveyor stopping to count longer in cases where an audible increase in counts is observed. However, with use of the newer technologies the surveyor is typically taken out of the process and post-processing of the continuously collected data without surveyor vigilance is typically employed. This new paradigm invalidates the *a priori* scan MDC equations available in NUREG-1507.

ORAU set out to develop a post-processed investigation level (IL) to identify areas for follow-up investigation and developed an *a posteriori* scan sensitivity methodology in Section 6.3 of NUREG-1507, Rev. 1. ORAU used commercially available statistical software for evaluating the survey data and setting the IL relative to representative background populations. Common statistical IL values, above which anomaly investigations are performed, include z-scores (normality assumed) or various background threshold value calculations, including use of the upper tolerance level (UTL), upper simultaneous limit (USL), and other statistics when the underlying data distribution is unknown or otherwise does not exhibit the characteristics of a normal distribution. Various examples are provided (Albequist, 2020). See Figure 2 below for an example use of UTL and USL for establishment of IL for continuously collected data.

Recently, PNNL was tasked with scoping out VSP tools to facilitate importation and analysis of continuously collected data including (i) development of tools to facilitate data importation, visualization and analysis of survey data collected without surveyor vigilance, (ii) calculation of *a priori* scan MDCs for continuously collected data, and (iii) methods to identify areas for follow-up investigation. The scoping report will be completed in FY2023. PNNL is also finalizing a “scan MDC” report presenting a novel lag k method for *a priori* calculation of scan MDC in FY2023.



*FIG. 2. Evaluation of Use of Upper Tolerance Limit (UTL) and Upper Simultaneous Limit (USL) for a Background and Background Plus Signal of 3,000 cpm-to-concentration ratio. Image credit: NUREG-1507, Rev. 1, Figure 6-7.*

## engineered SURFACE covers

Engineered surface covers can be a risk-significant barrier at many disposal sites and most notably uranium mill tailings disposal sites. Engineered covers serve several different functions including the following:

* Serving as an infiltration barrier;
* Limiting dose from surface exposure pathways (external and inhalation pathways);
* Providing isolation of waste (e.g., clay barrier to mitigate release of radon); and
* Provide physical stability.

The regulations in 10 Code of Federal Regulations (CFR) Part 40, Appendix A, provide that control of radiological hazards should be effective for 1,000 years, to the extent reasonably achievable, and in any case, for at least 200 years. However, various degradation mechanisms have been observed at uranium mill tailings disposal sites operating for just a few years or decades (e.g., surface and subsurface erosion; deposition of material in riprap; pedogenic processes leading to loosening of compacted cover materials; subsidence and differential settlement). These degradation mechanisms and observations appear to challenge the performance criteria for uranium mill tailings disposal sites in 10 CFR Part 40, Appendix A. NRC has sponsored many projects and activities to study the long-term performance of engineered surface covers including modeling, field studies, and conferences (see Table 1 below). One type of engineered surface cover that has experienced increased interest in recent years is the evapotranspiration cover (ET cover). The United States Department of Energy (DOE) is currently evaluating the use of ET covers at their uranium mill tailings disposal sites. NRC is currently developing draft guidance for designing, constructing, and monitoring ET covers.

TABLE 1. NRC Technical Reports on Engineered Surface Covers

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| NUREG number | Title |
| NUREG-1623 | Design of Erosion Protection for Long-Term Stabilization |
| NUREG/CR-7028 | Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-term Performance Assessment |
| NUREG/CP-0195 | Proceedings of the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities |
| NUREG/CR-7200 | Influence of Coupling Erosion and Hydrology on the Long-Term Performance of Engineered Surface Barriers |
| NUREG/CR-7288 | Evaluation of In-Service Radon Barriers over Uranium Mill Tailings Disposal Facilities |

## PUBLIC OUTREACH

NRC has recently hosted several public meetings and workshops to keep interested stakeholders involved in the guidance development process. Two subsurface investigations were held in July 2021 and May 2022, and a discrete radioactive particles workshop in November 2022. NRC also maintains an external web site that provides information on upcoming meetings, publication of draft documents for comment (or final document issuance), and to share information on the results and findings from workshops and meetings.

NRC has also worked with industry to address guidance and tool gaps to increase transparency in the license termination process. NRC plans to review industry guidance (NEI-22-01) that has been submitted to the NRC for review and approval in 2023. NEI-22-01 provides “how to” guidance on navigation of the license termination process focusing on reactor decommissioning. NEI-22-01 is also expected to help facilitate NRC staff review of license termination plans and final status surveys leading to programmatic efficiencies.

NRC’s outreach efforts are important to ensuring the transparency of the license termination process and the stability of the decommissioning program in the United States with the pace of reactor decommissioning expected to increase in the coming years. For additional information, please refer to NRC’s external public web site at the following URL: <https://www.nrc.gov/waste/decommissioning/whats-new.html>.

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