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Chapter 12
Radiological Assessment

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Chapter 12
Radiological Assessment

12.1 Introduction

The purpose of this chapter is to provide guidance on conducting and documenting environmental radiological surveys and sampling episodes and demonstrating compliance with N.J.A.C. 7:28-12, *Soil Remediation Standards for Radioactive Materials*. This chapter does not address building contamination.

The person responsible for remediating a radiologically contaminated site must obtain a copy of the latest version of the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (available at http://www.epa.gov/rpdweb00/marssim/) for reference. Please note that some of the requirements in this chapter are different than the guidance presented in the MARSSIM. This chapter instructs the reader when to use the MARSSIM.

Figure 12.1 shows the relationship between MARSSIM terminology and the NJDEP Technical Requirements for Site Remediation (N.J.A.C. 7:26E).

Any questions regarding this chapter should be directed to the NJDEP, Bureau of Environmental Radiation (BER) at (609) 984-5400 or through the radiation protection program's web site at http://www.state.nj.us/dep/rpp. A complete list of references, a glossary (statistical terms are defined in the MARSSIM glossary), and list of acronyms can be found at the end of this chapter.

12.2 The Planning Stage (Data Life Cycle)

The process of planning, implementing, assessing and evaluating survey results is known as the Data Life Cycle. Survey designs should be developed and documented using the Data Quality Objectives (DQO) Process outlined in the MARSSIM (Appendix D, *The Planning Phase of the Data Life Cycle*, and Section 2.3.1, *Planning Effective Surveys – Planning Phase*). The expected output of planning surveys using the DQO process is a Quality Assurance Project Plan (QAPP) which should integrate all the technical and quality aspects of the Data Life Cycle. It should define in detail how specific quality assurance and quality control (QA/QC) activities will be implemented during the various surveys.

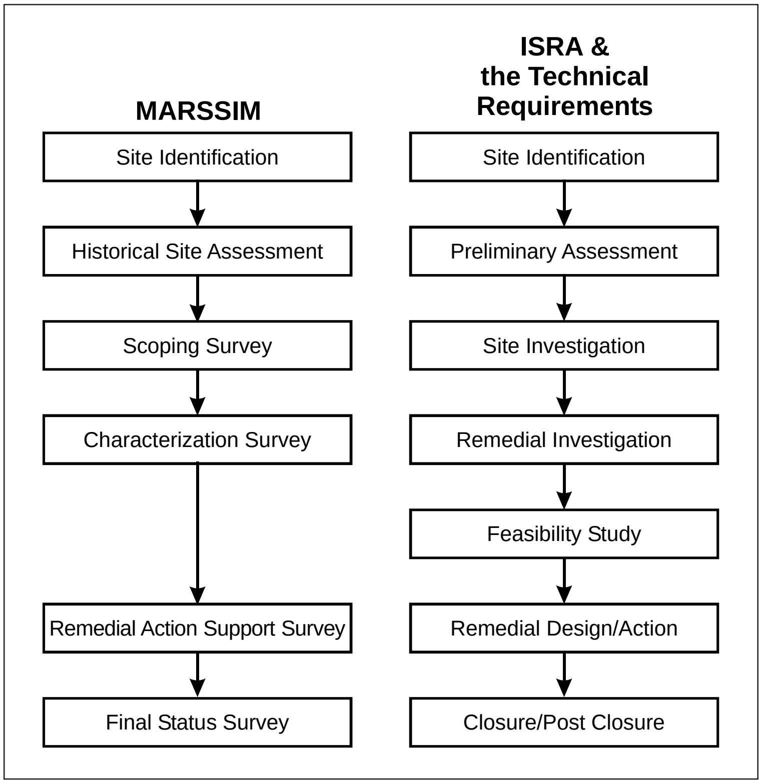

Figure 12.1 Comparison of MARSSIM and the Technical Requirements

Specific sampling, survey and laboratory requirements as they relate to QA/QC are found in N.J.A.C. 7:28-12.5, N.J.A.C. 7:26E-2, and Chapter 2 of this manual.

Comparison of the Radiation Survey & Site Investigation Process (MARSSIM) with ISRA & the Technical Requirements for Site Remediation. Note: The relationship between the MARSSIM process, the CERCLA process and RCRA process is discussed in Appendix F of the MARSSIM.

12.3 Site Identification/Historical Site Assessment

The purpose of the Historical Site Assessment (HSA) is to collect existing information on the site and its surroundings. A *site* is considered any installation, facility, or discrete, physically separate parcel of land that is being considered for survey and investigation.

The objectives of the HSA are to identify potential or known sources of contamination, determine if the site, or any portion of it, poses a threat to human health and the environment, and differentiate between impacted and non-impacted areas. It should also provide input for scoping and characterization surveys, assess the likelihood of contaminant migration, if migration off site is possible, and identify additional potential radiation sites related to the site being investigated (such as neighboring properties). The three steps of the HSA are 1) identify the candidate site, 2) perform a preliminary investigation of the site, and 3) visit or inspect the site.

The checklist on page 3-5, *Table 3.1 Questions Useful for the Preliminary HSA Investigation*, of the MARSSIM should be used to collect existing information on the site. Further guidance on conducting a Historical Site Assessment is provided in Chapter 3 and Appendix A, *Example of MARSSIM Applied to a Final Status Survey*, of the MARSSIM, including documentation (Section 3.8, *Historical Site Assessment Report*, of the MARSSIM).

12.4 The Scoping Survey

The purpose of the scoping survey is to provide site-specific information based on limited measurements. The objectives of the survey may include performing a preliminary risk assessment and providing data to complete the site prioritization scoring process (CERCLA and RCRA sites only), supporting classification of all or part of the site as a Class 3 area[1] (area classification is discussed further in Section 12.4.3 of this chapter), evaluating the suitability of the survey plan for use in characterization, providing input into the design of the characterization survey, obtaining an estimate of the variability in the residual radioactivity of the site, and identifying non-impacted areas that may be appropriate for reference areas. These surveys typically consist of judgement measurements based on the results of the Historical Site Assessment. Sufficient data should be collected to facilitate the area classification process. Figure 4.1, *Sequence of Preliminary Activities Leading to Survey Design*, in the MARSSIM illustrates the preliminary steps necessary for planning a scoping survey.

12.4.1 Identify Contaminants

For sites with multiple radionuclide contaminants, one of the objectives of the scoping survey could be to establish the ratios between each nuclide. For some sites, a review of the operating history would be helpful in establishing a ratio, and a limited number of samples could be collected to verify the suspected ratio. For other sites, a ratio might be better established as part of the characterization survey. Parts of the site might have different ratios, or there may not be a consistent ratio. Determining a consistent ratio may be difficult. Before establishing the derived concentration guidance levels[2] (DCGLs) based on a ratio, consultation with the BER is recommended. If hazardous substances are commingled with the radionuclide contamination, the user is referred to Chapter 3 of this Manual for details on sampling.

To determine whether the radionuclides are correlated or not, MARSSIM states "a simple way to judge this would be to make a scatter plot of the concentrations against each other, and see if the points appear to have an underlying linear pattern."[3] The correlation coefficient should be calculated as well to see if it lies nearer to one than to zero. A curve fit and test of the significance of the results should also be performed.

12.4.2 Establish the Derived Concentration Guideline Levels (DCGLs)

The DCGLs (soil remediation standards) to be used in New Jersey for naturally occurring radioactive materials (NORM) are established in N.J.A.C. 7:28-12, *Soil Remediation Standards for Materials* for unrestricted, limited restricted, and restricted use. DCGLs for any radioactive material may be developed by the person responsible for remediating the site by following the methodologies in *Development of Generic Standards for Remediation of Radioactively Contaminated Soils in New Jersey, A Pathways Analysis Approach*. This document may be obtained by calling (609) 984-5400 or from the Radiation Protection Programs web site at http://www.state.nj.us/dep/rpp. If an alternative standard is proposed, the requirements in N.J.A.C. 7:28-12.12, "Petition for alternative remediation standards for radioactive contamination," must be met. The DCGLs listed in N.J.A.C. 7:28-12.9, "Minimum remediation standards for radionuclide contamination of soil," are for use when only one radionuclide is present in the radioactive contamination on the site. If more than one nuclide is present, the sum of the fraction calculation must be performed as outlined in N.J.A.C. 7:28-12.9(b). It may be necessary to determine the ratio between the nuclides in order to establish the nuclide-specific DCGLs. The Radioactive Soil Remediation Standards spreadsheet, or RaSoRS, will be essential in determining the DCGLs for NORM and is available from the Radiation Protection Programs web site or by calling (609) 984-5400.

Section 4.3.3, *Use of DCGLs for Sites With Multiple Radionuclides*, of the MARSSIM discusses multiple radionuclides and how to apply the sum of the fractions rule. For sites with multiple radionuclide contaminants, it may be possible to measure just one of the contaminants and still demonstrate compliance for all the contaminants present using surrogate measurements. A discussion of the use of surrogates is found in Section 4.3.2, *DCGLs and the Use of Surrogate Measurements*, of the MARSSIM.

The proper use of surrogate measurements takes into account the contribution to dose from multiple radionuclides by establishing a modified $DCGL_{mod}$, and in this case, the sum of the fraction calculation is not necessary. The surrogate method depends on establishing consistent ratios and this may be difficult for two or more radionuclides. Consultation with the BER is recommended when multiple radionuclides are involved.

12.4.3 Classify the Area by Contamination Potential

The NJDEP supports the MARSSIM classification methods as discussed in Section 4.4, *Classify Areas by Contamination Potential*, of the MARSSIM. The area classification process looks at areas as either *non-impacted* or *impacted*, and further classifies *impacted* areas into Class 1, 2 or 3 based on the potential for residual radioactive contamination, with Class 1 having the greatest likelihood of being affected. The significance of survey unit classification is that this process determines the final status survey design and the procedures used to develop this design.

The scoping survey and historical site assessment can be used to determine initial classifications, but classification may change throughout the site investigation process. In order to classify an area, a comparison with the DCGL is made. All impacted areas are initially classified as Class 1 so that if a survey unit is classified incorrectly, the potential for making decision errors does not increase. MARSSIM defines Class 1 areas as areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination above the DCGL, while Class 2 and 3 areas are not expected to exceed the DCGL.

The site should be broken down into smaller survey units if appropriate and each survey unit should have only one classification. Sections 2.5.2, *Classification*, and 4.6, *Identify Survey Units*, in the MARSSIM has further information on identifying survey units. The suggested size of the survey units for each classification is given in this section. These are suggested maximum sizes and may be modified based on site-specific information. If an area greater than these suggested sizes is proposed, consultation with the BER is suggested before continuing with the site investigation process.

12.4.4 Determine Background

For radionuclides that are also present in background, Section 4.5, *Select Background Reference Areas*, of the MARSSIM provides information on selecting a background reference area. The scoping survey should be used to verify that the selected background reference area is non-impacted. Determination of the number of samples to collect in the background reference area is discussed under Section 12.5.2 of this manual, *The Final Status Survey*. If it is desirable to determine background before the final status survey, NUREG 5849, Manual for Conducting Radiological Surveys in Support of License Termination, Section 2.3.1 should be used. This section discusses the number of samples needed and how to determine if they are representative.

12.4.5 Perform the Survey

Information on how to conduct surveys is discussed in Section 4.7, *Select Instruments and Survey Techniques*, of the MARSSIM. The flow diagram (Fig. 4.2, *Flow Diagram for Selection of Field Survey Instrumentation for Direct Measurements and Analysis of Samples*) for selection of field instruments for direct measurements and analysis of samples should be used before proceeding with the survey. Criteria for selecting sample collection and measurement methods are discussed in Section 4.7.3, *Criteria for Selection of Sample Collection and Direct Measurement Methods*, of the MARSSIM.

For additional information regarding soil sampling, please refer to Chapter 6, *Sample Collection*, Subsection 6.2 in this sampling manual. For scanning soil with a NaI detector, the MDC_{scan}[4] values given in Table 6.7, *NaI(Tl) Scintillation Detector Scan MDCs for Common Radiological Contaminants*, of the MARSSIM provide an acceptable estimate of MDC_{scan}. The instruments selected must be capable of detecting the nuclides of interest at the levels of interest.

Section 4.8, *Site Preparation*, in the MARSSIM discusses how to prepare the site for the survey and how to lay out the reference coordinate system. Appendix A of the MARSSIM also has some useful information on the grid system and examples of scanning patterns. It may be useful to lay out the grid at this point for use later in the site investigation process.

Chapter 6 of this manual outlines the methodology for sampling surface soil, subsurface soil, ground water, streams, sediments, etc. These procedures shall be used. Water samples shall be analyzed for gross alpha and gross beta and isotopic gamma activity. If the gross alpha exceeds 5 pCi/L, additional tests shall be performed to identify and quantify specific radionuclides such as radium isotopes. If gross beta exceeds 50 pCi/L, the contributing radionuclides shall be identified. See N.J.A.C. 7:28-12.5, *Sampling, surveying and laboratory requirements*, for information pertaining to laboratory requirements.

Quality Control, as it relates to survey activities, is discussed in Chapter 2 of this manual and Section 4.9, *Quality Control*, of the MARSSIM.

12.4.6 Document the Scoping Survey Results

Documentation should include identification of the survey areas, classifications of each (and justification), proposed use of surrogates and the established ratios of nuclides, if applicable, the site-specific DCGLs and supporting documentation for these items. Guidance on reporting requirements can also be found in N.J.A.C. 7:26E, Technical Requirements for Site Remediation.

12.5 The Characterization Survey

The characterization survey may be used to satisfy a number of specific objectives, including those outlined in N.J.A.C. 7:26E-4.1. It is important to identify *specific* characterization objectives before planning to collect and analyze samples or make measurements in the field. Some examples of specific questions that might be asked in order to formulate the objectives are:

- How deep is the contamination in the survey unit (area of concern)?
- What is the concentration of ^{226}Ra in the pile of soil near the fence line?

In order to answer these and other questions, measurements will have to be taken for comparison with the established DCGLs.

Examples of some other objectives include: 1) evaluation of remedial alternatives (e.g. unrestricted use, limited restricted use, or alternative standards), 2) collect additional data to be used: as input to the final status survey design, to reevaluate the initial classification of survey units, to select instrumentation based on the necessary MDCs, to establish the acceptable Type I and Type II errors, and to fulfill the requirements for a Remedial Investigation/Feasibility Study (CERCLA sites only), and 3) evaluation of remediation technologies. The characterization objectives themselves determine the kinds of measurements, and in turn, the analyses and sensitivities needed for comparison with the DCGLs.

12.5.1 Determination of Lateral and Vertical Extent of Contamination

As discussed in Section 12.4.5 above, the DEP soil sampling procedures shall be used for the characterization survey. Gamma logging of boreholes is performed to identify the presence of subsurface deposits of gamma-emitting radionuclides.

A sensitive gamma detector such as a NaI gamma scintillation probe is lowered into the hole and a count rate determined at 0.5-foot increments. The sensitivity and specificity of this technique may be improved by placing the detector inside a shielded collimator assembly. A geologic description of the subsurface shall also be made. Soil sampling at depth should also be performed, based on the results of the gamma logging. It may be necessary to take only one sample if the readings are consistent, or more if there is greater variability in the gamma readings along the core.

Soil samples shall be analyzed in a DEP-certified laboratory. A list of certified laboratories may be obtained by contacting the NJDEP Office of Quality Assurance. It may be possible to limit the cost of analysis by correlating the gamma readings to concentration values. This may be acceptable provided enough data is collected to demonstrate a correlation. A correlation coefficient shall be calculated to support the assumed correlation. A minimum of 30 samples, representing the range of values shall be used to establish the correlation.

The number of samples to be taken depends on the objectives of the survey. If the characterization data is intended to be used for the final status survey, then the number of samples must be determined as outlined in Section 12.7, *The Final Status Survey*. Otherwise, a sufficient number of samples shall be collected to determine the vertical and lateral extent and to identify areas that require remediation (by comparing to the DCGLs).

12.5.2 Determine Background

For radionuclides that are also present in background, Section 4.5, *Select Background Reference Areas,* of the MARSSIM provides information on selecting a background reference area. The characterization survey can be used to further define the background reference area by determining radionuclide concentrations in environmental media.

12.5.3 Classify the Area by Contamination Potential

Review the initial area classifications made during the Scoping Survey and determine if any of them have changed.

12.5.4 Document the Characterization Survey Results

Documentation of the characterization survey should provide a complete record of the radiological status of the site. All sampling and analysis data (including QA/QC data) should be included, along with justifications for changes made to area classifications (if any). There should be enough information in this report to support approaches or alternatives to site cleanup.

12.6 The Remedial Action Support Survey

The remedial action support survey is conducted in order to support remediation activities by monitoring the effectiveness of the decontamination efforts. This survey should be limited to activities such as direct measurements and scanning surveys. One of the goals of the remedial action support survey is to help determine when a site is ready for a final status survey.

Measurement methods should be chosen which are capable of detecting the radiation of interest at concentrations between 10% and 50% of the $DCGL_W$.

Section 5.4, *Remedial Action Support Surveys*, of the MARSSIM provides specific guidance on this type of survey.

12.7 The Final Status Survey

The final status survey is performed in order to demonstrate that the residual radioactivity in each survey unit meets the predetermined criteria for release, whether it be for unrestricted, limited restricted, restricted, or alternate use. For the final status survey, the fundamental components being examined are the survey units.

Compliance is demonstrated through the use of statistical tests (either the Wilcoxon Rank Sum (WRS) test when the contaminant is present in the background, or the Sign Test, if the contaminant is not present in the background. The statistical tests evaluate the average concentration in each survey unit with the elevated measurement comparison for evaluating small areas of elevated activity. Section 8.2.3, *Select the Tests*, in the MARSSIM discusses the choice of statistical tests). It is the primary goal of the final status survey to demonstrate that all radiological parameters satisfy the established guideline values and conditions. Data obtained at other points in the survey and site investigation process can provide useful information.

It may be possible, that the DCGLs selected for a given site are close to background. This may be the case where multiple nuclides are present, the background is variable, and the site is to be released for unrestricted use. In this case, following the MARSSIM methods may be difficult. In these situations, it is recommended that the guidance in NUREG 1505, *A Non-Parametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys*, be used, specifically, Scenario

B. In Scenario B, instead of having to prove that the survey unit meets the release criterion, the owner has to prove that the survey unit does not meet the release criterion.

12.7.1 Revisit the Area Classifications

It is important at this stage in the process to be certain that all areas are classified correctly, as this information will be used to determine compliance. The criteria used for designating areas as Class 1, 2, or 3 shall be described in the final status survey, and compliance with the classification criteria shall be demonstrated in the final status survey. More information on survey investigations and reclassifications can be found in Section 5.5.3, *Developing an Integrated Survey Strategy*, of the MARSSIM.

12.7.2 Determine the Relative Shift

To be certain that the conclusions drawn from the samples are correct, a minimum number of samples are needed to obtain statistical confidence. In order to determine the number of samples, you must first determine the relative shift (Δ/σ_s). The relative shift is the ratio involving the concentration to be measured relative to the variability in that concentration, and can be thought of as an expression of the resolution of the measurements.

$$\Delta/\sigma_s = (DCGL_W - LBGR) / \sigma_s$$

where:

$DCGL_W$= derived concentration guideline
LBGR= concentration at the lower bound of the gray region; the Type II (β) error is set at the LBGR. The LBGR is always below the $DCGL_w$
σ_s= an estimate of the standard deviation of the concentration of residual radioactivity in the survey unit

The value for σ_s is determined either from existing measurements or by limited sampling. It could also be estimated if remediation will be performed. If, during the survey process, a background reference area is used and the σ_r in the reference area is greater than the σ_s in the survey unit, the larger value should be used to design the survey.

The DEP concurs with the MARSSIM recommendation to initially set the LBGR at 0.5 $DCGL_W$. Alternatively, the LBGR could be set at the expected concentration in the survey unit following remediation, or at the time of the final status survey. Since small values of Δ/σs result in large numbers of samples, it may be desirable to make the Δ/σ greater than 1. There are two ways to increase Δ/σ. The first is to increase the width of the gray region by making LBGR small. Only Type II decision errors occur in the gray region. The disadvantage of making the gray region larger is that the probability of incorrectly failing to release a survey unit will increase. The second way to increase Δ/σ is to make σ smaller. One way to make σ smaller is to have survey units that are relatively homogeneous for measured radioactivity. That is why selecting the boundaries of the survey unit is an important consideration. Another way to make σ small is by using more precise measurement methods. The more precise methods might be more expensive, but this may be compensated for by the decrease in the number of required measurements.

Generally, the design goal should be to achieve Δ/σ values between one and three. Overly optimistic estimates for σ should be avoided. The consequence of taking fewer samples than are needed, given the actual measurement variations, will be unnecessary remediations (increased Type II decision errors).

Section 5.5.2.2, *Contaminant Present in Background-Determining Numbers of Data Points for Statistical Tests*, and Appendix D, *The Planning Phase of the Data Life Cycle*, in the MARSSIM provide greater detail.

12.7.3 Determination of Acceptable Type I and Type II Decision Errors

A decision error is the probability of making an error in the decision on a survey unit by passing a survey unit that should fail (alpha or Type I) or by failing a survey unit that should pass (beta or Type II). The acceptable Type I (alpha) decision error rate is 0.05 or less. Any Type II (beta) decision error rate is acceptable to the NJDEP. However, the higher the Type II rate, the greater the probability that the site will not pass the statistical test, even though the site should pass.

Section 5.5.2.1, *Application of Decommissioning Criteria*, and Appendix D.6, *Specify Limits on Decision Errors*, of the MARSSIM provide greater detail on this process.

12.7.4 Determine the Number of Samples Needed

The minimum number of samples needed, N, can be determined from the equation for N found in Equation 5.1 in the MARSSIM. N is the total number of data points for each survey unit/reference area combination. For contaminants that are also present in background, the N data points are divided between the survey unit and the reference area. So N/2 measurements are performed in each survey unit, and N/2 measurements are performed in each reference area. Fewer samples will increase the probability of an acceptable survey unit failing to demonstrate compliance. Alternately, once the values for Δ/σ and the error types (α and β) have been established, the values for N/2 or N can be found in Tables 5.3, *Values of N/2 for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Present in Background*, and 5.5, *Values of N for Given Values of the Relative Shift, Δ/σ, α, and β when the Contaminant is Not Present in Background*, of the MARSSIM.

Section 5.5.2.2, *Contaminant Present in Background-Determining Numbers of Data Points for Statistical Tests*, in the MARSSIM outlines the process. If the radionuclides of interest are not present in the background, or they are a small percentage of the $DCGL_w$, then a determination will need to be made for the number of samples needed to perform a Sign Test, instead of the WRS Test. This information can be found in the same sections of the MARSSIM.

As an example, suppose you had the following scenario:

Background: A site has 14 survey units and one (1) reference area. ^{238}U is the radionuclide of concern, and measurements will be of nuclide concentration.

$DCGL_W$ ^{238}U = 10 pCi/g
σ_s = 3.2 pCi/g
Bkg. in reference area = 1.2 pCi/g
σ_r = 0.6 pCi/g
LBGR is selected to be 5 pCi/g
Δ/σ is then = (10-5)/3.2= 1.56

If α is 0.05 and β is 0.10, looking at Table 5.3, *Values of N/2 for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Present in Background*, in the MARSSIM gives a value of N/2 of 13 (meaning 13 samples from the reference area and 13 from the survey unit).

12.7.5 Additional Samples for Elevated Measurement Comparison in Class 1 Areas

Class 1 survey units may have small areas where concentrations exceed the $DCGL_W$ which the statistical tests described above may not successfully detect. Therefore, class 1 areas must be tested to demonstrate that they meet the dose criteria for release. This test is known as the elevated measurement comparison.

The number of survey data points needed for the statistical test is determined as discussed in Section 12.7.4 above. These data points are then positioned throughout the survey unit by first randomly selecting a start point and establishing a systematic pattern. The systematic sampling grid must be triangular for Class 1 areas. The number of calculated survey locations, N/2 (for when the contaminant is present in background; N if the Sign test is used), is used to determine the grid spacing, L, of the systematic sampling pattern (see Section 5.5.2.5 *Determining Survey Locations* in the MARSSIM). The grid area that is bounded by these survey locations is given by $A_{GRID}=0.866 \times L^2$ for a triangular grid. For a rectangular grid, $A_{GRID} = L^2$. This is the size of the area that could be missed through the established sampling pattern. In order to avoid missing an elevated area of this size, a $DCGL_{EMC}$ must be determined using the equation below:

$$DCGL_{EMC} = (\text{Area Factor}) \text{ X } (DCGL_W)$$

Area factors were calculated using RESRAD[5] (version 6.2.1) and are presented in Table 12.1. These area factors were determined by running RESRAD for each nuclide and varying the lot size and the length parallel to the aquifer. The area factors were then computed by taking the ratio of the dose per unit concentration generated by RESRAD for the default values (10,000 m^2) to that generated for the other areas listed. For sites with multiple radionuclides, the most conservative area factor (the smallest) can be used.

Next, the minimum detectable concentration (MDC) of the scan procedure, needed to detect an area of elevated activity at the limit determined by the area factor, must meet the following condition:

$$\text{Scan MDC}_{required} = DCGL_{EMC}$$

The actual MDCs of scanning techniques are then determined for the available instrumentation (see Section 6.7 *Detection Sensitivity* of the MARSSIM). If the actual scan MDC of the selected instrument is less than the required scan MDC, no additional sampling points are necessary for assessment of small areas of elevated activity. In other words, the scanning technique exhibits adequate sensitivity to detect the small areas of elevated activity that are missed by sampling.
If the actual scan MDC is greater than the required scan MDC, then it is necessary to calculate the area factor that corresponds to the actual scan MDC using the following equation:

$$\text{Area Factor} = \frac{\text{scan MDC(actual)}}{DCGL_W}$$

Next, find the grid area corresponding to that Area Factor from Table 12.1. Then calculate the number of sample points needed to produce that grid area as follows:

$$n_{EA} = \frac{\text{(Survey Unit Area)}}{\text{(Grid Area)}}$$

The calculated number of survey locations, n_{EA}, is used to determine a revised spacing, L, of the systematic pattern (refer to Section 5.5.2.5 *Determining Survey Locations* of the MARSSIM). Specifically, the spacing, L, of the pattern (when driven by areas of elevated activity) is given by:

$$L = \sqrt{\frac{A}{0.866 n_{EA}}}$$

for a triangular grid or:

$$L = \sqrt{\frac{Asu}{n_{EA}}}$$

for a rectangular grid.

where A_{SU} is the area of the survey unit. Grid spacing shall be rounded down to the nearest distance that can be conveniently measured in the field. If n_{EA} is calculated to be smaller than N (the number of data points calculated in Section 12.7.4 of this chapter), then N should be used to determine L.

Continuing with the example above, suppose you had the following:

Survey Unit area = 380m^2
$DCGL_W$ = 10 pCi/g of ^{238}U
Number of samples = 13

To determine the area that might be missed, first calculate L, the length of the grid:

$$L = \sqrt{\frac{380m^2}{(0.866)(13)}}$$

L = 5.8m

Then determine the area of the grid:

A = .866 x L^2
A = 29 m^2

Look in Table 12.1. The area factor that corresponds to a 29m^2 for ^{238}U is 6.2. Now determine the $DCGL_{EMC}$:

$DCGL_{EMC}$ = (Area Factor)($DCGL_W$)
$DCGL_{EMC}$ = 6.2 x 10 pCi/g = 62 pCi/g
Actual MDC_{scan} = 80 pCi/g

Since the Actual MDC is greater than the $DCGL_{EMC}$, the grid spaces must be made smaller by increasing the number of samples.

To determine the new number of samples needed (n_{EA}), the area factor corresponding to the MDC must be determined:

Area Factor = $MDC_{scan}/DCGL_w$
Area Factor = 80/10 = 8

Next, go to Table 12.1 and find the size of the new grid block area. In this case, for ^{238}U, an area factor of 8 corresponds to an area of about 20 m^2.

Now, calculate the number of sample points needed to produce that grid area:

n_{EA}= 380m^2/20m^2 = 19
So the length of the grid spacing is:

$$L = \sqrt{\frac{380m^2}{0.866(19)}}$$

L = 4.8 m

For multiple radionuclides, an MDC and an Area Factor of the mix may be needed. Chapters 9 and 12 of *Decommissioning Health Physics: A Handbook for MARSSIM Users*, (Abelquist, 2001) provides examples of how to determine these values.

Figure 5.3 (*Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units*) in the MARSSIM provides a concise overview of the procedure used to identify data needs for the assessment of small areas of elevated activity.

If the following condition is met, then the elevated measurement comparison is acceptable:

(δ/ $DCGL_W$) + {(avg. conc. in elevated area - δ)/(area factor for elevated area x $DCGL_W$)} <1
where δ = the average residual radioactivity concentration for all sample points in the survey unit.

If there is more than one elevated area, a separate term should be included for each one.

As an example, suppose you had the following data:

$DCGL_W$ ^{226}Ra = 3 pCi/g
$DCGL_{EMC}$ = 79.5 pCi/g (for a 1m^2 area)

There is one elevated area with an average concentration of 60 pCi/g.
The area factor for the elevated area is 26.5.
The results (pCi/g) of the other sampling points are:

1.0, 2.0, 1.5, 0.5, 2.2, 2.9, 1.0, 0.3, 2.0, and 1.0.
δ = 6.76 pCi/g above background

Since

6.76/3 + (60-6.76)/(26.5x3) is not < 1, therefore, the elevated area must be remediated.

The elevated measurement comparison method is described further in Section 8.5.1, *Elevated Measurement Comparison*, and Section 5.5.2.4, *Determining Data Points for Small Areas of Elevated Activity*, of the MARSSIM.

Table 12.1 Outdoor Area Dose Factors

	Grid Area								
Nuclide	**1 m²**	**3 m²**	**10 m²**	**30 m²**	**100 m²**	**300 m²**	**1000 m²**	**3000 m²**	**10,000 m²**
Ra-226, Po-210	26.5	11.9	5.6	3.9	2.8	2	1	1	1
Th-232, Th-228, Ra-228	15	6.9	3.3	2.4	1.8	1.5	1.1	1	1
U-238, Th-230, U-234	48.8	22.1	10.1	6.2	3.4	2.1	1.1	1	1

12.7.6 Determining Sample Locations

A reference coordinate system must first be established for the impacted areas. A single reference coordinate system may be used for a site, or different systems may be used for each survey unit or groups of survey units. Section 4.8.5, *Reference Coordinate System*, of the MARSSIM describes how to establish such a system.

Class 1 sampling locations are established in a triangular pattern. A rectangular or triangular pattern may be used for Class 2 areas. Measurements and samples in Class 3 survey units and reference areas should be taken at random locations. More information on establishing survey locations can be found in Section 5.5.2.5, *Determining Survey Locations*, of the MARSSIM.

12.7.7 Investigation Levels and Scanning Coverage Fractions

Investigation levels are radionuclide-specific levels of radioactivity used to indicate when additional investigations may be necessary. Investigation levels also serve as a quality control check to determine when a measurement process begins to get out of control. For example, a measurement that exceeds the investigation level may indicate that the survey unit has been improperly classified or it may indicate a failing instrument.

The investigation levels in Table 12.2 should be implemented. When an investigation level is exceeded, the first step is to confirm that the initial measurement/sample actually exceeds the particular investigation level. This may involve taking further measurements to determine that the area and level of the elevated residual radioactivity are such that the resulting dose meets the release criterion. Depending on the results of the investigation actions, the survey unit may require reclassification, remediation, and/or resurvey. If after further investigation it is determined that the area does exceed the investigation level, then it should be remediated. Further information on investigation levels is found in Section 5.5.2.6 *Determining Investigation Levels* of the MARSSIM.

Scanning is performed to locate small areas of elevated concentrations of residual radioactivity. Table 5.9 *Recommended Survey Coverage for Structures and Land Areas*, in the MARSSIM illustrates the acceptable scanning coverage based on Area Classification.

Table 12.2 Final Status Survey Investigation Levels

Survey Unit Classification	Flag Direct Measurement of Sample Result When:	Flag Scanning Measurement Result When:
Class 1	> $DCGL_W$ and a statistical parameter-based value	> $DCGL_{EMC}$
Class 2	> $DCGL_W$	> $DCGL_W$ or MDC_{SCAN}
Class 3	> fraction of $DCGL_W$	> $DCGL_W$ or MDC_{SCAN}

12.7.8 Special Survey Considerations Subsurface Residual Radioactivity

The MARSSIM final status survey method was designed specifically for residual radioactivity in the top 15 cm of soil. If previous surveys have shown that there is significant subsurface residual radioactivity, this must be taken into account. (consult with BER staff to determine if significant quantities of subsurface contamination exist). The characterization survey should determine the depth of the residual radioactivity. If RaSoRS was used to develop the $DCGL_W$, it was based on the assumption that this activity may be excavated in the future and that mixing of the residual radioactivity will occur in the process (note that since N.J.A.C. 7:28-12 bases the DCGLs on the vertical extent of contamination, subsurface residual radioactivity is permitted to be left in place).

When the appropriate DCGLs are established, the final status survey is performed by taking core samples to the depth of the residual radioactivity. The number of cores to be taken is the number N required for the WRS or sign test, as appropriate. Since the final status survey is performed before any cover is placed over the area, the elevated measurement comparison test should be performed to detect any areas of elevated activity (on the surface). The grid spacing shall be adjusted if necessary.

The Department is awaiting the MARSSIM guidance on subsurface contamination. Until that time, subsurface contamination will be treated on a case by case basis.

Triangular grids are required for Class 1 areas due to their better efficiency in location areas of elevated concentration.

12.7.9 Determining Compliance

The measurement data should first be reviewed to determine if the areas were properly classified. Refer to Section 8.2.2, *Conduct a Preliminary Data Review*, of the MARSSIM for an acceptable method. If it is shown during the final status survey that an area was misclassified with a less restrictive classification, the area should receive the correct classification and the final status survey for that area should be repeated.

If there are several areas that appear to be misclassified, it may be necessary to repeat the characterization, reclassify the areas, and re-survey them for the new classification.

The next step is to determine if the measurement results show that the survey unit(s) meets the release criteria. Chapter 8, *Interpretation of Survey Results*, of the MARSSIM provides an in-depth discussion of the interpretation of survey results, particularly for the final status survey.

Table 8.2, *Summary of Statistical Tests*, in the MARSSIM summarizes acceptable ways to interpret the sample measurements. Note that a description of the WRS test is found in Section 8.4, *Contaminant Present in Background*, of the MARSSIM, the Sign Test is found in Section 8.3, *Contaminant Not Present in Background*, and the elevated measurement comparison is described in Section 8.5 *Evaluating the Results: The Decision*.

If a survey unit fails, the measurement results should be evaluated to determine why. A survey unit fails when the null hypothesis is not rejected. When the null hypothesis is not rejected, it may be because it is in fact true, or it may be because the test did not have sufficient power to detect that it is not true. A retrospective power curve can be generated to determine if the test had sufficient power. If the retrospective power analysis shows that the test did not have sufficient power, then more samples may be all that is necessary rather than remediation.Of course, some failures may be because the residual radioactivity does not meet the remediation standards and further remediation will have to be performed.

Passing the statistical test is not the only criteria for determining compliance with the remediation standards. The following example illustrates this point. A Class 1 Survey unit passes the statistical tests and contains some areas that were flagged for investigation during scanning. Further investigation, sampling and analysis indicates one area is truly elevated. This area has a concentration that exceeds the $DCGL_{EMC}$. This area is then remediated. Remediation control sampling shows that the residual radioactivity was removed, and no other areas were contaminated with removed material. In this case one may simply document the original final status survey, the fact that remediation was performed, the results of the remedial action support survey, and the additional remediation data. In some cases, additional final status survey data may not be needed to demonstrate compliance with the release criterion.

Sections 8.2.2, *Conduct a Preliminary Data Review*, 8.5.3, *If the Survey Unit Fails*, and Appendix D, *The Planning Phase of the Data Life Cycle*, of the MARSSIM provide acceptable methods for reviewing measurement results.

12.7.10 Mixing After Demonstrating Compliance with the Pre-mixing DCGLs

N.J.A.C. 7:28-12.9(b) allows soils at the DCGLs listed in Tables 4A through 5B to remain at the specified thickness (vertical extent) together with the specified thickness of uncontaminated surface soil (USS). After it is demonstrated that the site meets the DCGLs in these tables, there is a requirement to mix the residual layer with the uncontaminated surface soil so that a uniform concentration is achieved throughout the soil column. This is done to avoid the requirement for a deed restriction to maintain the cover. A uniform concentration is determined by using the same number of sample points as determined above. At each sample point, a borehole shall be advanced to the depth of the disturbed soil. Surface soil samples shall be taken and analyzed at a certified laboratory. Gamma scanning may be used to verify that the concentration at depth does not vary by more than 30%.

12.7.11 Documenting the Final Status Survey

Documentation for the final status survey should be complete, and provide a clear record of the radiological status of the survey unit(s) relative to the established DCGLs. Sufficient data and information should be provided so that an independent evaluation of the survey results can be performed.

While much of the information in the final status survey will be available in other reports generated during the site survey and investigation process, where practical, this report should be a stand-alone document. Further guidance on documentation may be found in Appendix N, *Data Validation Using Data Descriptors*, of the MARSSIM.

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◂ Return to TOC

Acronyms

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DCGL	derived concentration guideline level
DQO	data quality objectives
DEP	Department of Environmental Protection
EMC	elevated measurement comparison
EPA	Environmental Protection Agency
HSA	Historical Site Assessment
LBGR	lower bound of the gray region
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	minimum detectable concentration
NORM	naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study

Glossary

Area of concern – any existing or former location where radioactive materials are or were known or suspected to have been discharged, generated, manufactured, refined, transported, stored, handled, treated, disposed, or where radioactive materials have or may have migrated.

Contaminated site – all portions of environmental media at a site and any location where contamination is emanating, or has emanated, therefrom, that contain radioactive materials at a concentration which fails to satisfy any applicable remediation standard.

Derived concentration guideline level (DCGL) – a derived, radionuclide-specific activity concentration within a survey unit corresponding to the release criterion (regulatory limit expressed in dose or risk). The DCGL is derived from the activity/dose relationship through various exposure pathway scenarios and is established in N.J.A.A. 7:28-12.

Data quality objectives (DQO) – qualitative and quantitative statements derived from the DQO process that clarify study technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

Data Quality Objectives Process – a systematic strategic planning tool based on the scientific method that identifies and defines the type, quality, and quantity of data needed to satisfy a specified use.

Final status survey – a survey or analysis, performed after remediation, which provides data that demonstrates that all radiological parameters satisfy the remediation standards.

Impacted area – any area with a possibility of containing residual radioactivity in excess of natural background levels.

Natural background radionuclide concentration – the average value of a particular radionuclide concentration in soils measured in areas in the vicinity of the site, in an area that has not been influenced by localized human activities, including the site's prior or current operations.

Piezometer – a small-diameter well generally used for water-level measurement.

Quality assurance – the total integrated program for assuring the reliability of monitoring and measurement data which includes a system for integrating the quality planning, quality assessment and quality improvement efforts to meet data end-user requirements.

Quality assurance project plan (QAPP) – a document which presents in specific terms, the policies, organization, objectives, functional activities and specific quality assurance/quality control activities designed to achieve the data quality goals or objectives of a specific project or operation.

Quality control – the routine application of procedures for attaining prescribed standards of performance in the monitoring and measurement process.

Remediation standards – the combination of numeric standards that establish a level or concentration, and narrative standards, to which radioactive contaminants must be treated, removed, or otherwise cleaned for soil, ground water or surface water, as provided by the Department pursuant to N.J.S.A. 58:10B-12, in order to meet the health risk or environmental standards.

Soil remediation standards – these are the specific DCGLs determined for a particular site through the use and implementation of N.J.A.C. 7:28-12, *Soil Remediation Standards for Radioactive Materials*.

Vertical extent – the average depth, measured in feet, of the post-remediation radioactive contamination over an affected area not to exceed the limits specified in the Multi-Agency Radiation Survey and Site Investigation Manual (NUREG 1575, EPA 402-R-97-016) and any subsequent revisions thereto.

Endnotes

[1]An impacted area with little or no potential for delivering a dose above the release criterion, and little or no potential for small areas of elevated activity.

[2]Derived from the activity / dose relationship through various exposure pathway scenarios; established in N.J.A.C. 7:28-12.

[3]Section I.11, *Multiple Radionuclides*, in the MARSSIM.

[4]Minimum detectable concentration – the a *priori* activity level that a specific instrument and technique can be expected to detect 95% of the time. The MDC_{scan} is simply the minimum detectable concentration of the scanning survey.

[5]The RaSoRS spreadsheet cannot be used when the size of the elevated area is smaller than the size of the house (1000 ft^2). However, since the area factors used in RaSoRS were obtained directly from RESRAD, the numbers in Table F.1 are acceptable for determining a $DCGL_{EMC}$.

Next Section