Pre-MARSSIM Surveys in a MARSSIM World: Demonstrating How Pre-MARSSIM Radiological Data Demonstrate Protectiveness at Formerly Utilized Sites Remedial Action Program Sites - 11319

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ABSTRACT

The U.S. Department of Energy (DOE) and other agencies conducted a significant amount of radiological remediation over decades prior to the development and implementation of the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) [1]. DOE work included response actions at sites included in the Formerly Utilized Sites Remedial Action Program (FUSRAP). Some stakeholders have suggested that DOE radiological cleanups based on pre-MARSSIM methods do not correspond to current techniques and that data should be reevaluated using MARSSIM protocols to demonstrate compliance.

This paper discusses the evolution of site assessment methods used for FUSRAP sites since the 1970s and demonstrates that an accepted technical basis was followed for assessments performed before the adoption of MARSSIM guidance. DOE FUSRAP and MARSSIM site assessment and radiological survey protocols are compared. A case study of a remediated FUSRAP site is presented to show how the results of DOE surveys conducted under older protocols demonstrate compliance with site cleanup limits and standards and, therefore, protectiveness.[1]

This analysis may apply to other sites where radiological contamination was assessed and remediated before MARSSIM site assessment protocols were developed and adopted.

INTRODUCTION

This paper examines the process used by the U.S. Department of Energy (DOE) to characterize, remediate, and certify radioactively contaminated sites under the Formerly Utilized Sites Remedial Action Program (FUSRAP) between 1979 and 1997, and compares that process to methodology specified in the 2000 *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) [1]. This comparison focuses on radiological contamination in soil but is applicable to surface contamination as well. Through this comparison, we show that the processes used by DOE were as effective at demonstrating compliance with cleanup goals as the methodology established in MARSSIM.

We use remediation records from the Niagara Falls Storage Site Vicinity Properties to compare FUSRAP remediation methodology to the significant elements of MARSSIM, and show how the DOE processes resulted in a high degree of certainty that the remediation activities at this site resulted in conformance to release criteria. We conclude that the two methods would both likely indicate conformance to standards for this site. Conclusions may apply to other FUSRAP sites remediated by DOE.

This paper is not intended to critique the validity of the DOE survey guidance applied during FUSRAP cleanups or to critique guidance set forth in MARSSIM; DOE's and MARSSIM's guidance have been peer-reviewed and accepted by the health physics community. Rather, we intend to compare the

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[1] In this paper and consistent with MARSSIM terminology, "criteria" refers to protective dose- or risk-based levels. "Limits," "guidelines," and "standards" are maximum levels (concentrations or activities) that may remain in a remediated area and not exceed dose- or risk-based criteria.

predecessor DOE site assessment guidance and practices for radiologically contaminated sites to MARSSIM protocols and show that, while survey and data interpretation methods may differ, both approaches are appropriate for determining whether a typical FUSRAP property meets established limits for the specific radiological conditions.

Evaluating the protectiveness or applicability of the various cleanup standards and limits used historically is beyond the scope of this paper. DOE cleanup limits for unrestricted use of a property were based on accepted release criteria. These criteria evolved as the health effects of radiation were better understood. Site-specific guidelines that were consistent with basic dose limits and probable site uses were developed. This approach is compatible with MARSSIM, which assumes that release criteria and cleanup standards have been identified or derived and are acceptable to the parties involved.

Background

The U.S. Atomic Energy Commission (AEC) established FUSRAP in March 1974 to evaluate radioactive contamination at sites where work had been performed in support of the U.S. Army Corps of Engineers (USACE) Manhattan Engineer District (MED) and early AEC programs. MED and AEC retained contractors at sites throughout the United States to supply materials and services. Activities included processing and storing uranium and thorium ores, refined source material, and other radioactive materials for nuclear weapons programs; performing metallurgical research; and providing production and machining services. Although most of the sites were decommissioned to guidelines that were in effect at the time the original work was completed, some of those guidelines had been superseded by more stringent standards by the 1970s.

Under FUSRAP, AEC identified sites where additional assessment and remediation of radioactive contamination was warranted in order to achieve protectiveness. In 1977, DOE assumed responsibility for administering and executing FUSRAP and eventually identified 46 sites that required cleanup. DOE remediation began in 1979 and continued until 1997, when Congress transferred responsibility for FUSRAP site characterization and remediation to USACE. By that time, DOE had cleaned up 25 of the sites. DOE is still responsible for determining if a site is eligible for remediation under FUSRAP and for the long-term surveillance and maintenance of remediated FUSRAP sites [2].

The principal mission of the DOE Office of Legacy Management (LM) is to ensure that assigned sites (including closed FUSRAP sites) remain protective of human health and the environment after remediation is complete [3]. DOE accomplishes this through a long-term surveillance and maintenance program designed to control residual risk and maintain safe site conditions. DOE assumes perpetual responsibility for remediated FUSRAP sites. Because most sites were cleaned up for unrestricted use, these long-term responsibilities largely consist of managing records and responding to the public’s inquiries about the sites.

FUSRAP SITE ASSESSMENT AND REMEDIATION METHODOLOGY

Evolution of FUSRAP Methodologies

Initial FUSRAP remedial action projects adhered to existing DOE and U.S. Nuclear Regulatory Commission (NRC) guidance. Survey design reflected the assumption that a subject site was contaminated until representative negative data proved otherwise. Site-specific survey plans described limits and standards, data requirements, instrument selection, sampling schemes, analytes, and other project parameters and specifications. FUSRAP-specific methods were later established in comprehensive program guidance.

DOE designed radiological surveys to acquire the data needed for a defined objective. All data were intended to support a final demonstration of compliance with cleanup limits. The DOE methodology was designed to identify uncontaminated areas early in the remediation process, eliminate them from further consideration, and concentrate on areas requiring remediation.

Survey activities were designed to detect and quantify contamination at a particular site. Initial design decisions were based on historical records and initial site visit information. As the remediation process proceeded, measurement and data-collection methods and requirements were adapted to site conditions.

Instruments and analytical methods were selected for surveys based on the ability to detect activities and concentrations well below authorized limits. Surveys incorporated a geodetic survey grid for locating measurement results and systematic and biased sample locations over the site. A chronology of site assessment guidance is presented in Table I.

Table I. Evolution of Site Assessment Guidance.

Date	Guidance	Significant Provisions
November 1976	NRC, *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material* [4]	Established limits for surface contamination
January 1986	DOE, *Summary Protocol—Identification, Designation, Remedial Action, Certification* (Summary Protocol) [5]	Codified DOE site assessment methodology
June 1986	DOE, *A Manual for Implementing Residual Radioactive Material Guidelines: A Supplement to U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites* [6]	Implementation guidance for the Summary Protocol
July 1988	DOE, *Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program, Implementation Plan for Radiological Surveys Protocols* [7]	Provided specific methodology for the four phases of the FUSRAP site assessment process
March 1992	NRC, *Manual for Conducting Radiological Surveys in Support of License Termination* (NUREG/CR-5849) [8]	Predecessor to MARSSIM guidance; updated NUREG-2082; addresses survey design, data quality, data reduction, decision making
August 2000	U.S. Environmental Protection Agency (EPA), DOE, and NRC, *Multi-Agency Radiation Survey and Site Investigation Manual* [1]	Supersedes NUREG-5849

Authorized limits were either generic, based on exposure assumptions, or derived on the basis of site-specific conditions. Applicable FUSRAP cleanup limits included NRC guidance for license termination, dose limits established by the International Commission on Radiological Protection, and the surgeon general's recommendations for structures affected by uranium mill tailings [4,9,10]. In 1983, EPA promulgated Title 40 *Code of Federal Regulations* Part 192 (40 CFR 192), "Standards for Remedial Actions at Inactive Uranium Processing Sites," and DOE published *Radiological Guidelines for Application to DOE's Formerly Utilized Sites Remedial Action Program* [11,12]. This DOE document was superseded by the 1985 *U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites* (FUSRAP Guidelines), which was revised in 1987 to reflect a revision of the total effective dose equivalent from 500 millirem per year (mrem/yr) to 100 mrem/yr [13,14]. In 1990, DOE issued Order 5400.5, *Radiation Protection of the Public and the Environment*, which contained the same cleanup limits that were established in the FUSRAP Guidelines [15].

The 1983 FUSRAP Guidelines specified generic limits for radium and thorium in soil, averaged over 100 m^2, reflecting standards established in 40 CFR 192. Limits for other radionuclides were to be derived using pathway analysis. The guidance addressed limiting maximum radionuclide concentrations (the "hot spot" criterion) and concentrations of mixtures of radionuclides (the sum-of-ratios rule). Surface contamination limits were stipulated. Supplemental limits could be applied in certain situations if cleanup limits could not be obtained. Exceptions to meeting authorized limits could be approved; this usually entailed invoking use restrictions to control exposure. In all cases, DOE applied the As Low As Reasonably Achievable (ALARA) principle.

DOE implemented the Summary Protocol in 1986 [5]. This document established a process to determine if a site was contaminated with residual radioactive material from MED or early AEC activities and whether the site was eligible for remediation under FUSRAP. It also established a general methodology for the remediation of eligible contamination and procedures for certification and release. This guidance was goals-oriented and not prescriptive with regard to process:

> Throughout this process, the professional judgment of the radiological survey personnel and the engineering and project management personnel is utilized . . . to determine the level of survey, engineering, and/or environmental work required to achieve the associated goals. [5]

The Summary Protocol prescribed four major phases of investigation and characterization, as described below. Specific survey techniques discussed below are from the 1988 FUSRAP implementation plan [7].

Preliminary Analysis Phase

This phase included a review of historical site operations, past processes, waste-handling practices, previous radiological surveys, contracts, materials inventories, activity reports, and correspondence. The assessment team conducted a document review before performing survey work. When possible, DOE located and interviewed people who had knowledge of the site or site operations. The research objectives were to identify potential radionuclides contaminating the site and estimate the distribution and magnitude of the contamination.

If current radiological conditions were not known, a radiological survey was conducted to determine if unacceptable levels of residual contamination remained on a candidate site. For sites where there was a potential for contamination involving off-site properties, the assessment task might have begun with a wide-area aerial or vehicle-based gamma survey. An on-site preliminary analysis survey was combined with a site visit to confirm land use and determine if an imminent hazard existed. Survey activities may have included scanning, direct radiation measurements, and the sampling of any media to demonstrate that contamination existed and to collect data sufficient to plan a more comprehensive survey to support designation and remedial action planning. If authority existed and radiological conditions exceeded guidelines, the site was recommended for designation and for remedial action.

Radiological Evaluation and Designation Phase

If more data were needed to determine FUSRAP eligibility, additional data were gathered during this phase. DOE conducted a radiological evaluation survey to “further evaluate the radiological conditions of the site . . . to compare the conditions to applicable guidelines and standards, to determine the potential for exposure, and to determine if there is a need for remedial action” [5]. The survey included a systematic phase, which entailed measuring and sampling surfaces, air, soil, water, and background levels. DOE conducted, if necessary, an extended phase survey that employed biased sampling, additional closer-spaced direct measurements and sampling to further delineate contamination extent, radon sampling in structures, and additional water and air sampling. Subsurface explorations at grid nodes and in anomalies included gamma measurements and soil sampling at depth. Survey data supported the release of those portions of the property where contamination levels did not exceed release limits. Only sites with FUSRAP-eligible contamination that exceeded guidelines were formally designated and continued through phases beyond the Radiological Evaluation and Designation Phase.

Engineering and Remedial Action Phase

After a site was designated, it entered the Engineering and Remedial Action Phase. During this phase, the most detailed radiological assessment work took place. This phase entailed radiological surveys to support remedial design and remedial action, and included post-remediation surveys to demonstrate that the site met cleanup limits.

Designs were based on results of gamma scans of the entire property; static gamma and beta/gamma measurements and systematic soil sample collection on grid node points; biased static and beta/gamma gamma measurements and sample collection where elevated activities were observed; and subsurface explorations at grid nodes and in anomalies. Grid spacing depended on initial gamma scan results and site knowledge.

DOE used radiation monitoring and sampling to guide remedial action. Removal progressed until residual activities met predetermined levels above background. When this condition was reached, DOE conducted a survey of the remediated areas, generally following the radiological-evaluation survey process. The report of post-remediation survey results included a comparison to applicable limits.

Verification of Site Condition Phase

DOE completed this phase using the *Verification and Certification Protocol* [16]. As a quality assurance measure, DOE required that a third party independently evaluate the radiological conditions of a remediated area and verify that guidelines had been adhered to and that radionuclide levels did not exceed limits. For FUSRAP, DOE retained Oak Ridge Associated Universities (ORAU) and the Oak Ridge Institute for Science and Education to perform this function and act as the independent verification contractor. As its name implies, the independent verification contractor remained independent of FUSRAP line management. The independent verification contractor’s work included reviewing documents, analyzing split samples or duplicate samples, and taking duplicate measurements.

The independent verification contractor issued a verification report and verification statement indicating that the site met cleanup and release limits. Regulators and other stakeholders also reviewed project documentation. If information indicated that the site met release criteria, DOE certified the site.

MARSSIM SITE ASSESSMENT AND REMEDIATION METHODOLOGY

MARSSIM provides guidance on the planning, implementation, and evaluation of radiological surveys for demonstrating compliance with dose- or risk-based regulations or standards. An evolution of previous guidance (e.g., NUREG-5849), MARSSIM provides a standardized and rigorous approach to the radiological site characterization and decommissioning process, and is widely accepted in the regulatory community.

Many readers may be very familiar with MARSSIM, and it is not our intent to restate its contents. Rather, as a prelude to the case study that follows, we present an overview that focuses on MARSSIM’s signature features. We will elaborate on key elements later in this paper, where we compare the approaches set forth in MARSSIM with those applied in earlier FUSRAP cleanups.

MARSSIM’s scope is limited to the characterization of building surfaces and surficial soils. Subsurface soils, buried infrastructure, materials and equipment, and groundwater all fall outside the scope of MARSSIM. This has implications for applicability at FUSRAP sites, where contamination is distributed in infrastructure and subsurface soils. Other current guidance addresses these occurrences.[2]

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[2] For example, *Multi-Agency Radiation Survey and Assessment of Materials and Equipment*, issued in 2009 as a supplement to MARSSIM, addresses methods and approaches for surveys of materials and equipment [17].

Signature Features

MARSSIM applies a new vocabulary to some concepts or approaches applied historically during site assessments. Key concepts include:

- The application of the data quality objective (DQO) process,
- The use of derived concentration guideline levels (DCGLs),
- The classification of survey units,
- Instrument scan sensitivity, and
- The use of statistical tests to demonstrate compliance depending on the radionuclide distribution (and variability) in both survey and background reference areas.

These features are summarized below.

DQOs—MARSSIM describes a seven-step DQO process. This process, originally developed by EPA [18], entails the qualitative and quantitative clarification of survey objectives to ensure that survey results are of sufficient quality and quantity to support the final decision that a surveyed area meets or exceeds cleanup standards.

Several qualitative elements of the DQO process are intuitive—(1) define the problem, (2) identify the decision to be made, (3) identify the inputs to that decision, (4) define the boundaries of the study—and have probably been applied historically at most sites, but they may not have been enumerated. The three remaining DQO steps—(5) developing a decision rule, (6) specifying limits on decision errors, and (7) optimizing the data collection design—all invoke the application of statistical techniques; however, they were not necessarily prescribed or employed in the pre-MARSSIM era. Step 7 entails applying statistical techniques to determine the sample size for both direct measurements and soil samples—one of the signature features of MARSSIM.

DCGLs—MARSSIM defines DCGLs as derived, radionuclide-specific activity concentrations (e.g., in disintegrations per minute per 100 square centimeters or picocuries per gram) within a survey unit that correspond to the dose- or risk-based release criterion. MARSSIM does not dictate how DCGLs are derived; rather, the guidance states that the DCGLs should be based on exposure-pathway modeling (implying site-specific spatial and temporal averaging). When there are multiple radionuclides, DCGLs are adjusted downward using the unity rule, equivalent to the sum-of-ratios concept mentioned earlier, to ensure that release limits are met.

MARSSIM defines two types of DCGLs based on the distribution of contamination: $DCGL_W$ and $DCGL_{EMC}$. $DCGL_W$ is compared to average concentrations measured over a wide area using statistical tests. $DCGL_{EMC}$ is intended for small areas of elevated activity, or “hot spots.” $DCGL_{EMC}$ is derived by multiplying $DCGL_W$ by a user-defined area factor. Only the $DCGL_W$ is used for decision making. Exceeding a $DCGL_{EMC}$ merely triggers further investigation.

Classification of Survey Units—MARSSIM requires that the site or property be divided into survey units based on contamination potential. An area is defined as “impacted” or “not impacted.” For impacted areas, MARSSIM uses three classifications of contamination potential: Class 1 (contamination likely above the $DCGL_W$), Class 2 (impacted, but contamination expected to be less than the $DCGL_W$), and Class 3 (impacted, but negligible potential for contamination above background concentrations). Essentially, these survey units constitute the boundaries of the study (DQO Step 4). How survey units are classified dictates the level of study rigor required and affects decisions regarding release. For more information on the application of these classifications, see “Comparison” below, and refer to Table III.

Instrumentation Scan Sensitivity—MARSSIM focuses extensively on instrumentation scanning sensitivity or minimum detectable concentration. The minimum detectable concentration must be established early in the planning phase because it greatly influences the survey design and the decision-making process.

Statistical Approaches to Demonstrate Compliance—MARSSIM uses nonparametric statistical methods to demonstrate that the survey data support the assertion that the site meets the release criteria within an acceptable degree of uncertainty. MARSSIM guidance recommends acceptable Type I (false negative) and Type II (false positive) errors (i.e., a Type I error passes a survey unit that does not satisfy release criteria, and a Type II error fails a survey unit that satisfies release criteria).

The number of samples required in a particular survey unit is based on its class designation, the DCGL relative to background or the scan sensitivity, the expected standard deviation of the contaminant in background areas and in the survey unit, and the acceptable probability of making Type I and Type II decision errors.

Key Components of Survey Design

The radiation survey and site investigation (RSSI) process recommended in MARSSIM consists of a graded approach that starts with a historical site assessment, followed by a series of surveys that culminate in the final status survey, MARSSIM's primary focus. The ultimate purpose of the RSSI process is to demonstrate compliance with dose- or risk-based release criteria for sites with radioactive contamination. As indicated below, the RSSI process consists of six principal steps that generally parallel the FUSRAP process discussed previously (from site identification to certification):

1. Site identification
2. Historical site assessment
3. Scoping survey
4. Characterization survey
5. Remedial action support survey
6. Final status survey

The final status survey entails using the appropriate radiation-detection equipment to perform comprehensive scans of areas and collect static measurements at locations established by the MARSSIM grid structure; and sample collection. The number of static measurements and samples depends on statistically valid sample populations. Essential steps of the final status survey include:

- Identifying the contaminants, establishing the DCGLs (release criteria translated into maximum allowable measurable concentrations), and deciding whether the unity rule will be used for multiple radionuclides.
- Classifying site areas and identifying survey units.
- Identifying background reference areas.
- Selecting field and laboratory instrumentation and specifying measurement protocols. Scan and measurement minimum detectable concentrations are defined in MARSSIM as the *a priori* activity level that a specific instrument and technique can be expected to detect 95 percent of the time.
- Selecting the statistical test (e.g., if contaminants are present in background, use the Wilcoxin Rank Sum test; if not, use the Sign test).
- Selecting DQOs for determining sample size to establish acceptable probabilities of Type I and Type II errors.
- Determining the number of static measurements and samples.
- Creating a reference grid and establishing sample locations based on the sample size determination.

COMPARISON OF FUSRAP AND MARSSIM SITE ASSESSMENT METHODOLOGIES

As discussed previously, DOE's FUSRAP cleanups spanned nearly two decades (1979–1997), all preceding MARSSIM's development, and some preceding a prolific era of newly issued site characterization and risk-assessment guidance. Furthermore, the advent of computer programs streamlined what was previously a laborious data-collection and data-reduction process. For example, COMPASS facilitated the use of MARSSIM, and RESRAD made it easier to derive DCGLs [19,20]. At the same time, instrumentation became more usable by automatically attributing data with location and other information and formatting data for uploading into data processing and archiving systems. We will compare the overall survey processes and then some of the signature features of the MARSSIM and DOE methods addressed earlier.

Radiological Survey and Site Investigation Process (General Approach)

As demonstrated later in the case study, FUSRAP data acquisition and decision making followed an iterative process similar to that recommended in MARSSIM (Table II). For FUSRAP sites, based on a records search and site reconnaissance, initial surveys analogous to MARSSIM's scoping and characterization surveys were conducted to identify contaminated areas. FUSRAP survey design was based on the same "contaminated until proven clean" assumption applied in MARSSIM (i.e., contamination in a survey unit was assumed to exceed the release criteria until data indicated otherwise). Under FUSRAP, if it was determined that remediation was necessary, contaminated areas were remediated based on real-time measurements—*all* elevated areas were remediated (as opposed to a statistically derived subset allowed by MARSSIM) until field readings indicated that guidelines were met. These efforts culminated in a survey analogous to the MARSSIM final status survey. DOE collected additional post-remediation samples for confirmatory analysis, typically on 10 m grid nodes, and gamma exposure rates were obtained for each sampling location. These results were compared to the limits and guidelines for compliance. Instead of making a MARSSIM-type statistical comparison of concentrations and activities to limits, DOE showed that concentrations averaged over 100 m^2 areas did not exceed the authorized limits and that final conditions met the hot spot criterion and sum-of-ratios rule. FUSRAP cleanups required mandatory independent verification (including the analysis of duplicate measurements and samples; the analysis of sample splits from post-remediation collection; and a quality assurance review of field records, raw data, and calculations), whereas MARSSIM only recommends, but does not require, independent verification.

Table II. Comparison of Overall FUSRAP and MARSSIM Methodologies.

FUSRAP	MARSSIM	Comments
Preliminary Analysis Phase—Site information is reviewed; the presence of radiological contamination is confirmed; the site's eligibility for FUSRAP remediation is confirmed.	A site identification, historical site assessment, and scoping survey are performed.	Site conditions, in general, are determined.
Radiological Evaluation and Designation Phase—DOE demonstrates that contamination exceeds guidelines for FUSRAP and remediation is necessary; DOE formally includes the site in FUSRAP.	A characterization survey is performed.	The FUSRAP process is designed to support legal determination of eligibility; uncontaminated sites are excluded under the FUSRAP process.
Engineering and Remedial Action Phase—Culminates in a post-remediation survey report.	A characterization survey, remedial action support survey, and final status survey are performed.	Under MARSSIM, data are collected to release uncontaminated areas; all previous surveys help support the final surveys in both methodologies.
Verification and Certification Phase—An independent verification survey is conducted.	Statistical tests support decision making.	

Survey Design

As stated earlier, one of the fundamental elements of MARSSIM methodology is reliance on survey unit classification. Table III compares the key survey design features (survey unit area and recommended coverage) recommended in MARSSIM to previous FUSRAP methods.

Table III. Comparison of MARSSIM and FUSRAP Survey Design. a

MARSSIM Survey Unit Classification	Definition	MARSSIM Survey Unit Area Definition	Recommended Survey Coverage	Generic FUSRAP Approach
Class 1	Areas with known or potential contamination, expected above $DCGL_W$	Land: Up to 2,000 m^2 Structures: Up to 100 m^2	100 percent scan (structures and land areas) Number of surface activity or soil measurements based on statistical tests, number defines grid size (systematic sampling)	No survey unit classification—essentially, all areas chosen for investigation were initially equivalent to a MARSSIM Class 1 survey unit 100 percent gamma scan Systematic sampling—grid size varied depending on area and results of gamma scan, but were generally conservative relative to MARSSIM standards (often 10 m, could be larger) based on site characteristics. Data needed to support averaging to meet soil guidelines over a 100 m^2 area
Class 2	Areas with known or potential contamination, not expected above $DCGL_W$	Land: 2,000 to 10,000 m^2 Structures: 100 to 1,000 m^2	10 to 100 percent scan—systematic and judgmental Number of data points dependent on statistical tests	
Class 3	Areas with low potential for contamination above background	No limit	Judgmental	
Non-Impacted	Areas that have no reasonable potential for residual contamination	No survey required	Not applicable	

a Table adapted from Tables 1 and 2 in the MARSSIM "Roadmap" [1].

Decision Making: Evaluating Compliance with Release Limits

FUSRAP generic cleanup limits are analogous to the $DCGL_W$ in MARSSIM. MARSSIM recommends that a determination of compliance (comparison of data to the $DCGL_W$) use statistical analysis of data collected during a final status survey. The design of the final status survey depends on factors such as the size of the survey area and the acceptable probability that the $DCGL_W$ is met. Some individual results may exceed the $DCGL_W$ as long as the probability of Type I errors (false negatives) is controlled.

Under FUSRAP methods, individual data were typically compared to the limit or guideline. Area averaging was acceptable when the limits were written as maximum concentrations averaged over 100 m^2. This is equivalent to the most conservative decision-making rule in MARSSIM, whereby no results exceed the $DCGL_W$; in this case, no additional statistical data reduction is required (see Table 8.2 in MARSSIM). The hot spot criterion, which controls maximum concentrations in smaller areas, was also invoked. Analogous provisions were developed for surface contamination.

Table IV compares FUSRAP and MARSSIM methods.

Table IV. Comparison of MARSSIM and FUSRAP Radiological Site Assessment Approaches.

Endpoint/ Category	FUSRAP	MARSSIM
General	Based on guidance and expert judgment; survey units equivalent to MARSSIM Class 1 protocols; may be more conservative in some circumstances; individual results had to be less than the cleanup limit	Allows graded approach to demonstrate compliance—reliance on statistics; includes guidance on instrumentation and implementation of DQO process; includes by reference other DOE, EPA, and NRC guidance; statistical tests indicated uncertainty of false negative and false positive errors
Nature of Contamination	Can be any radionuclides but usually uranium decay series; typically in the form of discrete pieces of material, volumetric contamination in open land, or surface contamination on structures	Only addresses surface contamination and surface soils; subsurface or volumetric contamination outside MARSSIM scope (but addressed in other guidance)
Initial Assumptions	Equivalent to assumptions for MARSSIM Class 1 classification; survey undertaken assuming area was contaminated	Impacted areas assumed to be contaminated; classification (Class 1, 2, and 3) performed to employ graded approach when sufficient data are available
Release Limits and Guidelines	Based on not exceeding public dose limit; established limits including DOE Order 5400.5 (derived limits developed by pathway analysis, ALARA, sum of ratios; hot spot criteria applied); provisions for supplemental limits and exceptions	Development of DCGLs outside MARSSIM scope (can use RESRAD and COMPASS); MARSSIM recognizes flexibility in deriving guidelines by factoring in plausible future land use and exposure scenarios
Data Quality Objectives	General discussion in Summary Protocol [5]; refined for each survey plan	A fundamental component; systematic development of DQOs
Survey Design and Establishing Survey Units	Essentially all contaminated areas equivalent to Class 1; sample size populations calculated for anomalies and remediated units; 100 percent scans in potentially contaminated areas with systematic and biased surface (and subsurface for open land) sampling or direct measurements, smear sampling for structures; grid spacing reflects contamination distribution; composite samples in later post-remediation surveys representing 100 m^2 areas; survey design incorporated accepted AEC and DOE practices	Survey unit classification based on contamination potential; sample population based on DCGLs, expected standard deviation of the contaminant in background and in the survey unit, and the acceptable probability of incorrectly classifying a survey unit (e.g., Type I and Type II decision errors)
Demonstration of Compliance/ Verification	Demonstration that all results are less than standards or that average concentrations or activities within defined area meet standard; established maximum concentrations or activities	If all results are not less than $DCGL_W$, nonparametric statistical tests used to demonstrate compliance
Verification	Required independent verification by third party	Third-party verification encouraged but not mandated

CASE STUDY: DEMONSTRATION OF COMPLIANCE AT THE NIAGARA FALLS, NY, VICINITY PROPERTIES SITE

This case study demonstrates an implementation of DOE site assessment and remediation methodology for soil contamination and illustrates the iterative nature of the FUSRAP process. The methodology includes elements that are equivalent to MARSSIM methodology, as noted in the text.

Background and Setting

The federal government acquired the Lake Ontario Ordnance Works in the early 1940s. Most of the property was subsequently sold, and the federal government retained ownership of the Niagara Falls Storage Site. Multiple episodes of remediation occurred in the 1950s through the 1970s as standards became more stringent [21].

The site was used for the storage and disposal of uranium-processing residues and contaminated material from various sources, including waste containing mixed fission products from the Knolls Atomic Power Laboratory, cesium and strontium spark gaps, and radioactive animal-testing waste from the University of Rochester. Material containing uranium metal was stored at the facility. Slag containing naturally occurring radioactive material (uranium and daughters) was used extensively for construction. Contaminated debris from decommissioned plants was disposed of at the Lake Ontario Ordnance Works. Contaminant sources were documented, but DOE determined that records of material handling were probably not complete.

Based on site history, wastes were eligible for remediation under FUSRAP (wastes were generated as a result of MED and AEC activities). Preliminary surveys of the area (aerial, scan van) indicated that contamination exceeded FUSRAP Guidelines in many locations, including the Niagara Falls Storage Site proper and associated vicinity properties (VPs). The VPs were collectively designated as a FUSRAP site. Based on historical knowledge, it was known that different properties were used for different purposes and that the nature of contamination was likely to vary considerably. For purposes of remediation and certification, each VP was addressed individually and could be thought of as a survey unit in MARSSIM terms.

DOE guidelines include a basic dose limit for the general public for exposure to radiation from DOE activities (including remedial actions), which was used to establish generic soil guidelines that apply to “worst-case plausible-use” scenarios [15]. MARSSIM would refer to the basic dose limit as a release criterion.

The FUSRAP Guidelines specified generic limits for Ra-226, Ra-228, Th-230, and Th-232 in surface and subsurface soil, averaged over 100 m^2. Site-specific soils cleanup limits for uranium and Cs-137 were derived using RESRAD [22]. These limits were used as DCGLs consistent with MARSSIM methodology.

Historical information indicated that residual waste from Knolls Atomic Power Laboratory may contain radionuclides that did not emit gamma radiation such as Sr-90 and, potentially, trace amounts of Pu-239. However, concentrations were much smaller than concentrations of Cs-137. Therefore, Cs-137 was found to be a valid surrogate for the other associated radionuclides. Using a surrogate is consistent with the MARSSIM process.

Characterization Process

Upon designation, the operating assumption for each Niagara Falls Storage Site VP was that it contained contamination above FUSRAP Guidelines (Class 1 designation according to MARRSIM). Accordingly, comprehensive radiological surveys were conducted by ORAU or Oak Ridge National Laboratory. The surveys for each VP followed a systematic process:

- The VP was cleared, and a grid was established. Grid spacing varied based on radiological conditions as determined from the walkover scan or historical knowledge.
- Walkover gamma surface scans were conducted over 100 percent of accessible areas.
- Gamma exposure rates were measured at the surface and 1 m above the surface at each grid node.
- Beta/gamma dose rates were measured 1 cm above the surface at each grid node.
- Systematic surface soil samples were collected at grid nodes and, possibly, at regular intermediate locations.
- If warranted, based on prior survey results, biased samples were collected from areas of known contamination and anomalies, 1-m-high beta/gamma dose rates and gamma exposure rates were measured, and surface exposure rates were re-measured to determine if sampling resulted in source removal.
- Analytes in soil samples included Ra-226, Th-230, Th-232, U-238, and Cs-137.
- Ground-penetrating radar surveys were performed where burial areas were known or suspected.
- Boreholes were drilled and logged in known burial areas, in contaminated areas, and in ground-penetrating radar anomalies. Water and soil samples were collected from the borings. Downhole gamma logging was performed to increase the volume of subsurface investigation.

The combination of characterization approaches used at each property was intended to result in a high probability of identifying contamination exceeding FUSRAP guidelines. While Type I (false negative) errors were not explicitly addressed during survey design, this approach minimized their likelihood. The sitewide gamma scans and systematic sampling, combined with the biased (judgmental) sampling of anomalies, would have met the goals of a MARSSIM Class 1 final status survey.

Upon completion of characterization activities, radiological assessment reports were prepared for each of the VPs. Based on the results of these assessments, DOE determined if remediation of a particular property was required. In some instances, properties had small numbers of isolated elevated results (point sources) that were reduced through sampling. DOE decided that if averaging the results resulted in compliance with the FUSRAP Guidelines and gamma scan results did not find elevated activities outside of sampled areas, remediation was not required and the property could proceed to certification; the assessment surveys for these VPs served as final status surveys. This is similar to, albeit more simplistic than, the application of statistical tests according to MARSSIM.

The assessment surveys identified areas where results exceeded authorized limits. Volumes of material requiring remediation were estimated. The survey report included maps showing the sampling grids, measurement and sampling locations, and areas where radionuclide concentrations in soil exceeded limits. Analytical and measurement results were presented in the summary reports, and the sites proceeded to remediation.

Remediation Process

Based on the radiological characterization survey results, DOE developed remediation plans to guide activities. Remediation activities consisted of the following:

- Contaminated areas were resurveyed and marked for excavation.
- Contaminated soils were removed from marked areas to the depth specified.
- Radiological measurements were collected on the excavated surface, and additional contamination was removed until measurements indicated that cleanup limits were not exceeded.
- A 10 m grid was established in the excavated areas, composite soil samples were collected from within each 100 m^2 area, and direct measurements were obtained for each grid node.

Post-remediation measurements were typically much lower than the release limits. For example, Ra-226 concentrations generally were near 2 pCi/g. In keeping with the ALARA principle, conservative gamma activity levels used for excavation control surveys resulted in residual contamination being removed even if it did not exceed the release limits. Cleanup to near background levels was often the consequence of applying the ALARA principle.

Post-remediation reports summarized the remediation activities for and post-remediation status of each property. Extent of contamination maps, excavations maps, sample location maps, and measurement and sample analysis results were included [23,24].

Post-remediation survey data collected for the remediated areas, combined with pre-remediation data collected for the unremediated areas, serve as the basis for certification and are equivalent to a MARSSIM final status survey for the property.

Verification Process

ORAU served as the independent verification contractor. In conjunction with post-remediation sampling, ORAU performed an independent verification of the cleanup work for the VPs. The verification process included:

- A review of characterization reports, engineering drawings, and post-remediation reports;
- Laboratory analysis of selected splits of samples collected by the remediation contractor; and
- A survey of the excavated areas, including visual inspections, gamma scans, direct measurements, and surface and subsurface sampling on representative portions of the excavated surfaces.

Verification survey results were reported separately [25, 26].

ORAU prepared statements of certification indicating that the properties complied with DOE release criteria. DOE sent copies of the statements to property owners, published a *Federal Register* notice of certification, and made the certification docket available for public review [27].

CONCLUSIONS

- Release limits are assumed to be protective, and the FUSRAP and MARSSIM site assessment methodologies both address how to demonstrate conformance to those limits.
- MARSSIM represents an evolution of site assessment methodology. MARSSIM is intended to allow flexibility and a graded approach to data collection and to instill consistency in survey methods. The guidance builds on survey methods that previously were employed to demonstrate conformance to release limits.
- FUSRAP and MARSSIM methodologies are generally equivalent: acquiring site knowledge, identifying release criteria and cleanup limits, designing surveys and creating survey plans, collecting data, and determining the degree of compliance.
- DOE radiological site assessment and release methods were at least as conservative as the most conservative MARSSIM methods. DOE post-remediation levels usually were far less than release limits.
- DOE data reduction typically consisted of comparing results to authorized limits. Generally, all results had to be less than the authorized limits to achieve certification. In a MARSSIM context, DOE essentially demonstrated that $DCGL_W$ was less than the release limits for Class I survey units.
- DOE radiological survey data may not conform to MARSSIM data requirements.

- By using a 100 percent gamma scan for gamma-emitting radionuclides (the most common FUSRAP contaminants), DOE was able to detect and remove residual contamination. Contamination may have been overlooked if the survey units had been classified under MARSSIM as Class 2 or Class 3.
- For many FUSRAP sites, the contamination consisted of small areas or discrete pieces of material that were usually found by biased sampling guided by gamma scans. MARSSIM would require these occurrences to be addressed as Class 1 survey units, and a graded approach could not be used.
- DOE mandated independent verification as an essential quality assurance measure. Typically, representatives from other regulatory agencies and other stakeholders also reviewed DOE's results.[3]

REFERENCES

1. U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission, and U.S. Department of Energy, "Multi-Agency Radiation Survey and Site Investigation Manual," NUREG-1575, Revision 1; EPA 402-R-97-016, Revision 1; DOE/EH-0624, Revision 1 (August 2000).
2. U.S. Department of Energy and U.S. Army Corps of Engineers, "Memorandum of Understanding between the U.S. Department of Energy and the U.S. Army Corps of Engineers Regarding Program Administration and Execution of the Formerly Utilized Sites Remedial Action Program (FUSRAP)," (March 1999).
3. U.S. Department of Energy, "U.S. Department of Energy Office of Legacy Management Strategic Plan," Washington, DC (May 2007).
4. U.S. Nuclear Regulatory Commission, "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material" (November 1976).
5. U.S. Department of Energy, "Summary Protocol—Identification, Designation, Remedial Action, Certification," (January 1986).
6. U.S. Department of Energy, "A Manual for Implementing Residual Radioactive Material Guidelines: A Supplement to U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites," DOE/CH-8901 (June 1989).
7. U.S. Department of Energy, "Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program, Implementation Plan for Radiological Surveys Protocols," (July 1988).
8. U.S. Nuclear Regulatory Commission, "Manual for Conducting Radiological Surveys in Support of License Termination," NUREG/CR 5849, ORAU-92/C57 (1992).
9. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection," ICRP 26 (1977).
10. 10 CFR 712, "Surgeon General's Guidelines, Part 172, Grand Junction Remedial Action Criteria," *Code of Federal Regulations*, published in the *Federal Register*, Volume 41, Number 253, pages 56777 to 56778 (December 30, 1976).
11. 40 CFR 192, "Standards for Remedial Actions at Inactive Uranium Processing Sites," *Code of Federal Regulations*, published in the *Federal Register*, Volume 48, Number 3, page 590 (January 5, 1983).

[3] Although DOE was self-regulated under Atomic Energy Act authority, DOE established cleanup limits and determined that remediation was complete in consultation with state regulators.

12. U.S. Department of Energy, “Radiological Guidelines for Application to DOE’s Formerly Utilized Sites Remedial Action Program,” ORO-831 (March 1983).
13 U.S. Department of Energy, “U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites,” Revision 1 (July 1985). [Total Effective Dose Equivalent (TEDE) is 500 mrem/yr]
14. U.S. Department of Energy, “U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites,” Revision 2 (March 1987). [TEDE is 100 mrem/yr]
15. U.S. Department of Energy, “DOE Order 5400.5, Radiation Protection of the Public and the Environment,” (February 8. 1990). [revised on January 7, 1993]
16. U.S. Department of Energy, “Verification and Certification Protocol—Supplement Number 2 to the FUSRAP Summary Protocol,” (November 1985).
17. U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission, and U.S. Department of Energy, “Multi-Agency Radiation Survey and Assessment of Materials and Equipment,” NUREG-1575, Supplement 1; EPA 402-R-09-001; DOE/HS-0004 (January 2009).
18. U.S. Environmental Protection Agency, “Guidance for the Data Quality Objectives Process,” EPA-QA-G-4, EPA/600/R-96/055 (September 1994).
19. COMPASS software, available at http://orise.orau.gov/files/ieav/project-summaries/project-compass.pdf.
20. U.S. Department of Energy, “RESidual RADioactivity (RESRAD) Computer Code,” (1989).
21. U.S. Department of Energy, “Radiological Site Assessment Plan for Portions of the Former Lake Ontario Ordnance Works,” in “Radiological Survey Plan of Property Declared Excess—Former Lake Ontario Ordnance Works,” letter from W. Bidd, DOE, to W. Mott, DOE (June 1, 1981).
22. U.S. Department of Energy, “Derivation of a Uranium and Cesium-137 Residual Radioactive Material Guidelines for the Niagara Falls Storage Site,” Argonne National Laboratory, Chicago, IL (August 1988).
23. U.S. Department of Energy, “Post-Remedial Action Report for the Niagara Falls Storage Site Vicinity Properties—1983 and 1984, Lewiston, New York,” DOE/RO/20722-84 (December 1986).
24. U.S. Department of Energy, “Post-Remedial Action Report for the Niagara Falls Storage Site Vicinity Properties—1985 and 1986, Lewiston, New York,” DOE/RO/20722-133 (January 1989).
25. U.S. Department of Energy. “Verification of 1983 and 1984 Remedial Actions, Niagara Falls Storage Site Vicinity Properties, Lewiston, New York,” (December 1989).
26. U.S. Department of Energy, “Verification of 1985 and 1986 Remedial Actions, Niagara Falls Storage Site Vicinity Properties, Lewiston, New York,” (July 1990).
27. U.S. Department of Energy, “Certification Docket for the Remedial Action Performed at the Niagara Falls Storage Site Vicinity Properties in Lewiston, New York, from 1983 through 1986,” (July1992).