5 SURVEY PLANNING AND DESIGN

5.1 Introduction

This chapter is intended to assist the user in planning a strategy for conducting a final status survey, with the ultimate objective being to demonstrate compliance with the derived concentration guideline levels (DCGLs). The survey types that make up the Radiation Survey and Site Investigation (RSSI) Process include scoping, characterization, remedial action support, and final status surveys. Although the scoping, characterization, and remedial action support surveys have multiple objectives, this manual focuses on those aspects related to supporting the final status survey and demonstrating compliance with DCGLs. In general, each of these survey types expands upon the data collected during the previous survey (*e.g.*, the characterization survey is planned with information collected during the scoping survey) up through the final status survey. The purpose of the final status survey is to demonstrate that the release criterion established by the regulatory agency has not been exceeded. This final release objective should be kept in mind throughout the design and planning phases for each of the other survey types. For example, scoping surveys may be designed to meet the objectives of the final status survey such that the scoping survey report is also the final status survey report. The survey and analytical procedures referenced in this chapter are described in Chapter 6, Chapter 7, and Appendix H. An example of a final status survey, as described in Section 5.5, appears in Appendix A. In addition, example checklists are provided for each type of survey to assist the user in obtaining the necessary information for planning a final status survey.

5.2 Scoping Surveys

5.2.1 General

If the data collected during the Historical Site Assessment (HSA) indicate that a site or area is impacted, a scoping survey could be performed. The objective of this survey is to augment the HSA for sites with potential residual contamination. Specific objectives may include: 1) performing a preliminary risk assessment and providing data to complete the site prioritization scoring process (CERCLA and RCRA sites only), 2) providing input to the characterization survey design, if necessary, 3) supporting the classification of all or part of the site as a Class 3 area for planning the final status survey, 4) obtaining an estimate of the variability in the residual radioactivity concentration for the site, and 5) identifying non-impacted areas that may be appropriate for reference areas and estimating the variability in radionuclide concentrations when the radionuclide of interest is present in background.

Scoping survey information needed when conducting a preliminary risk assessment (as noted above for CERCLA and RCRA sites) includes the general radiation levels at the site and gross levels of residual contamination on building surfaces and in environmental media. If unexpected conditions are identified that prevent the completion of the survey, the MARSSIM user should contact the responsible regulatory agency for further guidance. Sites that meet the National Contingency Plan criteria for a removal should be referred to the Superfund Removal program (EPA 1988c).

If the HSA indicates that contamination is likely, a scoping survey could be performed to provide initial estimates of the level of effort for remediation and information for planning a more detailed survey, such as a characterization survey. Not all radiological parameters need to be assessed when planning for additional characterization because total surface activity or limited sample collection may be sufficient to meet the objectives of the scoping survey.

Once a review of pertinent site history indicates that an area is impacted, the minimum survey coverage at the site will include a Class 3 area final status survey prior to the site being released. For scoping surveys with this objective, identifying radiological decision levels is necessary for selecting instruments and procedures with the necessary detection sensitivities to demonstrate compliance with the release criterion. A methodology for planning, conducting, and documenting scoping surveys is described in the following sections.

5.2.2 Survey Design

Planning a scoping survey involves reviewing the HSA (Chapter 3). This process considers available information concerning locations of spills or other releases of radioactive material. Reviewing the radioactive materials license or similar documentation provides information on the identity, locations, and general quantities of radioactive material used at the site. This information helps to determine which areas are likely to contain residual radioactivity and, thus, areas where scoping survey activities will be concentrated. The information may also identify one or more non-impacted areas as potential reference areas when radionuclides of concern are present in background (Section 4.5). Following the review of the HSA, DCGLs that are appropriate for the site are selected. The DCGLs may be adjusted later if a determination is made to use site-specific information to support the development of DCGLs.

If residual radioactivity is identified during the scoping survey, the area may be classified as Class 1 or Class 2 for final status survey planning (refer to Section 4.4 for guidance on initial classification), and a characterization survey is subsequently performed. For scoping surveys that are designed to provide input for characterization surveys, measurements and sampling may not be as comprehensive or performed to the same level of sensitivity necessary for final status surveys. The design of the scoping survey should be based on specific data quality objectives (DQOs; see Section 2.3.1 and Appendix D) for the information to be collected.

For scoping surveys that potentially serve to release the site from further consideration, the survey design should consist of sampling based on the HSA data and professional judgment. If residual radioactivity is *not* identified during judgment sampling, it may be appropriate to classify the area as Class 3 and perform a final status survey for Class 3 areas. Refer to Section 5.5 for a description of final status surveys. However, collecting additional information during subsequent surveys (*e.g.*, characterization surveys) may be necessary to make a final determination as to area classification.

5.2.3 Conducting Surveys

Scoping survey activities performed for preliminary risk assessment or to provide input for additional characterization include a limited amount of surface scanning, surface activity measurements, and sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials). In this case, scans, direct measurements, and samples are used to examine areas likely to contain residual radioactivity. These activities are conducted based on HSA data, preliminary investigation surveys, and professional judgment.

Background activity and radiation levels for the area should be determined, including direct radiation levels on building surfaces and radionuclide concentrations in media. Survey locations should be referenced to grid coordinates, if appropriate, or fixed site features. It may be considered appropriate to establish a reference coordinate system in the event that contamination is detected above the DCGLs (Section 4.8.5). Samples collected as part of a scoping survey should consider any sample tracking requirements, including chain of custody, if required (Section 7.8).

Scoping surveys that are expected to be used as Class 3 area final status surveys should be designed following the guidance in Section 5.5. These surveys should also include judgment measurements and sampling in areas likely to have accumulated residual radioactivity (Section 5.5.3).

5.2.4 Evaluating Survey Results

Survey data are converted to the same units as those in which DCGLs are expressed (Section 6.6). Identification of potential radionuclide contaminants at the site is performed using direct measurements or laboratory analysis of samples. The data are compared to the appropriate regulatory DCGLs.

For scoping survey activities that provide an initial assessment of the radiological hazards at the site, or provide input for additional characterization, the survey data are used to identify locations and general extent of residual radioactivity. Scoping surveys that are expected to be used as Class 3 area final status surveys should follow the methodology presented in Chapter 8 to determine if the release criterion has been exceeded.

5.2.5 Documentation

How the results of the scoping survey are documented depends on the specific objectives of the survey. For scoping surveys that provide additional information for characterization surveys, the documentation should provide general information on the radiological status of the site. Survey results should include identification of the potential contaminants (including the methods used for radionuclide identification), general extent of contamination (*e.g.*, activity levels, area of contamination, and depth of contamination), and possibly even relative ratios of radionuclides to facilitate DCGL application. A narrative report or a report in the form of a letter may suffice for scoping surveys used to provide input for characterization surveys. Sites being released from further consideration should provide a level of documentation consistent with final status survey reports.

EXAMPLE SCOPING SURVEY CHECKLIST

SURVEY DESIGN

_____ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be appropriate for the specified survey objectives.

_____ Review the Historical Site Assessment for:

- _____ Operational history (*e.g.*, problems, spills, releases, or notices of violation) and available documentation (*e.g.*, radioactive materials license).

- _____ Other available resources—site personnel, former workers, residents, *etc.*

- _____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, moved, relocated, and disposed.

- _____ Release and migration pathways.

- _____ Areas that are potentially affected and likely to contain residual contamination. Note: Survey activities will be concentrated in these areas.

- _____ Types and quantities of materials likely to remain onsite—consider radioactive decay.

_____ Select separate DCGLs for the site based on the HSA review. (It may be necessary to assume appropriate regulatory DCGLs in order to permit selection of survey methods and instrumentation for the expected contaminants and quantities.)

CONDUCTING SURVEYS

_____ Follow the survey design documented in the QAPP. Record deviations from the stated objectives or documented SOPs and document additional observations made when conducting the survey.

_____ Select instrumentation based on the specific DQOs of the survey. Consider detection capabilities for the expected contaminants and quantities.

_____ Determine background activity and radiation levels for the area; include direct radiation levels on building surfaces, radionuclide concentrations in media, and exposure rates.

_____ Record measurement and sample locations referenced to grid coordinates or fixed site features.

_____ For scoping surveys that are conducted as Class 3 area final status surveys, follow guidance for final status surveys.

_____ Conduct scoping survey, which involves judgment measurements and sampling based on HSA results:

    _____ Perform investigatory surface scanning.

    _____ Conduct limited surface activity measurements.

    _____ Perform limited sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials).

    _____ Maintain sample tracking.

EVALUATING SURVEY RESULTS

_____ Compare survey results with the DQOs.

_____ Identify radionuclides of concern.

_____ Identify impacted areas and general extent of contamination.

_____ Estimate the variability in the residual radioactivity levels for the site.

_____ Adjust DCGLs based on survey findings (the DCGLs initially selected may not be appropriate for the site).

_____ Determine the need for additional action (*e.g.*, none, remediate, more surveys)

_____ Prepare report for regulatory agency (determine if letter report is sufficient).

5.3 Characterization Surveys

5.3.1 General

Characterization surveys may be performed to satisfy a number of specific objectives. Examples of characterization survey objectives include: 1) determining the nature and extent of radiological contamination, 2) evaluating remediation alternatives (*e.g.*, unrestricted use, restricted use, onsite disposal, off-site disposal, *etc.*), 3) input to pathway analysis/dose or risk assessment models for determining site-specific DCGLs (Bq/kg, Bq/m^2), 4) estimating the occupational and public health and safety impacts during decommissioning, 5) evaluating remediation technologies, 6) input to final status survey design, and 7) Remedial Investigation/Feasibility Study requirements (CERCLA sites only) or RCRA Facility Investigation/Corrective Measures Study requirements (RCRA sites only).

The scope of this manual precludes detailed discussions of characterization survey design for each of these objectives, and therefore, the user should consult other references for specific characterization survey objectives not covered. For example, the *Decommissioning Handbook* (DOE 1994) is a good reference for characterization objectives that are concerned with evaluating remediation technologies or unrestricted/restricted use alternatives. Other references (EPA 1988b, 1988c, 1994a; NRC 1994) should be consulted for planning decommissioning actions, including decontamination techniques, projected schedules, costs, and waste volumes, and health and safety considerations during decontamination. Also, the types of characterization data needed to support risk or dose modeling should be determined from the specific modeling code documentation.

This manual concentrates on providing information for the final status survey design, with limited coverage on determining the specific nature and extent of radionuclide contamination. The specific objectives for providing information to the final status survey design include: 1) estimating the projected radiological status at the time of the final status survey, in terms of radionuclides present, concentration ranges and variances, spatial distribution, *etc.*, 2) evaluating potential reference areas to be used for background measurements, if necessary, 3) reevaluating the initial classification of survey units, 4) selecting instrumentation based on the necessary MDCs, and 5) establishing acceptable Type I and Type II errors with the regulatory agency (Appendix D provides guidance on establishing acceptable decision error rates). Many of these objectives are satisfied by determining the specific nature and extent of contamination of structures, residues, and environmental media. Additional detail on the performance of characterization surveys designed to determine the general extent of contamination can be found in the NRC's *Draft Branch Technical Position on Site Characterization for Decommissioning* (NRC 1994a) and EPA's RI/FS guidance (EPA 1988b; EPA 1993c).

Results of the characterization survey should include: 1) the identification and distribution of contamination in buildings, structures, and other site facilities; 2) the concentration and distribution of contaminants in surface and subsurface soils; 3) the distribution and concentration of contaminants in surface water, ground water, and sediments, and 4) the distribution and concentration of contaminants in other impacted media such as vegetation or paint. The characterization should include sufficient information on the physical characteristics of the site, including surface features, meteorology and climatology, surface water hydrology, geology, demography and land use, and hydrogeology. This survey should also address environmental conditions that could affect the rate and direction of contaminant transport in the environment, depending on the extent of contamination identified above.

The following sections describe a method for planning, conducting, and documenting characterization surveys. Alternative methodologies may also be acceptable to the regulatory agencies.

5.3.2 Survey Design

The design of the site characterization survey is based on the specific DQOs for the information to be collected, and is planned using the HSA and scoping survey results. The DQO Process ensures that an adequate amount of data with sufficient quality are collected for the purpose of characterization. The site characterization process typically begins with a review of the HSA, which includes available information on site description, operational history, and the type and extent of contamination (from the scoping survey, if performed). The site description, or conceptual site model as first developed in Section 3.6.4, consists of the general area, dimensions, and locations of contaminated areas on the site. A site map should show site boundaries, roads, hydrogeologic features, major structures, and other features that could affect decommissioning activities.

The operational history includes records of site conditions prior to operational activities, operational activities of the facility, effluents and on-site disposal, and significant incidents—including spills or other unusual occurrences—involving the spread of contamination around the site and on areas previously released from radiological controls. This review should include other available resources, such as site personnel, former workers, residents, *etc.* Historic aerial photographs and site location maps may be particularly useful in identifying potential areas of contamination.

The types and quantities of materials that were handled and the locations and disposition of radioactive materials should be reviewed using available documentation (*e.g.*, the radioactive materials license). Contamination release and migration pathways should be identified, as well as areas that are potentially affected and are likely to contain residual contamination. The types and quantities of materials likely to remain onsite, considering radioactive decay, should be determined.

The characterization survey should clearly identify those portions of the site (*e.g.*, soil, structures, and water) that have been affected by site activities and are potentially contaminated. The survey should also identify the portions of the site that have not been affected by these activities. In some cases where no remediation is anticipated, results of the characterization survey may indicate compliance with DCGLs established by the regulatory agency. When planning for the potential use of characterization survey data as part of the final status survey, the characterization data must be of sufficient quality and quantity for that use (see Section 5.5). There are several processes that are likely to occur in conjunction with characterization. These include considering and evaluating remediation alternatives, and calculating site-specific DCGLs.

The survey should also provide information on variations in the contaminant distribution in the survey area. The contaminant variation in each survey unit contributes to determining the number of data points based on the statistical tests used during the final status survey (Section 5.5.2). Additionally, characterization data may be used to justify reclassification for some survey units (*e.g.*, from Class 1 to Class 2).

Note that because of site-specific characteristics of contamination, performing all types of measurements described here may not be relevant at every site. For example, detailed characterization data may not be needed for areas with contamination well above the DCGLs that clearly require remediation. Judgment should be used in determining the types of characterization information needed to provide an appropriate basis for decontamination decisions.

5.3.3 Conducting Surveys

Characterization survey activities often involve the detailed assessment of various types of building and environmental media, including building surfaces, surface and subsurface soil, surface water, and ground water. The HSA data should be used to identify the potentially contaminated media onsite (see Section 3.6.3). Identifying the media that may contain contamination is useful for preliminary survey unit classification and for planning subsequent survey activities. Selection of survey instrumentation and analytical techniques are typically based on a knowledge of the appropriate DCGLs, because remediation decisions are made based on the level of the residual contamination as compared to the DCGL. Exposure rate measurements may be needed to assess occupational and public health and safety. The location of underground utilities should be considered before conducting a survey to avoid compounding the problems at the site.

5.3.3.1 Structure Surveys

Surveys of building surfaces and structures include surface scanning, surface activity measurements, exposure rate measurements, and sample collection (*e.g.*, smears, subfloor soil, water, paint, and building materials). Both field survey instrumentation (Chapter 6) and analytical laboratory equipment and procedures (Chapter 7) are selected based on their detection capabilities for the expected contaminants and their quantities. Field and laboratory instruments are described in Appendix H.

Background activity and radiation levels for the area should be determined from appropriate background reference areas. Background assessments include surface activity measurements on building surfaces, exposure rates, and radionuclide concentrations in various media (refer to Section 4.5).

Measurement locations should be documented using reference system coordinates, if appropriate, or fixed site features. A typical reference system spacing for building surfaces is 1 meter. This is chosen to facilitate identifying survey locations, evaluating small areas of elevated activity, and determining survey unit average activity levels.

Scans should be conducted in areas likely to contain residual activity, based on the results of the HSA and scoping survey.

Both systematic and judgment surface activity measurements are performed. Judgment direct measurements are performed at locations of elevated direct radiation, as identified by surface scans, to provide data on upper ranges of residual contamination levels. Judgment measurements may also be performed in sewers, air ducts, storage tanks, septic systems and on roofs of buildings, if necessary. Each surface activity measurement location should be carefully recorded on the appropriate survey form.

Exposure rate measurements and media sampling are performed as necessary. For example, subfloor soil samples may provide information on the horizontal and vertical extent of contamination. Similarly, concrete core samples are necessary to evaluate the depth of activated concrete in a reactor facility. Note that one type of radiological measurement may be sufficient to determine the extent of contamination. For example, surface activity measurements alone may be all that is needed to demonstrate that decontamination of a particular area is necessary; exposure rate measurements would add little to this determination.

Lastly, the measuring and sampling techniques should be commensurate with the intended use of the data, as characterization survey data may be used to supplement final status survey data, provided that the data meet the selected DQOs.

5.3.3.2 Land Area Surveys

Characterization surveys for surface and subsurface soils and media involve employing techniques to determine the lateral and vertical extent and radionuclide concentrations in the soil. This may be performed using either sampling and laboratory analyses, or *in situ* gamma spectrometry analyses, depending on the detection capabilities of each methodology for the expected contaminants and concentrations. Note that *in situ* gamma spectrometry analyses or any direct surface measurement cannot easily be used to determine vertical distributions of radionuclides. Sample collection followed by laboratory analysis introduces several additional sources of uncertainty that need to be considered during survey design. In many cases, a combination of direct measurements and samples is required to meet the objectives of the survey.

Radionuclide concentrations in background soil samples should be determined for a sufficient number of soil samples that are representative of the soil in terms of soil type, soil depth, *etc.* It is important that the background samples be collected in non-impacted areas. Consideration should be given to spatial variations in the background radionuclide concentrations as discussed in Section 4.5 and NRC draft report NUREG-1501 (NRC 1994b).

Sample locations should be documented using reference system coordinates (see Section 4.8.5), if appropriate, or fixed site features. A typical reference system spacing for open land areas is 10 meters (NRC 1992a). This spacing is somewhat arbitrary and is chosen to facilitate determining survey unit locations and evaluating areas of elevated radioactivity.

Surface scans for gamma activity should be conducted in areas likely to contain residual activity. Beta scans may be appropriate if the contamination is near the surface and represents the prominent radiation emitted from the contamination. The sensitivity of the scanning technique should be appropriate to meet the DQOs.

Both surface and subsurface soil and media samples may be necessary. Subsurface soil samples should be collected where surface contamination is present and where subsurface contamination is known or suspected. Boreholes should be constructed to provide samples representing subsurface deposits.

Exposure rate measurements at 1 meter above the sampling location may also be appropriate. Each surface and subsurface soil sampling and measurement location should be carefully recorded.

5.3.3.3 Other Measurements/Sampling Locations

Surface Water and Sediments. Surface water and sediment sampling may be necessary depending on the potential for these media to be contaminated. The contamination potential depends on several factors, including the proximity of surface water bodies to the site, size of the drainage area, total annual rainfall, and spatial and temporal variability in surface water flow rate and volume. Refer to Section 3.6.3.3 for further consideration of the necessity for surface water and sediment sampling.

Characterizing surface water involves techniques that determine the extent and distribution of contaminants. This may be performed by collecting grab samples of the surface water in a well-mixed zone. At certain sites, it may be necessary to collect stratified water samples to provide information on the vertical distribution of contamination. Sediment sampling should also be performed to assess the relationship between the composition of the suspended sediment and the bedload sediment fractions (*i.e.*, suspended sediments compared to deposited sediments). When judgment sampling is used to find radionuclides in sediments, contaminated sediments are more likely to be accumulated on fine-grained deposits found in low-energy environments (*e.g.*, deposited silt on inner curves of streams).

Radionuclide concentrations in background water samples should be determined for a sufficient number of water samples that are upstream of the site or in areas unaffected by site operations. Consideration should be given to any spatial or temporal variations in the background radionuclide concentrations.

Sampling locations should be documented using reference system coordinates, if appropriate, or scale drawings of the surface water bodies. Effects of variability of surface water flow rate should be considered. Surface scans for gamma activity may be conducted in areas likely to contain residual activity (*e.g.*, along the banks) based on the results of the document review and/or preliminary investigation surveys.

Surface water sampling should be performed in areas of runoff from active operations, at plant outfall locations, both upstream and downstream of the outfall, and any other areas likely to contain residual activity (see Section 3.6.3.3). Measurements of radionuclide concentrations in water should include gross alpha and gross beta assessments, as well as any necessary radionuclide-specific analyses. Non-radiological parameters, such as specific conductance, pH, and total organic carbon may be used as surrogate indicators of potential contamination, provided that a specific relationship exists between the radionuclide concentration and the level of the indicator (*e.g.*, a linear relationship between pH and the radionuclide concentration in water is found to exist, then the pH may be measured such that the radionuclide concentration can be calculated based on the known relationship rather than performing an expensive nuclide-specific analysis). The use of surrogate measurements is discussed in Section 4.3.2.

Each surface water and sediment sampling location should be carefully recorded on the appropriate survey form. Additionally, surface water flow models may be used to illustrate contaminant concentrations and migration rates.

Ground Water. Ground-water sampling may be necessary depending on the local geology, potential for subsurface contamination, and the regulatory framework. Because different agencies handle ground water contamination situations in different ways (*e.g.*, EPA's Superfund program and some States require compliance with maximum contaminant levels specified in the Safe Drinking Water Act), the responsible regulatory agency should be contacted if ground water contamination is expected. The need for ground-water sampling is described in Section 3.6.3.4.

If ground-water contamination is identified, the responsible regulatory agency should be contacted at once because: 1) ground water release criteria and DCGLs should be established by the appropriate agency (Section 4.3), and 2) the default DCGLs for soil may be inappropriate since they are usually based on initially uncontaminated ground water.

Characterization of ground-water contamination should determine the extent and distribution of contaminants, rates and direction of ground water migration, and the assessment of potential effects of ground water withdrawal on the migration of ground water contaminants. This may be performed by designing a suitable monitoring well network. The actual number and location of monitoring wells depends on the size of the contaminated area, the type and extent of the contaminants, the hydrogeologic system, and the objectives of the monitoring program.

When ground-water samples are taken, background should be determined by sufficient sampling and analysis of ground-water samples collected from the same aquifer upgradient of the site. The background samples should not be affected by site operations and should be representative of the quality of the ground water that would exist if the site had not been contaminated. Consideration should be given to any spatial or temporal variations in the background radionuclide concentrations.

Sampling locations should be referenced to grid coordinates, if appropriate, or to scale drawings of the ground-water monitoring wells. Construction specifications on the monitoring wells should also be provided, including elevation, internal and external dimensions, types of casings, type of screen and its location, borehole diameter, and other necessary information on the wells.

In addition to organic and inorganic constituents, ground-water sampling and analyses should include all significant radiological contaminants. Measurements in potential sources of drinking water should include gross alpha and gross beta assessments, as well as any other radionuclide-specific analyses. Non-radiological parameters, such as specific conductance, pH, and total organic carbon may be used as surrogate indicators of potential contamination, provided that a specific relationship exists between the radionuclide concentration and the level of the indicator.

Each ground-water monitoring well location should be carefully recorded on the appropriate survey form. Additionally, contaminant concentrations and sources should be plotted on a map to illustrate the relationship among contamination, sources, hydrogeologic features and boundary conditions, and property boundaries (EPA 1993b).

Other Media. Air sampling may be necessary at some sites depending on the local geology and the radionuclides of potential concern. This may include collecting air samples or filtering the air to collect resuspended particulates. Air sampling is often restricted to monitoring activities for occupational and public health and safety and is not required to demonstrate compliance with risk- or dose-based regulations. Section 3.6.3.5 describes examples of sites where air sampling may provide information useful to designing a final status survey. At some sites, radon measurements may be used to indicate the presence of radium, thorium, or uranium in the soil. Section 6.9 and Appendix H provide information on this type of sampling.

In rare cases, vegetation samples may be collected as part of a characterization survey to provide information in preparation for a final status survey. Because most risk- and dose-based regulations are concerned with potential future land use that may differ from the current land use, vegetation samples are unsuitable for demonstrating compliance with regulations. There is a relationship between radionuclide concentrations in plants and those in soil (the soil-to-plant transfer factor is used in many models to develop DCGLs) and the plant concentration could be used as a surrogate measurement of the soil concentration. In most cases, a measurement of the soil itself as the parameter of interest is more appropriate and introduces less uncertainty in the result.

5.3.4 Evaluating Survey Results

Survey data are converted to the same units as those in which DCGLs are expressed (Section 6.6). Identification of potential radionuclide contaminants at the site is performed through laboratory and *in situ* analyses. Appropriate regulatory DCGLs for the site are selected and the data are then compared to the DCGLs. For characterization data that are used to supplement final status survey data, the statistical methodology in Chapter 8 should be followed to determine if a survey unit satisfies the release criteria.

For characterization data that are used to help guide remediation efforts, the survey data are used to identify locations and general extent of residual activity. The survey results are first compared with DCGLs. Surfaces and environmental media are then differentiated as exceeding DCGLs, not exceeding DCGLs, or not contaminated, depending on the measurement results relative to the DCGL value. Direct measurements indicating areas of elevated activity are further evaluated and the need for additional measurements is determined.

5.3.5 Documentation

Documentation of the site characterization survey should provide a complete and unambiguous record of the radiological status of the site. In addition, sufficient information to characterize the extent of contamination, including all possible affected environmental media, should be provided in the report. This report should also provide sufficient information to support reasonable approaches or alternatives to site decontamination.

EXAMPLE CHARACTERIZATION SURVEY CHECKLIST

SURVEY DESIGN

________ Enumerate DQOs: State objective of the survey; survey instrumentation capabilities should be appropriate for the specific survey objective.

________ Review the Historical Site Assessment for:

- _______ Operational history (*e.g.*, any problems, spills, or releases) and available documentation (*e.g.*, radioactive materials license).
- _______ Other available resources—site personnel, former workers, residents, *etc.*
- _______ Types and quantities of materials that were handled and where radioactive materials were stored, handled, and disposed of.
- _______ Release and migration pathways.
- _______ Information on the potential for residual radioactivity that may be useful during area classification for final status survey design. Note: Survey activities will be concentrated in Class 1 and Class 2 areas.
- _______ Types and quantities of materials likely to remain on-site—consider radioactive decay.

CONDUCTING SURVEYS

_______ Select instrumentation based on detection capabilities for the expected contaminants and quantities and a knowledge of the appropriate DCGLs.

_______ Determine background activity and radiation levels for the area; include surface activity levels on building surfaces, radionuclide concentrations in environmental media, and exposure rates.

_______ Establish a reference coordinate system. Prepare scale drawings for surface water and ground-water monitoring well locations.

_______ Perform thorough surface scans of all potentially contaminated areas, *(e.g.*, indoor areas include expansion joints, stress cracks, penetrations into floors and walls for piping, conduit, and anchor bolts, and wall/floor interfaces); outdoor areas include radioactive material storage areas, areas downwind of stack release points, surface drainage pathways, and roadways that may have been used for transport of radioactive or contaminated materials.

_______ Perform systematic surface activity measurements.

_______ Perform systematic smear, surface and subsurface soil and media, sediment, surface water and groundwater sampling, if appropriate for the site.

_______ Perform judgment direct measurements and sampling of areas of elevated activity of residual radioactivity to provide data on upper ranges of residual contamination levels.

_______ Document survey and sampling locations.

_______ Maintain chain of custody of samples when necessary.

Note: One category of radiological data (*e.g.*, radionuclide concentration, direct radiation level, or surface contamination) may be sufficient to determine the extent of contamination; other measurements may not be necessary (*e.g.*, removable surface contamination or exposure rate measurements).

Note: Measuring and sampling techniques should be commensurate with the intended use of the data because characterization survey data may be used to supplement final status survey data.

EVALUATING SURVEY RESULTS

_______ Compare survey results with DCGLs. Differentiate surfaces/areas as exceeding DCGLs, not exceeding DCGLs, or not contaminated.

_______ Evaluate all locations of elevated direct measurements and determine the need for additional measurements/samples.

_______ Prepare site characterization survey report.

5.4 Remedial Action Support Surveys

5.4.1 General

Remedial action support surveys are conducted to 1) support remediation activities, 2) determine when a site or survey unit is ready for the final status survey, and 3) provide updated estimates of site-specific parameters to use for planning the final status survey. This manual does not discuss the routine operational surveys (*e.g.*, air sampling, dose rate measurements, environmental sampling) conducted to support remediation activities.

A remedial action support survey serves to monitor the effectiveness of decontamination efforts that are intended to reduce residual radioactivity to acceptable levels. This type of survey guides the cleanup in a real-time mode. The remedial action support survey typically relies on a simple radiological parameter, such as direct radiation near the surface, as an indicator of effectiveness. The investigation level (the level below which there is an acceptable level of assurance that the established DCGLs have been attained) is determined and used for immediate, in-field decisions (Section 5.5.2.6). Such a survey is intended for expediency and cost effectiveness and does not provide thorough or accurate data describing the radiological status of the site. Note that this survey does not provide information that can be used to demonstrate compliance with the DCGLs and is an interim step in the compliance demonstration process. Areas that are determined to satisfy the DCGLs on the basis of the remedial action support survey will then be surveyed in detail by the final status survey. Alternatively, the remedial action support survey can be designed to meet the objectives of a final status survey as described in Section 5.5. DCGLs may be recalculated based on the results of the remediation process as the regulatory program allows or permits.

Remedial activities result in changes to the distribution of contamination within a survey unit. The site-specific parameters used during final status survey planning (*e.g.*, variability in the radionuclide concentration within a survey unit or probability of small areas of elevated activity) will change during remediation. For most survey units, values for these parameters will need to be re-established following remediation. Obtaining updated values for these critical planning parameters should be considered when designing a remedial action support survey.

5.4.2 Survey Design

The objective of the remedial action support survey is to detect the presence of residual activity at or below the DCGL criteria. Although the presence of small areas of elevated radioactivity may satisfy the elevated measurement criteria, it may be more efficient to design the remedial action support survey to identify residual radioactivity at the $DCGL_W$ (and to remediate small areas of elevated activity that may potentially satisfy the release criteria). Survey instrumentation and techniques are therefore selected based on the detection capabilities for the known or suspected contaminants and DCGLs to be achieved.

There will be radionuclides and media that cannot be evaluated at the $DCGL_W$ using field monitoring techniques. For these cases, it may be feasible to collect and analyze samples by methods that are quicker and less costly than radionuclide-specific laboratory procedures. Field laboratories and screening techniques may be acceptable alternatives to more expensive analyses. Reviewing remediation plans may be required to get an indication of the location and amount of remaining contamination following remediation.

5.4.3 Conducting Surveys

Field survey instruments and procedures are selected based on their detection capabilities for the expected contaminants and their quantities. Survey methods typically include scans of surfaces followed by direct measurements to identify residual radioactivity. The surface activity levels are compared to the DCGLs, and a determination is made on the need for further decontamination efforts.

Survey activities for soil excavations include surface scans using field instrumentation sensitive to beta and gamma activity. Because it is difficult to correlate scanning results to radionuclide concentrations in soil, judgment should be carefully exercised when using scan results to guide the cleanup efforts. Field laboratories and screening techniques may provide a better approach for determining whether or not further soil remediation is necessary.

5.4.4 Evaluating Survey Results

Survey data (*e.g.*, surface activity levels and radionuclide concentrations in various media) are converted to standard units and compared to the DCGLs (Section 6.6). If results of these survey activities indicate that remediation has been successful in meeting the DCGLs, decontamination efforts are ceased and final status survey activities are initiated. Further remediation may be needed if results indicate the presence of residual activity in excess of the DCGLs.

5.4.5 Documentation

The remedial action support survey is intended to guide the cleanup and alert those performing remedial activities that additional remediation is needed or that the site may be ready to initiate a final survey. Data that indicate an area has been successfully remediated could be used to estimate the variance for the survey units in that area. Information identifying areas of elevated activity that existed prior to remediation may be useful for planning final status surveys.

EXAMPLE REMEDIAL ACTION SUPPORT SURVEY CHECKLIST

SURVEY DESIGN

________ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be able to detect residual contamination at the DCGL.

________ Review the remediation plans.

________ Determine applicability of monitoring surfaces/soils for the radionuclides of concern. Note: Remedial action support surveys may not be feasible for surfaces contaminated with very low energy beta emitters or for soils or media contaminated with pure alpha emitters.

________ Select simple radiological parameters (*e.g.*, surface activity) that can be used to make immediate in-field decisions on the effectiveness of the remedial action.

CONDUCTING SURVEYS

________ Select instrumentation based on its detection capabilities for the expected contaminants.

________ Perform scanning and surface activity measurements near the surface being decontaminated.

________ Survey soil excavations and perform field evaluation of samples (*e.g.*, gamma spectrometry of undried/non-homogenized soil) as remedial actions progress.

EVALUATING SURVEY RESULTS

________ Compare survey results with DCGLs using survey data as a field decision tool to guide the remedial actions in a real-time mode.

________ Document survey results.

5.5 Final Status Surveys

5.5.1 General

A final status survey is performed to demonstrate that residual radioactivity in each survey unit satisfies the predetermined criteria for release for unrestricted use or, where appropriate, for use with designated limitations. The survey provides data to demonstrate that all radiological parameters do not exceed the established DCGLs. For these reasons, more detailed guidance is provided for this category of survey. For the final status survey, survey units represent the fundamental elements for compliance demonstration using the statistical tests (see Section 4.6). The documentation specified in the following sections helps ensure a consistent approach among different organizations and regulatory agencies. This allows for comparisons of survey results between sites or facilities.

This section describes methods for planning and conducting final status surveys to satisfy the objectives of the regulatory agencies. The MARSSIM approach recognizes that alternative methods may be acceptable to those agencies. Flow diagrams and a checklist to assist the user in planning a survey are included in this section.

5.5.2 Survey Design

Figures 5.1 through 5.3 illustrate the process of designing a final status survey. This process begins with development of DQOs. On the basis of these objectives and the known or anticipated radiological conditions at the site, the numbers and locations of measurement and sampling points used to demonstrate compliance with the release criterion are then determined. Finally, survey techniques appropriate to develop adequate data (see Chapters 6 and 7) are selected and implemented.

Planning for the final status survey should include early discussions with the regulatory agency concerning logistics for confirmatory or verification surveys. A confirmatory survey (also known as an independent verification survey), may be performed by the responsible regulatory agency or by an independent third party (*e.g.*, contracted by the regulatory agency) to provide data to substantiate results of the final status survey. Actual field measurements and sampling may be performed. Another purpose of the confirmatory activities may be to identify any deficiencies in the final status survey documentation based on a thorough review of survey procedures and results. Independent confirmatory survey activities are usually limited in scope to spot-checking conditions at selected locations, comparing findings with those of the final status survey, and performing independent statistical evaluations of the data developed from the confirmatory survey and the final status survey.

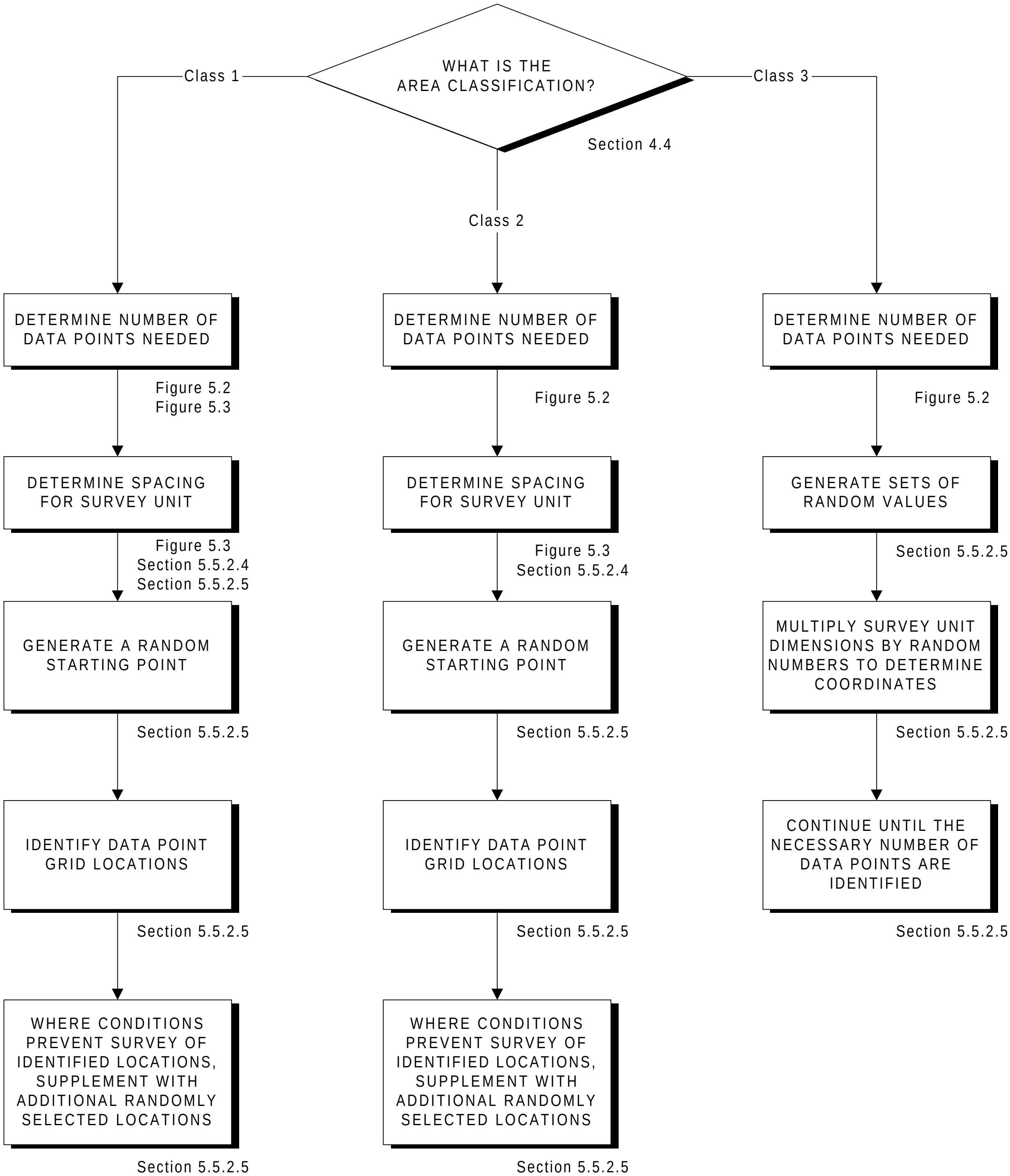

Figure 5.1 Flow Diagram Illustrating the Process for Identifying Measurement Locations (Refer to Section 5.5.2.5)

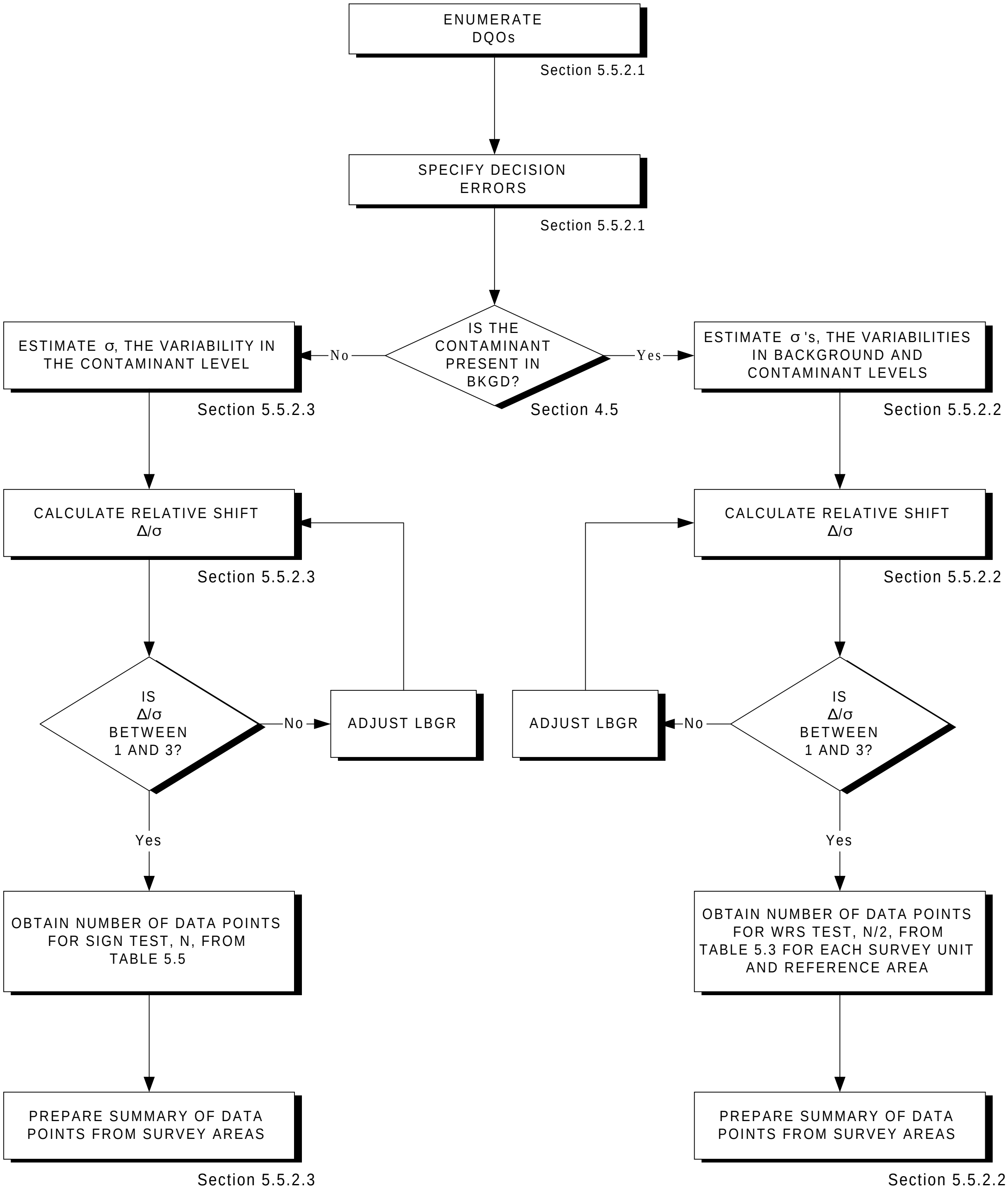

Figure 5.2 Flow Diagram for Identifying the Number of Data Points, N, for Statistical Tests

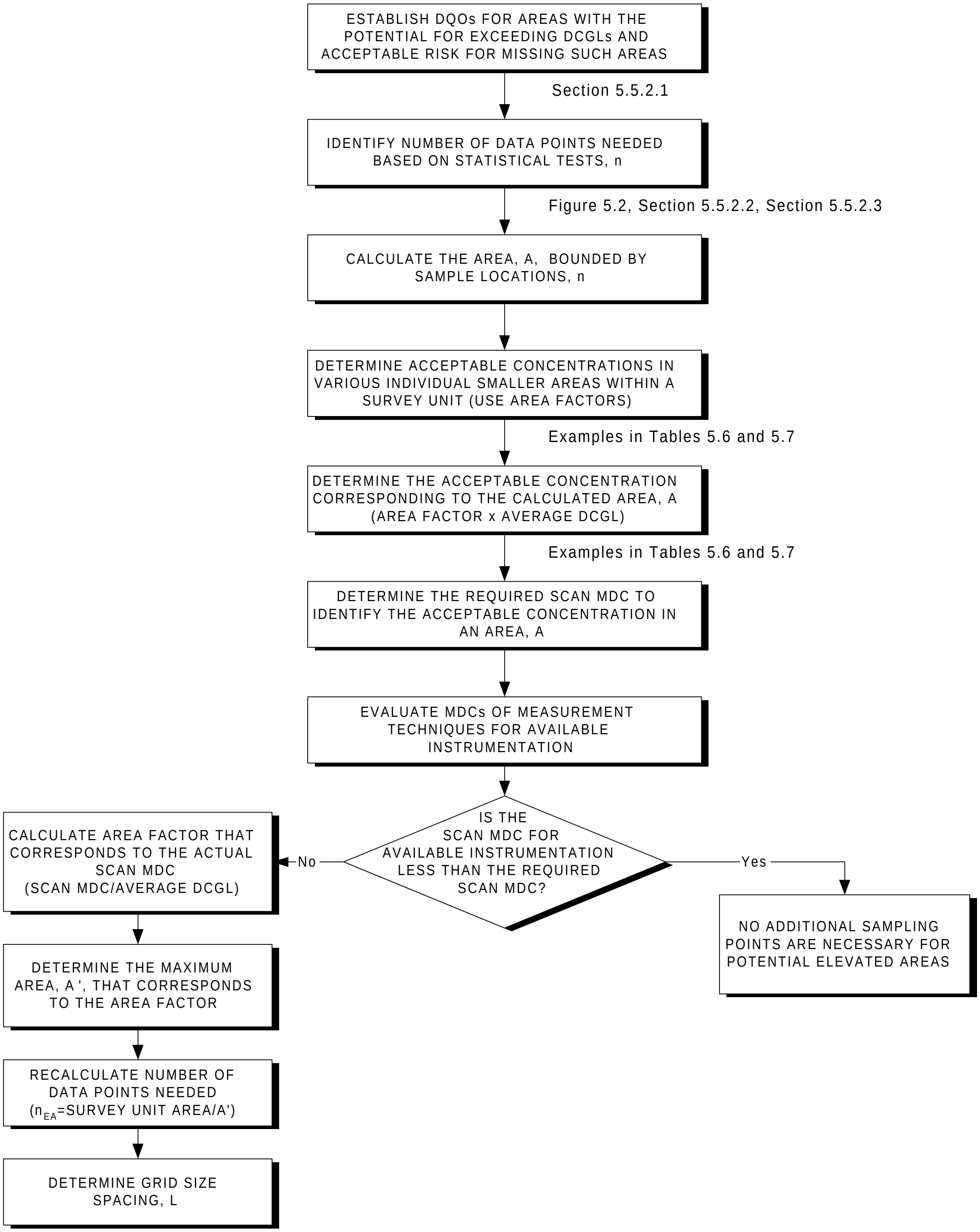

Figure 5.3 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units (Refer to Section 5.5.2.4)

5.5.2.1 Application of Decommissioning Criteria

The DQO Process, as it is applied to decommissioning surveys, is described in more detail in Appendix D of this manual and in EPA and NRC guidance documents (EPA 1994, 1987b, 1987c; NRC 1997a). As part of this process, the objective of the survey and the null and alternative hypotheses should be clearly stated. The objective of final status surveys is typically to demonstrate that residual radioactivity levels meet the release criterion. In demonstrating that this objective is met, the null hypothesis (H_o) tested is that residual contamination exceeds the release criterion; the alternative hypothesis (H_a) is that residual contamination meets the release criterion.

Two statistical tests are used to evaluate data from final status surveys. For contaminants that are present in background, the Wilcoxon Rank Sum (WRS) test is used. When contaminants are not present in background, the Sign test is used. To determine data needs for these tests, the acceptable probability of making Type I decision errors (α) and Type II decision errors (β) should be established (see Appendix D, Section D.6). The acceptable decision error rates are a function of the amount of residual radioactivity and are determined during survey planning using the DQO Process.

The final step of the DQO process includes selecting the optimal design that satisfies the DQOs. For some sites or survey units, the guidance provided in this section may result in a survey design that cannot be accomplished with the available resources. For these situations, the planning team will need to relax one or more of the constraints used to develop the survey design as described in Appendix D. Examples of survey design constraints discussed in this section include:

- increasing the decision error rates, not forgetting to consider the risks associated with making an incorrect decision
- increasing the width of the gray region by decreasing the lower bound of the gray region
- changing the boundaries—it may be possible to reduce measurement costs by changing or eliminating survey units that may require different decisions

5.5.2.2 Contaminant Present in Background—Determining Numbers of Data Points for Statistical Tests

The comparison of measurements from the reference area and survey unit is made using the WRS test, which should be conducted for each survey unit. In addition, the elevated measurement comparison (EMC) is performed against each measurement to ensure that the measurement result does not exceed a specified investigation level. If any measurement in the remediated survey unit exceeds the specified investigation level, then additional investigation is recommended, at least locally, regardless of the outcome of the WRS test.

The WRS test is most effective when residual radioactivity is uniformly present throughout a survey unit. The test is designed to detect whether or not this activity exceeds the $DCGL_W$. The advantage of this nonparametric test is that it does not assume the data are normally or log-normally distributed. The WRS test also allows for “less than” measurements to be present in the reference area and the survey units. As a general rule, this test can be used with up to 40 % “less than” measurements in either the reference area or the survey unit. However, the use of “less than” values in data reporting is not recommended. Wherever possible, the actual result of a measurement, together with its uncertainty, should be reported.

This section introduces several terms and statistical parameters that will be used to determine the number of data points needed to apply the nonparametric tests. An example is provided to better illustrate the application of these statistical concepts.

Calculate the Relative Shift. The lower bound of the gray region (LBGR) is selected during the DQO Process along with the target values for α and β. The width of the gray region, equal to (DCGL - LBGR), is a parameter that is central to the WRS test. This parameter is also referred to as the shift, Δ. The absolute size of the shift is actually of less importance than the relative shift, Δ/σ, where σ is an estimate of the standard deviation of the measured values in the survey unit. This estimate of σ includes both the real spatial variability in the quantity being measured and the precision of the chosen measurement system. The relative shift, Δ/σ, is an expression of the resolution of the measurements in units of measurement uncertainty.

The shift ($\Delta = DCGL_W - LBGR$) and the estimated standard deviation in the measurements of the contaminant (σ_r and σ_s) are used to calculate the relative shift, Δ/σ (see Appendix D, Section D.6). The standard deviations in the contaminant level will likely be available from previous survey data (*e.g.*, scoping or characterization survey data for unremediated survey units or remedial action support surveys for remediated survey units). If they are not available, it may be necessary to 1) perform some limited preliminary measurements (about 5 to 20) to estimate the distributions, or 2) to make a reasonable estimate based on available site knowledge. If the first approach above is used, it is important to note that the scoping or characterization survey data or preliminary measurements used to estimate the standard deviation should use the same technique as that to be used during the final status survey. When preliminary data are not obtained, it may be reasonable to assume a coefficient of variation on the order of 30%, based on experience.

The value selected as an estimate of σ for a survey unit may be based on data collected only from within that survey unit or from data collected from a much larger area of the site. Note that survey units are not finalized until the planning stage of the final status survey. This means that there may be some difficulty in determining which individual measurements from a preliminary survey may later represent a particular survey unit. For many sites, the most practical solution is to estimate σ for each area classification (*i.e.*, Class 1, Class 2, and Class 3) for both interior and exterior survey units. This will result in all exterior Class 3 survey units using the same estimate of σ, all exterior Class 2 survey units using a second estimate for σ, and all exterior Class 1 survey units using a third estimate for σ. If there are multiple types of surfaces within an area classification, additional estimates of σ may be required. For example, a Class 2 concrete floor may require a different estimate of σ than a Class 2 cinder block wall, or a Class 3 unpaved parking area may require a different estimate of σ than a Class 3 lawn. In addition, MARSSIM recommends that a separate estimate of σ be obtained for every reference area.

The importance of choosing appropriate values for σ_r and σ_s must be emphasized. *If the value is grossly underestimated*, the number of data points will be too few to obtain the desired power level for the test and a resurvey may be recommended (refer to Chapter 8). If, on the other hand, *the value is overestimated*, the number of data points determined will be unnecessarily large.

Values for the relative shift that are less than one will result in a large number of measurements needed to demonstrate compliance. The number of data points will also increase as Δ becomes smaller. Since the DCGL is fixed, this means that the lower bound of the gray region also has a significant effect on the estimated number of measurements needed to demonstrate compliance. When the estimated standard deviations in the reference area and survey units are different, the larger value should be used to calculate the relative shift (Δ/σ).

Determine P_r. The probability that a random measurement from the survey unit exceeds a random measurement from the background reference area by less than the $DCGL_W$ when the survey unit median is equal to the LBGR above background is defined as P_r. P_r is used in Equation 5-1 for determining the number of measurements to be performed during the survey. Table 5.1 lists relative shift values and values for P_r. Using the relative shift calculated in the preceding section, the value of P_r can be obtained from Table 5.1. Information on calculating individual values of P_r is available in NUREG-1505 (NRC 1997a).

If the actual value of the relative shift is not listed in Table 5.1, always select the next lower value that appears in the table. For example, Δ/σ=1.67 does not appear in Table 5.1. The next lower value is 1.6, so the value of P_r would be 0.871014.

Determine Decision Error Percentiles. The next step in this process is to determine the percentiles, $Z_{1-\alpha}$ and $Z_{1-ß}$, represented by the selected decision error levels, α and ß, respectively (see Table 5.2). $Z_{1-\alpha}$ and $Z_{1-ß}$ are standard statistical values (Harnett 1975).

Table 5.1 Values of P_r for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Present in Background

Δ/σ	P_r	Δ/σ	P_r
0.1	0.528182	1.4	0.838864
0.2	0.556223	1.5	0.855541
0.3	0.583985	1.6	0.871014
0.4	0.611335	1.7	0.885299
0.5	0.638143	1.8	0.898420
0.6	0.664290	1.9	0.910413
0.7	0.689665	2.0	0.921319
0.8	0.714167	2.25	0.944167
0.9	0.737710	2.5	0.961428
1.0	0.760217	2.75	0.974067
1.1	0.781627	3.0	0.983039
1.2	0.801892	3.5	0.993329
1.3	0.820978	4.0	0.997658

If Δ/σ > 4.0, use P_r = 1.000000

Table 5.2 Percentiles Represented by Selected Values of α and ß

α (or ß)	$Z_{1-\alpha}$ (or $Z_{1-ß}$)	α (or β)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)
0.005	2.576	0.10	1.282
0.01	2.326	0.15	1.036
0.015	2.241	0.20	0.842
0.025	1.960	0.25	0.674
0.05	1.645	0.30	0.524

Calculate Number of Data Points for WRS Test. The number of data points, N, to be obtained from each reference area/survey unit pair for the WRS test is next calculated using

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(P_r - 0.5)^2} \tag{5-1}$$

The value of N calculated using equation 5-1 is an approximation based on estimates of σ and P_r, so there is some uncertainty associated with this calculation. In addition, there will be some missing or unusable data from any survey. The rate of missing or unusable measurements, R, expected to occur in survey units or reference areas and the uncertainty associated with the calculation of N should be accounted for during survey planning. The number of data points should be increased by 20%, and rounded up, over the values calculated using equation 5-1 to obtain sufficient data points to attain the desired power level with the statistical tests and allow for possible lost or unusable data. The value of 20% is selected to account for a reasonable amount of uncertainty in the parameters used to calculate N and still allow flexibility to account for some lost or unusable data. The recommended 20% correction factor should be applied as a minimum value. Experience and site-specific considerations should be used to increase the correction factor if required. If the user determines that the 20% increase in the number of measurements is excessive for a specific site, a retrospective power curve should be used to demonstrate that the survey design provides adequate power to support the decision (see Appendix I).

N is the total number of data points for each survey unit/reference area combination. The N data points are divided between the survey unit, n, and the reference area, m. The simplest method for distributing the N data points is to assign half the data points to the survey unit and half to the reference area, so n=m=N/2. This means that N/2 measurements are performed in each survey unit, and N/2 measurements are performed in each reference area. If more than one survey unit is associated with a particular reference area, N/2 measurements should be performed in each survey unit and N/2 measurements should be performed in the reference area.

Obtain Number of Data Points for WRS Test from Table 5.3. Table 5.3 provides a list of the number of data points used to demonstrate compliance using the WRS test for selected values of α, β, and Δ/σ. The values listed in Table 5.3 represent the number of measurements to be performed in each survey unit as well as in the corresponding reference area. The values were calculated using Equation 5-1 and increased by 20% for the reasons discussed in the previous section.

Example:

A site has 14 survey units and 1 reference area, and the same type of instrument and method is used to perform measurements in each area. The contaminant has a $DCGL_W$ which when converted to cpm equals 160 cpm. The contaminant is present in background at a level of 45 ± 7 (1σ) cpm. The standard deviation of the contaminant in the survey area is ± 20 cpm, based on previous survey results for

Table 5.3 Values of N/2 for Use with the Wilcoxon Rank Sum Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	5452	4627	3972	3278	2268	4627	3870	3273	2646	1748	3972	3273	2726	2157	1355	3278	2646	2157	1655	964	2268	1748	1355	964	459
0.2	1370	1163	998	824	570	1163	973	823	665	440	998	823	685	542	341	824	665	542	416	243	570	440	341	243	116
0.3	614	521	448	370	256	521	436	369	298	197	448	369	307	243	153	370	298	243	187	109	256	197	153	109	52
0.4	350	297	255	211	146	297	248	210	170	112	255	210	175	139	87	211	170	139	106	62	146	112	87	62	30
0.5	227	193	166	137	95	193	162	137	111	73	166	137	114	90	57	137	111	90	69	41	95	73	57	41	20
0.6	161	137	117	97	67	137	114	97	78	52	117	97	81	64	40	97	78	64	49	29	67	52	40	29	14
0.7	121	103	88	73	51	103	86	73	59	39	88	73	61	48	30	73	59	48	37	22	51	39	30	22	11
0.8	95	81	69	57	40	81	68	57	46	31	69	57	48	38	24	57	46	38	29	17	40	31	24	17	8
0.9	77	66	56	47	32	66	55	46	38	25	56	46	39	31	20	47	38	31	24	14	32	25	20	14	7
1.0	64	55	47	39	27	55	46	39	32	21	47	39	32	26	16	39	32	26	20	12	27	21	16	12	6
1.1	55	47	40	33	23	47	39	33	27	18	40	33	28	22	14	33	27	22	17	10	23	18	14	10	5
1.2	48	41	35	29	20	41	34	29	24	16	35	29	24	19	12	29	24	19	15	9	20	16	12	9	4
1.3	43	36	31	26	18	36	30	26	21	14	31	26	22	17	11	26	21	17	13	8	18	14	11	8	4
1.4	38	32	28	23	16	32	27	23	19	13	28	23	19	15	10	23	19	15	12	7	16	13	10	7	4
1.5	35	30	25	21	15	30	25	21	17	11	25	21	18	14	9	21	17	14	11	7	15	11	9	7	3
1.6	32	27	23	19	14	27	23	19	16	11	23	19	16	13	8	19	16	13	10	6	14	11	8	6	3
1.7	30	25	22	18	13	25	21	18	15	10	22	18	15	12	8	18	15	12	9	6	13	10	8	6	3
1.8	28	24	20	17	12	24	20	17	14	9	20	17	14	11	7	17	14	11	9	5	12	9	7	5	3
1.9	26	22	19	16	11	22	19	16	13	9	19	16	13	11	7	16	13	11	8	5	11	9	7	5	3
2.0	25	21	18	15	11	21	18	15	12	8	18	15	13	10	7	15	12	10	8	5	11	8	7	5	3
2.25	22	19	16	14	10	19	16	14	11	8	16	14	11	9	6	14	11	9	7	4	10	8	6	4	2
2.5	21	18	15	13	9	18	15	13	10	7	15	13	11	9	6	13	10	9	7	4	9	7	6	4	2
2.75	20	17	15	12	9	17	14	12	10	7	15	12	10	8	5	12	10	8	6	4	9	7	5	4	2
3.0	19	16	14	12	8	16	14	12	10	6	14	12	10	8	5	12	10	8	6	4	8	6	5	4	2
3.5	18	16	13	11	8	16	13	11	9	6	13	11	9	8	5	11	9	8	6	4	8	6	5	4	2
4.0	18	15	13	11	8	15	13	11	9	6	13	11	9	7	5	11	9	7	6	4	8	6	5	4	2

the same or similar contaminant distribution. When the estimated standard deviation in the reference area and the survey units are different, the larger value, 20 cpm in this example, should be used to calculate the relative shift. During the DQO process the LBGR is selected to be one-half the $DCGL_W$ (80 cpm) as an arbitrary starting point for developing an acceptable survey design,[1] and Type I and Type II error values (α and β) of 0.05 have been selected. Determine the number of data points to be obtained from the reference area and from each of the survey units for the statistical tests.

The value of the relative shift for the reference area, Δ/σ, is (160-80)/20 or 4. From Table 5.1, the value of P_r is 0.997658. Values of percentiles, represented by the selected decision error levels, are obtained from Table 5.2. In this case $Z_{1-\alpha}$ (for α = 0.05) is 1.645 and $Z_{1-\beta}$ (β = 0.05) is also 1.645.

The number of data points, N, for the WRS test of each combination of reference area and survey units can be calculated using Equation 5-1

$$N = \frac{(1.645 + 1.645)^2}{3(0.997658 - 0.5)^2} = 14.6$$

Adding an additional 20% gives 17.5 which is then rounded up to the next even number, 18. This yields 9 data points for the reference area and 9 for each survey unit.

Alternatively, the number of data points can be obtained directly from Table 5.3. For α=0.05, β=0.05, and Δ/σ=4.0 a value of 9 is obtained for N/2. The table value has already been increased by 20% to account for missing or unusable data.

5.5.2.3 Contaminant Not Present in Background—Determining Numbers of Data Points for Statistical Tests

For the situation where the contaminant is not present in background or is present at such a small fraction of the $DCGL_W$ as to be considered insignificant, a background reference area is not necessary. Instead, the contaminant levels are compared directly with the DCGL value. The general approach closely parallels that used for the situation when the contaminant is present in background as described in Section 5.5.2.2. However, the statistical tests differ slightly. The one-sample Sign test replaces the two-sample Wilcoxon Rank Sum test described above.

[1] Appendix D provides more detailed guidance on the selection of the LBGR.

Calculate the Relative Shift. The initial step in determining the number of data points in the one-sample case is to calculate the relative shift, Δ/σ_s = (DCGL-LBGR)/σ_s, from the DCGL value, the lower bound of the gray region (LBGR), and the standard deviation of the contaminant in the survey unit, σ_s, as described in Section 5.5.2.2. Also as described in Section 5.5.2.2, the value of σ_s may be obtained from earlier surveys, limited preliminary measurements, or a reasonable estimate. Values of the relative shift that are less than one will result in a large number of measurements needed to demonstrate compliance.

Determine Sign p. Sign p is the estimated probability that a random measurement from the survey unit will be less than the $DCGL_W$ when the survey unit median is actually at the LBGR. The Sign p is used to calculate the minimum number of data points necessary for the survey to meet the DQOs. The value of the relative shift calculated in the previous section is used to obtain the corresponding value of Sign p from Table 5.4.

Table 5.4 Values of Sign p for Given Values of the Relative Shift, Δ/σ, when the Contaminant is Not Present in Background

Δ/σ	Sign p	Δ/σ	Sign p
0.1	0.539828	1.2	0.884930
0.2	0.579260	1.3	0.903199
0.3	0.617911	1.4	0.919243
0.4	0.655422	1.5	0.933193
0.5	0.691462	1.6	0.945201
0.6	0.725747	1.7	0.955435
0.7	0.758036	1.8	0.964070
0.8	0.788145	1.9	0.971284
0.9	0.815940	2.0	0.977250
1.0	0.841345	2.5	0.993790
1.1	0.864334	3.0	0.998650

If $\Delta/\sigma > 3.0$, use Sign p = 1.000000

Determine Decision Error Percentiles. The next step in this process is to determine the percentiles, $Z_{1-\alpha}$ and $Z_{1-ß}$, represented by the selected decision error levels, α and ß, respectively (see Table 5.2).

Calculate Number of Data Points for Sign Test. The number of data points, N, to be obtained for the Sign test is next calculated using the following formula:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(Sign\ p - 0.5)^2} \qquad 5\text{-}2$$

Finally, the number of anticipated data points should be increased by at least 20% as discussed in Section 5.5.2.2 to ensure sufficient power of the tests and to allow for possible data losses.

Obtain Number of Data Points for Sign Test from Table 5.5. Table 5.5 provides a list of the number of data points used to demonstrate compliance using the Sign test for selected values of α, β, and Δ/σ. The values listed in Table 5.5 represent the number of measurements to be performed in each survey unit. These values were calculated using Equation 5-2 and increased by 20% to account for missing or unusable data and uncertainty in the calculated value of N.

Example:

A site has 1 survey unit. The DCGL level for the contaminant of interest is 140 Bq/kg (3.9 pCi/g) in soil. The contaminant is not present in background; data from previous investigations indicate average residual contamination at the survey unit of 3.7 ± 3.7 (1σ) Bq/kg. The lower bound of the gray region was selected to be 110 Bq/kg. A value of 0.05 is next selected for the probability of Type I decision errors (α) and a value of 0.01 is selected for the probability of Type II decision errors (β) based on the survey objectives. Determine the number of data points to be obtained from the survey unit for the statistical tests.

The value of the shift parameter, Δ/σ, is (140-110)/3.7 or 8. From Table 5.4, the value of Sign p is 1.0. Since Δ/σ>3, the width of the gray region can be reduced. If the LBGR is raised to 125, then Δ/σ is (140-125)/3.7 or 4. The value of Sign p remains at 1.0. Thus, the number of data points calculated will not change. The probability of a Type II error is now specified at 125 Bq/kg (3.4 pCi/g) rather than 110 Bq/kg (3.0 pCi/g). As a consequence, the probability of a Type II error at 110 Bq/kg (3.0 pCi/g) will be even smaller.

Values of percentiles, represented by the selected decision error levels are obtained from Table 5.2. $Z_{1-\alpha}$ (for α = 0.05) is 1.645, and $Z_{1-\beta}$ (β = 0.01) is 2.326.

Table 5.5 Values of N for Use with the Sign Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	4095	3476	2984	2463	1704	3476	2907	2459	1989	1313	2984	2459	2048	1620	1018	2463	1989	1620	1244	725	1704	1313	1018	725	345
0.2	1035	879	754	623	431	879	735	622	503	333	754	622	518	410	258	623	503	410	315	184	431	333	258	184	88
0.3	468	398	341	282	195	398	333	281	227	150	341	281	234	185	117	282	227	185	143	83	195	150	117	83	40
0.4	270	230	197	162	113	230	1921	162	131	87	197	162	136	107	68	162	131	107	82	48	113	87	68	48	23
0.5	178	152	130	107	75	152	126	107	87	58	130	107	89	71	45	107	87	71	54	33	75	58	45	33	16
0.6	129	110	94	77	54	110	92	77	63	42	94	77	65	52	33	77	63	52	40	23	54	42	33	23	11
0.7	99	83	72	59	41	83	70	59	48	33	72	59	50	40	26	59	48	40	30	18	41	33	26	18	9
0.8	80	68	58	48	34	68	57	48	39	26	58	48	40	32	21	48	39	32	24	15	34	26	21	15	8
0.9	66	57	48	40	28	57	47	40	33	22	48	40	34	27	17	40	33	27	21	12	28	22	17	12	6
1.0	57	48	41	34	24	48	40	34	28	18	41	34	29	23	15	34	28	23	18	11	24	18	15	11	5
1.1	50	42	36	30	21	42	35	30	24	17	36	30	26	21	14	30	24	21	16	10	21	17	14	10	5
1.2	45	38	33	27	20	38	32	27	22	15	33	27	23	18	12	27	22	18	15	9	20	15	12	9	5
1.3	41	35	30	26	17	35	29	24	21	14	30	24	21	17	11	26	21	17	14	8	17	14	11	8	4
1.4	38	33	28	23	16	33	27	23	18	12	28	23	20	16	10	23	18	16	12	8	16	12	10	8	4
1.5	35	30	27	22	15	30	26	22	17	12	27	22	18	15	10	22	17	15	11	8	15	12	10	8	4
1.6	34	29	24	21	15	29	24	21	17	11	24	21	17	14	9	21	17	14	11	6	15	11	9	6	4
1.7	33	28	24	20	14	28	23	20	16	11	24	20	17	14	9	20	16	14	10	6	14	11	9	6	4
1.8	32	27	23	20	14	27	22	20	16	11	23	20	16	12	9	20	16	12	10	6	14	11	9	6	4
1.9	30	26	22	18	14	26	22	18	15	10	22	18	16	12	9	18	15	12	10	6	14	10	9	6	4
2.0	29	26	22	18	12	26	21	18	15	10	22	18	15	12	8	18	15	12	10	6	12	10	8	6	3
2.5	28	23	21	17	12	23	20	17	14	10	21	17	15	11	8	17	14	11	9	5	12	10	8	5	3
3.0	27	23	20	17	12	23	20	17	14	9	20	17	14	11	8	17	14	11	9	5	12	9	8	5	3

The number of data points, N, for the Sign test can be calculated using Equation 5-2.

$$N = \frac{(1.645 + 2.326)^2}{4(1.0 - 0.5)^2} = 15.85$$

Adding an additional 20% gives 19.2 and rounding up yields 20 data points for the survey unit.

Alternatively, the number of data points can be obtained directly from Table 5.5. For α=0.05, β=0.01, and Δ/σ>3.0 a value of 20 is obtained for N. The table value has already been increased by 20% to account for missing or unusable data and uncertainty in the calculated value of N.

5.5.2.4 Determining Data Points for Small Areas of Elevated Activity

The statistical tests described above (also see Chapter 8) evaluate whether or not the residual radioactivity in an area exceeds the $DCGL_W$ for contamination conditions that are approximately uniform across the survey unit. In addition, there should be a reasonable level of assurance that any small areas of elevated residual radioactivity that could be significant relative to the $DCGL_{EMC}$ are not missed during the final status survey. The statistical tests introduced in the previous sections may not successfully detect small areas of elevated contamination. Instead, systematic measurements and sampling, in conjunction with surface scanning, are used to obtain adequate assurance that small areas of elevated radioactivity will still satisfy the release criterion or the $DCGL_{EMC}$. The procedure is applicable for all radionuclides, regardless of whether or not they are present in background, and is implemented for survey units classified as Class 1.

The number of survey data points needed for the statistical tests discussed in Section 5.5.2.2 or 5.5.2.3 is identified (the appropriate section depends on whether the contaminant is present in background or not). These data points are then positioned throughout the survey unit by first randomly selecting a start point and establishing a systematic pattern. This systematic sampling grid may be either triangular or square. The triangular grid is generally more efficient for locating small areas of elevated activity. Appendix D includes a brief discussion on the efficiency of triangular and square grids for locating areas of elevated activity. A more detailed discussion is provided by EPA (EPA 1994b).

The number of calculated survey locations, n, is used to determine the grid spacing, L, of the systematic sampling pattern (see Section 5.5.2.5). The grid area that is bounded by these survey locations is given by $A = 0.866 \times L^2$ for a triangular grid and $A = L^2$ for a square grid. The risk of not sampling a circular area—equal to A—of elevated activity by use of a random-start grid pattern is illustrated in Figure D.7 in Appendix D.

One method for determining values for the $DCGL_{EMC}$ is to modify the $DCGL_w$ using a correction factor that accounts for the difference in area and the resulting change in dose or risk. The area factor is the magnitude by which the concentration within the small area of elevated activity can exceed $DCGL_W$ while maintaining compliance with the release criterion. The area factor is determined based on specific regulatory agency guidance.

Tables 5.6 and 5.7 provide examples of area factors generated using exposure pathway models. The outdoor area factors listed in Table 5.6 were calculated using RESRAD 5.6. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/kg (1 pCi/g). The area of contamination in RESRAD 5.6 defaults to 10,000 m^2. Other than changing the area (*i.e.*, 1, 3, 10, 30, 100, 300, 1,000, or 3,000 m^2), the RESRAD default values were not changed. The area factors were then computed by taking the ratio of the dose or risk per unit concentration generated by RESRAD for the default 10,000 m^2 to that generated for the other areas listed. If the DCGL for residual radioactivity distributed over 10,000 m^2 is multiplied by this value, the resulting concentration distributed over the specified smaller area delivers the same calculated dose. The indoor area factors listed in Table 5.7 were calculated in a similar manner using RESRAD-BUILD 1.5. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/m^2 (1 pCi/m^2). The area of contamination in RESRAD-BUILD 1.5 defaults to 36 m^2. The other areas compared to this value were 1, 4, 9, 16, or 25 m^2. Removable surface contamination was assumed to be 10%. No other changes to the default values were made. Note that the use of RESRAD to determine area factors is for illustration purposes only. The MARSSIM user should consult with the responsible regulatory agency for guidance on acceptable techniques to determine area factors.

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—is calculated as follows:

$$Scan\ MDC\ (required) = (DCGL_W) \times (Area\ Factor) \qquad 5\text{-}3$$

The actual MDCs of scanning techniques are then determined for the available instrumentation (see Section 6.7). The actual MDC of the selected scanning technique is compared to the required scan MDC. If the actual scan MDC 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 small areas of elevated activity.

Table 5.6 Illustrative Examples of Outdoor Area Dose Factors*

Nuclide	Area Factor								
	1 m^2	3 m^2	10 m^2	30 m^2	100 m^2	300 m^2	1000 m^2	3000 m^2	10000 m^2
Am-241	208.7	139.7	96.3	44.2	13.4	4.4	1.3	1.0	1.0
Co-60	9.8	4.4	2.1	1.5	1.2	1.1	1.1	1.0	1.0
Cs-137	11.0	5.0	2.4	1.7	1.4	1.3	1.1	1.1	1.0
Ni-63	1175.2	463.7	154.8	54.2	16.6	5.6	1.7	1.5	1.0
Ra-226	54.8	21.3	7.8	3.2	1.1	1.1	1.0	1.0	1.0
Th-232	12.5	6.2	3.2	2.3	1.8	1.5	1.1	1.0	1.0
U-238	30.6	18.3	11.1	8.4	6.7	4.4	1.3	1.0	1.0

* The values listed in Table 5.6 are for illustrative purposes only. Consult regulatory guidance to determine area factors to be used for compliance demonstration.

Table 5.7 Illustrative Examples of Indoor Area Dose Factors*

Nuclide	Area Factor					
	1 m^2	4 m^2	9 m^2	16 m^2	25 m^2	36 m^2
Am-241	36.0	9.0	4.0	2.2	1.4	1.0
Co-60	9.2	3.1	1.9	1.4	1.2	1.0
Cs-137	9.4	3.2	1.9	1.4	1.2	1.0
Ni-63	36.0	9.0	4.0	2.3	1.4	1.0
Ra-226	18.1	5.5	2.9	1.9	1.3	1.0
Th-232	36.0	9.0	4.0	2.2	1.4	1.0
U-238	35.7	9.0	4.0	2.2	1.4	1.0

* The values listed in Table 5.7 are for illustrative purposes only. Consult regulatory guidance to determine area factors to be used for compliance demonstration.

If the actual scan MDC is greater than the required scan MDC (*i.e.*, the available scan sensitivity is not sufficient to detect small areas of elevated activity), then it is necessary to calculate the area factor that corresponds to the actual scan MDC:

$$Area\ Factor = \frac{scan\ MDC\ (actual)}{DCGL} \qquad 5\text{-}4$$

The size of the area of elevated activity (in m^2) that corresponds to this area factor is then obtained from specific regulatory agency guidance, and may be similar to those illustrated in Table 5.6 or Table 5.7. The data needs for assessing small areas of elevated activity can then be determined by dividing the area of elevated activity acceptable to the regulatory agency into the survey unit area. For example, if the area of elevated activity is 100 m^2 (from Table 5.6) and the survey unit area is 2,000 m^2, then the calculated number of survey locations is 20. 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). Specifically, the spacing, L, of the pattern (when driven by the areas of elevated activity) is given by:

$$L = \sqrt{\frac{A}{0.866\ n_{EA}}} \quad for\ a\ triangular\ grid \qquad 5\text{-}5$$

$$L = \sqrt{\frac{A}{n_{EA}}} \quad for\ a\ square\ grid \qquad 5\text{-}6$$

where A is the area of the survey unit. Grid spacings should generally be rounded *down* to the nearest distance that can be conveniently measured in the field.

If the number of data points required to identify areas of elevated activity (n_{EA}) is greater than the number of data points calculated using Equation 5-1 (N/2) or Equation 5-2 (N), L should be calculated using Equation 5-5 or Equation 5-6. This value of L is then used to determine the measurement locations as described in Section 5.5.2.5. If n_{EA} is smaller than N/2 or N, L is calculated using Equation 5-7 or Equation 5-8 as described in Section 5.5.2.5. The statistical tests are performed using this larger number of data points. Figure 5.3 provides a concise overview of the procedure used to identify data needs for the assessment of small areas of elevated activity. If residual radioactivity is found in an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule (described in Section 4.3.3) can be used to ensure that the total dose or risk does not exceed the release criterion (see Section 8.5.2). If there is more than one elevated area, a separate term should be included for each. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally apply only to Class 1 survey units, since areas of elevated activity should not exist in Class 2 or Class 3 survey units.

When the detection limit of the scanning technique is very large relative to the $DCGL_{EMC}$, the number of measurements estimated to demonstrate compliance using the statistical tests may become unreasonably large. In this situation perform an evaluation of the survey objectives and considerations. These considerations may include the survey design and measurement methodology, exposure pathway modeling assumptions and parameter values used to determine the DCGLs, Historical Site Assessment conclusions concerning source terms and radionuclide distributions, and the results of scoping and characterization surveys. In most cases the result of this evaluation is not expected to justify an unreasonably large number of measurements.

Example 1:

A Class 1 land area survey unit of 1,500 m^2 is potentially contaminated with ^{60}Co. The $DCGL_W$ value for ^{60}Co is 110 Bq/kg (3 pCi/g) and the scan sensitivity for this radionuclide has been determined to be 150 Bq/kg (4 pCi/g). Calculations indicate the number of data points needed for statistical testing is 27. The distance between measurement locations for this number of data points and the given land area is 8 m. The area encompassed by a triangular sampling pattern of 8 m is approximately 55.4 m^2. From Table 5.6 an area factor of about 1.4 is determined by interpolation. The acceptable concentration in a 55.4 m^2 area is therefore 160 Bq/kg (1.4 × 110 Bq/kg). Since the scan sensitivity of the procedure to be used is less than the $DCGL_W$ times the area factor, no additional data points are needed to demonstrate compliance with the elevated measurement comparison criteria.

Example 2:

A Class 1 land area survey unit of 1500 m^2 is potentially contaminated with ^{60}Co. The DCGL for ^{60}Co is 110 Bq/kg (3 pCi/g). In contrast to Example 1, the scan sensitivity for this radionuclide has been determined to be 170 Bq/kg (4.6 pCi/g). Calculations indicate the number of data points needed for statistical testing is 15. The distance between measurement locations for this number of data points and land area is 10 m. The area encompassed by a triangular sampling pattern of 10 m is approximately 86.6 m^2. From Table 5.6 an area factor of about 1.3 is determined by interpolation. The acceptable concentration in a 86.6 m^2 area is therefore 140 Bq/kg (1.3 × 110 Bq/kg). Since the scan sensitivity of the procedure to be used is greater than the $DCGL_W$ times the area factor, the data points obtained for the statistical testing may not be sufficient to demonstrate compliance using the elevated measurement comparison. The area multiplier for elevated activity that would have to be achieved is 1.5 (170/110 Bq/kg). This is equivalent to an area of 30 m^2 (Table 5.6) which would be obtained with a spacing of about 6 m. A triangular pattern of 6 m spacing includes 50 data points, so 50 measurements should be performed in the survey unit.

5.5.2.5 Determining Survey Locations

A scale drawing of the survey unit is prepared, along with the overlying planar reference coordinate system or grid system. Any location within the survey area is thus identifiable by a unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit are then determined. Identifying and documenting a specific location for each measurement performed is an important part of a final status survey to ensure that measurements can be reproduced if necessary. The reference coordinate system described in Section 4.8.5 provides a method for relating measurements to a specific location within a survey unit.

If the same values for α, β, and Δ/σ are used in Equations 5-1 or Equation 5-2, the required number of measurements is independent of survey unit classification. This means that the same number of measurements could be performed in a Class 1, Class 2, or Class 3 survey unit. While this is a best case scenario, it points out the importance of identifying appropriate survey units (*e.g.*, size, classification) in defining the level of survey effort. The spacing of measurements is affected by the number of measurements, which is independent of classification. However, the spacing of measurements is also affected by survey unit area, the variability in the contaminant concentration, and the interface with the models used to develop the DCGLs which are dependent on classification.

Land Areas. Measurements and samples in Class 3 survey units and reference areas should be taken at random locations. These locations are determined by generating sets of random numbers (2 values, representing the X axis and Y axis distances). Random numbers can be generated by calculator or computer, or can be obtained from mathematical tables. Sufficient sets of numbers will be needed to identify the total number of survey locations established for the survey unit. Each set of random numbers is multiplied by the appropriate survey unit dimension to provide coordinates, relative to the origin of the survey unit reference grid pattern. Coordinates identified in this manner, which do not fall within the survey until area or which cannot be surveyed, due to site conditions, are replaced with other survey points determined in the same manner. Figure 5.4 is an example of a random sampling pattern. In this example, 8 data points were identified using the appropriate formula based on the statistical tests (*i.e.*, Equation 5-1 or Equation 5-2). The locations of these points were determined using the table of random numbers found in Appendix I, Table I.6.

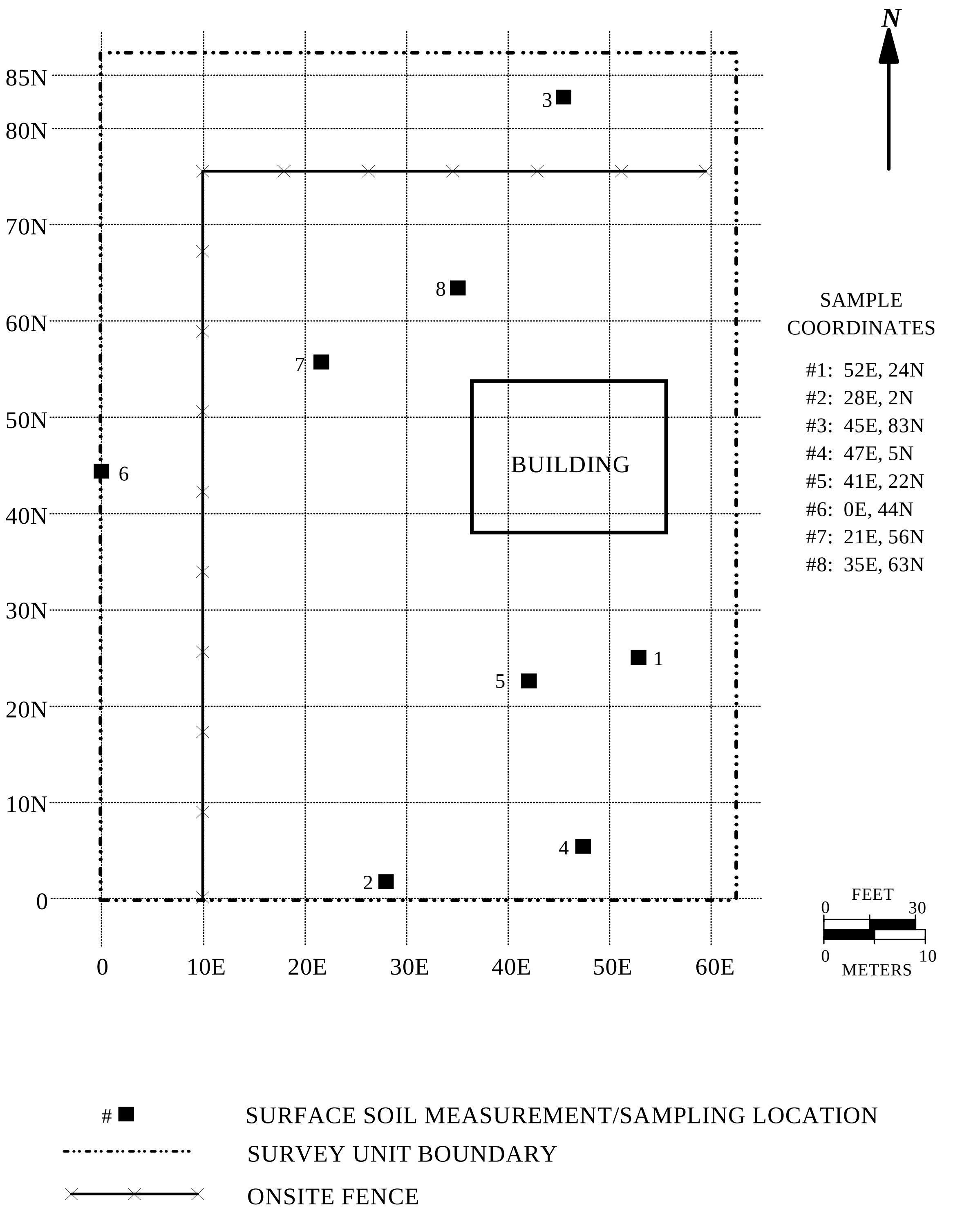

Figure 5.4 Example of a Random Measurement Pattern

Class 2 areas are surveyed on a random-start systematic pattern. The number of calculated survey locations, n, based on the statistical tests, is used to determine the spacing, L, of a systematic pattern by:

$$L = \sqrt{\frac{A}{0.866\ n}} \quad for\ a\ triangular\ grid \tag{5-7}$$

$$L = \sqrt{\frac{A}{n}} \quad for\ a\ square\ grid \tag{5-8}$$

where A is the area of the survey unit.

After L is determined, a random coordinate location is identified, as described previously, for a survey pattern starting location. Beginning at the random starting coordinate, a row of points is identified, parallel to the X axis, at intervals of L.

For a triangular grid, a second row of points is then developed, parallel to the first row, at a distance of 0.866 × L from the first row. Survey points along that second row are midway (on the X-axis) between the points on the first row. This process is repeated to identify a pattern of survey locations throughout the affected survey unit. If identified points fall outside the survey unit or at locations which cannot be surveyed, additional points are determined using the random process described above, until the desired total number of points is identified.

An example of such a survey pattern is shown in Figure 5.5. In this example, the statistical test calculations estimate 20 samples (Table 5.5, α=0.01, β=0.05, Δ/σ>3.0). The random-start coordinate was 27E, 53N. The grid spacing was calculated using Equation 5-7:

$$L = \sqrt{\frac{5{,}100\ m^2}{0.866\ \times\ 20}} = 17\ m.$$

Two points were identified on a row parallel to the X-axis, each 17 m from the starting point. The subsequent rows were positioned 0.866 × L, or 15 m, from the initial row. This random-start triangular sampling process resulted in 21 sampling locations, one of which was inaccessible because of the building location, which yields the desired number of data points.

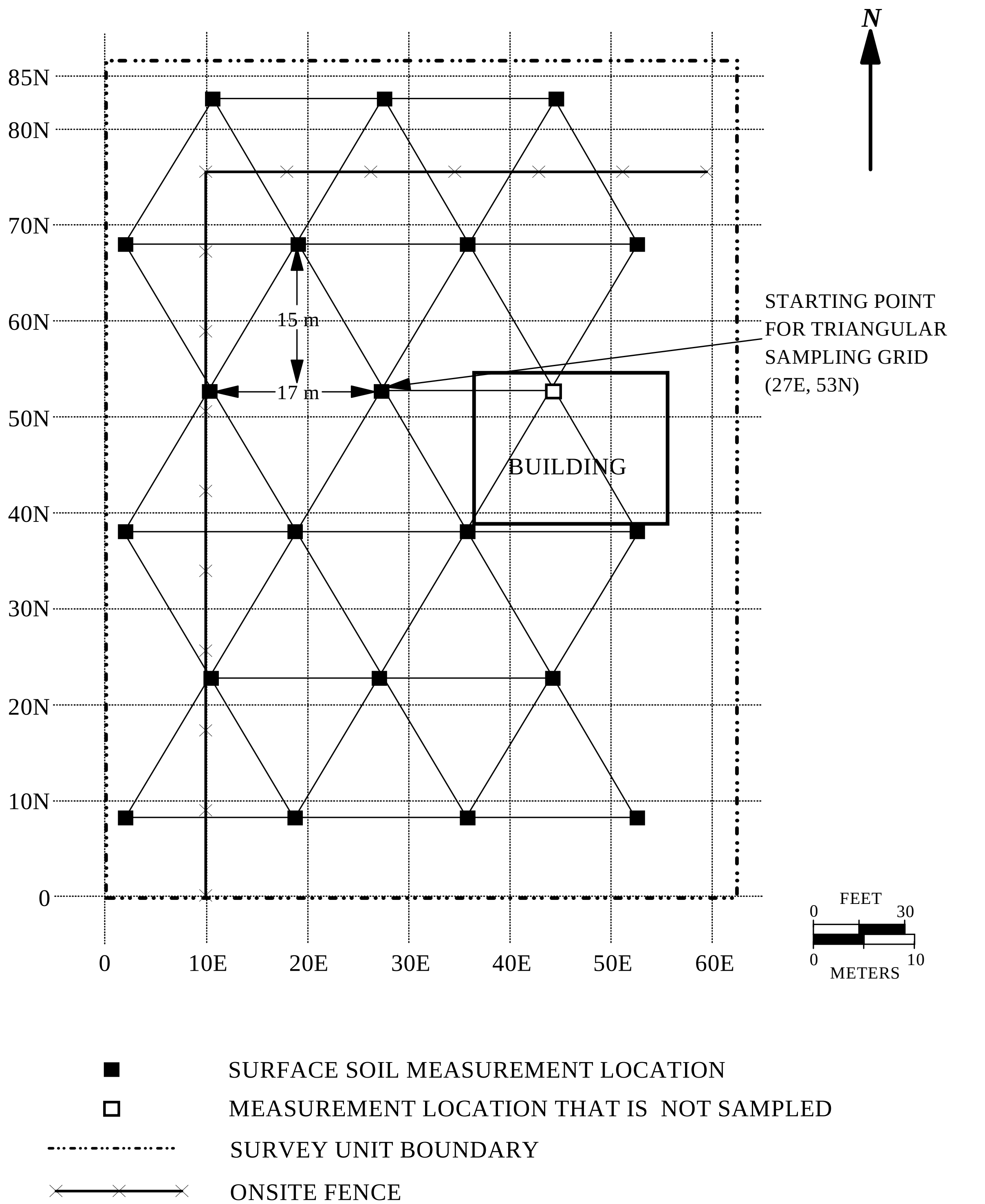

Figure 5.5 Example of a Random-Start Triangular Grid Measurement Pattern

For Class 1 areas a systematic pattern, having dimensions determined in Section 5.5.2.4, is installed on the survey unit. The starting point for this pattern is selected at random, as described above for Class 2 areas. The same process as described above for Class 2 areas applies to Class 1, only the estimated number of samples is different.

Structure Surfaces. All structure surfaces for a specific survey unit are included on a single reference grid system for purposes of identifying survey locations. The same methods as described above for land areas are then used to locate survey points for all classifications of areas.

In addition to the survey locations identified for statistical evaluations and elevated measurement comparisons, data will likely be obtained from judgment locations that are selected due to unusual appearance, location relative to contamination areas, high potential for residual activity, general supplemental information, *etc.* Data points selected based on professional judgment are not included with the data points from the random-start triangular grid for statistical evaluations; instead they are compared individually with the established DCGLs and conditions. Measurement locations selected based on professional judgment violate the assumption of unbiased measurements used to develop the statistical tests described in Chapter 8.

5.5.2.6 Determining Investigation Levels

An important aspect of the final status survey is the design and implementation of investigation levels. 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 (see Section 4.4) or it may indicate a failing instrument.

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 or risk meets the release criterion.[2] Depending on the results of the investigation actions, the survey unit may require reclassification, remediation, and/or resurvey. Table 5.8 illustrates an example of how investigation levels can be developed.

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[2] Rather than, or in addition to, taking further measurements the investigation may involve assessing the adequacy of the exposure pathway model used to obtain the DCGLs and area factors, and the consistency of the results obtained with the Historical Site Assessment and the scoping, characterization and remedial action support surveys.

Table 5.8 Example Final Status Survey Investigation Levels

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

When determining an investigation level using a statistical-based parameter (*e.g.*, standard deviation) one should consider survey objectives, underlying radionuclide distributions and an understanding of corresponding types (*e.g.*, normal, log normal, non-parametric), descriptors (*e.g.*, standard deviation, mean, median), population stratifications (*i.e.*, are there sub-groups present?), and other prior survey and historical information. For example, a level might be arbitrarily established at the mean + 3s, where s is the standard deviation of the survey unit, assuming a normal distribution. A higher value might be used if locating discrete sources of higher activity was a primary survey objective. By the time the final status survey is conducted, survey units should be defined. Estimates of the mean, variance, and standard deviation of the radionuclide activity levels within the survey units should also be available.

For a Class 1 survey unit, measurements above the $DCGL_W$ are not necessarily unexpected. However, a measurement above the $DCGL_W$ at one of the discrete measurement locations might be considered unusual if it were much higher than all of the other discrete measurements. Thus, any discrete measurement that is both above the $DCGL_W$ and above the statistical-based parameter for the measurements should be investigated further. Any measurement, either at a discrete location or from a scan, that is above the $DCGL_{EMC}$ should be flagged for further investigation.

In Class 2 or Class 3 areas, neither measurements above the $DCGL_W$ nor areas of elevated activity are expected. Any measurement at a discrete location exceeding the $DCGL_W$ in these areas should be flagged for further investigation. Because the survey design for Class 2 and Class 3 survey units is not driven by the EMC, the scanning MDC might exceed the $DCGL_W$. In this case, any indication of residual radioactivity during the scan would warrant further investigation.

The basis for using the $DCGL_{EMC}$ rather than the more conservative criteria for Class 2 and Class 3 areas should be justified in survey planning documents. For example, where there is high uncertainty in the reported scanning MDC, a more conservative criteria would be warranted.

Similarly, DQA for scanning may warrant a more conservative flag, as would greater uncertainty from Historical Site Assessment or other surveys on the size of potential areas of elevated activity. In some cases, it may even be necessary to agree in advance with the regulatory agency responsible for the site on which site-specific investigation will be used if other than those presented in Table 5.8.

Because there is a low expectation for residual radioactivity in a Class 3 area, it may be prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The level selected in these situations depends on the site, the radionuclides of concern, and the measurement and scanning methods chosen. This level should be set using the DQO Process during the survey design phase of the Data Life Cycle. In some cases, the user may also wish to follow this procedure for Class 2 and even Class 1 survey units.

5.5.3 Developing an Integrated Survey Strategy

The final step in survey design is to integrate the survey techniques (Chapter 6) with the number of measurements and measurement spacing determined earlier in this chapter. This integration along with the guidance provided in other portions of this manual produce an overall strategy for performing the survey. Table 5.9 provides a summary of the recommended survey coverage for structures and land areas. This survey coverage for different areas is the subject of this section.

Random measurement patterns are used for Class 3 survey units to ensure that the measurements are independent and support the assumptions of the statistical tests. Systematic grids are used for Class 2 survey units because there is an increased probability of small areas of elevated activity. The use of a systematic grid allows the decision maker to draw conclusions about the size of the potential areas of elevated activity based on the area between measurement locations. The random starting point of the grid provides an unbiased method for obtaining measurement locations to be used in the statistical tests. Class 1 survey units have the highest potential for small areas of elevated activity, so the areas between measurement locations are adjusted to ensure that these areas can be detected by scanning techniques.

The objectives of the scanning surveys are different. Scanning is used to identify locations within the survey unit that exceed the investigation level. These locations are marked and receive additional investigations to determine the concentration, area, and extent of the contamination.

For Class 1 areas, scanning surveys are designed to detect small areas of elevated activity that are not detected by the measurements using the systematic pattern. For this reason the measurement locations, and the number of measurements, may need to be adjusted based on the sensitivity of the scanning technique (Section 5.5.2.4). This is also the reason for recommending 100%

Table 5.9 Recommended Survey Coverage for Structures and Land Areas

Area Classification	Structures		Land Areas	
	Surface Scans	Surface Activity Measurements	Surface Scans	Soil Samples
Class 1	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional measurements may be necessary for small areas of elevated activity (Section 5.5.2.4)	100%	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3); additional measurements may be necessary for small areas of elevated activity (Section 5.5.2.4)
Class 2	10 to 100% (10 to 50% for upper walls and ceilings) Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	10 to 100% Systematic and Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)
Class 3	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)	Judgmental	Number of data points from statistical tests (Sections 5.5.2.2 and 5.5.2.3)

coverage for the scanning survey. 100% coverage means that the entire surface area of the survey unit is covered by the field of view of the scanning instrument. If the field of view is two meters wide, the survey instrument can be moved along parallel paths two meters apart to provide 100% coverage. If the field of view of the detector is 5 cm, the parallel paths should be 5 cm apart.

Scanning surveys in Class 2 areas are also primarily performed to find areas of elevated activity not detected by the measurements using the systematic pattern. However, the measurement locations are not adjusted based on sensitivity of the scanning technique and scanning is performed in portions of the survey unit. The level of scanning effort should be proportional to the potential for finding areas of elevated activity based on the conceptual site model developed and refined from Section 3.6.4. A larger portion of the survey unit would be scanned in Class 2 survey units that have residual radioactivity close to the release criterion, but for survey units that are closer to background scanning, a smaller portion of the survey unit may be appropriate. Class 2 survey units have a lower probability for areas of elevated activity than Class 1 survey units, but some portions of the survey unit may have a higher potential than others. Judgmental scanning surveys focus on the portions of the survey unit with the highest probability for areas of elevated activity. If the entire survey unit has an equal probability for areas of elevated activity, or the judgmental scans don't cover at least 10% of the area, systematic scans along transects of the survey unit or scanning surveys of randomly selected grid blocks are performed.

Class 3 areas have the lowest potential for areas of elevated activity. For this reason, scanning surveys are recommended for areas with the highest potential for contamination (*e.g.*, corners, ditches, drains) based on professional judgment. Such recommendations are typically provided by a health physics professional with radiation survey experience. This provides a qualitative level of confidence that no areas of elevated activity were missed by the random measurements or that there were no errors made in the classification of the area.

The sensitivity for scanning techniques used in Class 2 and Class 3 areas is not tied to the area between measurement locations, as they are in a Class 1 area (see Section 5.5.2.4). The scanning techniques selected should represent the best reasonable effort based on the survey objectives. Structure surfaces are generally scanned for alpha, beta, and gamma emitting radionuclides. Scanning for alpha emitters or low-energy (<100 keV) beta emitters for land area survey units is generally not considered effective because of problems with attenuation and media interferences. If one can reasonably expect to find any residual radioactivity, it is prudent to perform a judgmental scanning survey.

If the equipment and methodology used for scanning is capable of providing data of the same quality as direct measurements (*e.g.*, detection limit, location of measurements, ability to record and document results), then scanning may be used in place of direct measurements. Results should be documented for at least the number of locations estimated for the statistical tests. The same logic can be applied for using direct measurements instead of sampling. In addition, some direct measurement systems may be able to provide scanning data.

As previously discussed, investigation levels are determined and used to indicate when additional investigations may be necessary or when a measurement process begins to get out of control. The results of all investigations should be documented in the final status survey report, including the results of scan surveys that may have potentially identified areas of elevated direct radiation.

5.5.3.1 Structure Surveys

Class 1 Areas. Surface scans are performed over 100% of structure surfaces for radiations which might be emitted from the potential radionuclide contaminants. Locations of direct radiation, distinguishable above background radiation, are identified and evaluated. Results of initial and followup direct measurements and sampling at these locations are recorded and documented in the final status survey report. Measurements of total and removable contamination are performed at locations identified by scans and at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are present, *in situ* gamma spectroscopy may be used to identify the presence of specific radionuclides or to demonstrate compliance with the release criterion.

Direct measurement or sample investigation levels for Class 1 areas should establish a course of action for individual measurements that approach or exceed the $DCGL_W$. Because measurements above the $DCGL_W$ are not necessarily unexpected in a Class 1 survey unit, additional investigation levels may be established to identify discrete measurements that are much higher than the other measurements. Any discrete measurement that is both above the $DCGL_W$ and exceeds three times the standard deviation (s) of the mean should be investigated further (Section 5.5.2.6). Any measurement (direct measurement, sample, or scan) that exceeds the $DCGL_{EMC}$ should be flagged for further investigation. The results of the investigation and any additional remediation that was performed should be included in the final status survey report. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 2 Areas. Surface scans are performed over 10 to 100% of structure surfaces. Generally, upper wall surfaces and ceilings should receive surface scans over 10 to 50% of these areas. Locations of scanning survey results above the investigation level are identified and investigated. If small areas of elevated activity are confirmed by this investigation, all or part of the survey unit should be reclassified as Class 1 and the survey strategy for that survey unit redesigned accordingly.

Investigation levels for Class 2 areas should establish a course of action for individual measurements that exceed or approach the $DCGL_w$. The results of the investigation of the positive measurements and basis for reclassifying all or part of the survey unit as Class 1 should be included in the final status survey report. Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to identify the presence of specific radionuclides or to demonstrate compliance with the release criterion. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 3 Areas. Scans of Class 3 area surfaces should be performed for all radiations which might be emitted from the potential radionuclide contaminants. MARSSIM recommends that the surface area be scanned. Locations of scanning survey results above the investigation level are identified and evaluated. Measurements of total and removable contamination are performed at the locations identified by the scans and at the randomly selected locations that are chosen in accordance with Section 5.5.2.5. Identification of contamination suggests that the area may be incorrectly classified. If so, a re-evaluation of the Class 3 area classification should be performed and, if appropriate, all or part of the survey unit should be resurveyed as a Class 1 or Class 2 area. In some cases the investigation may include measurements by *in situ* gamma spectroscopy at a few locations in each structure in a Class 3 area. A gamma spectroscopy system might even be an appropriate substitution for surface scans.

Because there is a low expectation for residual radioactivity in a Class 3 area, it may be prudent to investigate any measurement exceeding even a fraction of the $DCGL_W$. The investigation level selected will depend on the site, the radionuclides of concern, and the measurement and scanning methods chosen. This level should be determined using the DQO Process during survey planning. In some cases, the user may wish to follow this procedure for Class 2 survey units.

The results of the investigation of the measurements that exceed the investigation level and the basis for reclassifying all or part of the survey unit as Class 1 or Class 2 should be included in the final status survey report. The data are tested relative to the preestablished criteria. If additional data are needed, they should be collected and evaluated as part of the entire data set.

5.5.3.2 Land Area Surveys

Class 1 Areas. As with structure surfaces, 100% scanning coverage of Class 1 land areas is recommended. Locations of scanning survey results above the investigation level are identified and evaluated. Results of initial and followup direct measurements and sampling at these locations are recorded. Soil sampling is performed at locations identified by scans and at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to confirm the absence of specific radionuclides or to demonstrate compliance.

Direct measurement or sample investigation levels for Class 1 areas should establish a course of action for individual measurements that approach or exceed the $DCGL_W$. Because measurements above the $DCGL_W$ are not necessarily unexpected in a Class 1 survey unit, additional investigation levels may be established to identify discrete measurements that are much higher than the other measurements. Any discrete measurement that is both above the $DCGL_W$ and exceeds three standard deviations above the mean should be investigated further (Section 5.5.2.6). Any measurement (direct measurement, sample, or scan) that exceeds the $DCGL_{EMC}$ should be flagged for further investigation. The results of the investigation and any additional remediation that was performed should be included in the final status survey report. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Class 2 Areas. Surface scans are performed over 10 to 100% of open land surfaces. Locations of direct radiation above the scanning survey investigation level are identified and evaluated. If small areas of elevated activity are identified, the survey unit should be reclassified as “Class 1” and the survey strategy for that survey unit redesigned accordingly.

If small areas of elevated activity above DCGL values are not identified, direct measurement or soil sampling is performed at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are contaminants, *in situ* gamma spectroscopy may be used to confirm the absence of specific radionuclides or to demonstrate compliance. Data are reviewed as described in Section 8.2.2, additional data are collected as necessary, and the final complete data set evaluated as described in Section 8.3 or Section 8.4.

Investigation levels for Class 2 areas should establish levels for investigation of individual measurements close to but below the $DCGL_w$. The results of the investigation of the positive measurements and basis for reclassifying all or part of the survey unit as Class 1 should be included in the final status survey report.

Class 3 Areas. Class 3 areas may be uniformly scanned for radiations from the radionuclides of interest, or the scanning may be performed in areas with the greatest potential for residual contamination based on professional judgment and the objectives of the survey. In some cases a combination of these approaches may be the most appropriate. Locations exceeding the scanning survey investigation level are evaluated, and, if the presence of contamination not occurring in background is identified, reevaluation of the classification of contamination potential should be performed.

Investigation levels for Class 3 areas should be established to identify areas of elevated activity that may indicate the presence of residual radioactivity. Scanning survey locations that exceed the investigation level should be flagged for further investigation. The results of the investigation and basis for reclassifying all or part of the survey unit as Class 1 or Class 2 should be included in the final status survey report. The data are tested relative to the preestablished criteria. If additional data are needed, they should be collected and evaluated as part of the entire data set. Soil sampling is performed at randomly selected locations (Section 5.5.2.5); if the contaminant can be measured at DCGL levels by *in situ* techniques, this method may be used to replace or supplement the sampling and laboratory analysis approach. For gamma emitting radionuclides, the above data should be supplemented by several exposure rate and/or *in situ* gamma spectrometry measurements. Survey results are tested for compliance with DCGLs and additional data are collected and tested, as necessary.

5.5.3.3 Other Measurement/Sampling Locations

In addition to the building and land surface areas described above, there are numerous other locations where measurements and/or sampling may be necessary. Examples include items of equipment and furnishings, building fixtures, drains, ducts, and piping. Many of these items or locations have both internal and external surfaces with potential residual radioactivity. Subsurface measurements and/or sampling may also be necessary. Guidance on conducting or evaluating these types of surveys is outside the scope of MARSSIM.

Special situations may be evaluated by judgment sampling and measurements. Data from such surveys should be compared directly with DCGLs developed for the specific situation. Areas of elevated direct radiation identified by surface scans are typically followed by direct measurements or samples. These direct measurements and samples are not included in the nonparametric tests described in this manual, but rather, should be compared directly with DCGLs developed for the specific situation.

Quality control measurements are recommended for all surveys, as described in Section 4.9, Section 6.2, and Section 7.2. Also, some regulatory programs require removable activity measurements (*e.g.*, NRC Regulatory Guide 1.86; NRC 1974). These additional measurements should be considered during survey planning.

5.5.4 Evaluating Survey Results

After data are converted to DCGL units, the process of comparing the results to the DCGLs, conditions, and objectives begins. Individual measurements and sample concentrations are first compared to DCGL levels for evidence of small areas of elevated activity and not to determine if reclassification is necessary. Additional data or additional remediation and resurvey may be necessary. Data are then evaluated using statistical methods to determine if they exceed the release criterion. If the release criterion has been exceeded or if results indicate the need for additional data points, appropriate further actions will be determined by the site management and the responsible regulatory agency. The scope of further actions should be agreed upon and developed as part of the DQO Process before the survey begins (Appendix D). Finally, the results of the survey are compared with the data quality objectives established during the planning phase of the project. Note that Data Quality Objectives may require a report of the semi-quantitative evaluation of removable contamination resulting from the analysis of smears. These results may be used to satisfy regulatory requirements or to evaluate the effectiveness of ALARA procedures. Chapter 8 describes detailed procedures for evaluating survey results.

5.5.5 Documentation

Documentation of the final status survey should provide a complete and unambiguous record of the radiological status of the survey unit, relative to the established DCGLs. In addition, sufficient data and information should be provided to enable an independent re-creation and evaluation at some future time. Much of the information in the final status report will be available from other decommissioning documents; however, to the extent practicable, this report should be a stand-alone document with minimum information incorporated by reference. The report should be independently reviewed (see Section 3.9) and should be approved by a designated person (or persons) who is capable of evaluating all aspects of the report prior to release, publication, or distribution.

EXAMPLE FINAL STATUS SURVEY CHECKLIST

SURVEY PREPARATIONS

_______ Ensure that residual radioactivity limits have been determined for the radionuclides present at the site, typically performed during earlier surveys associated with the decommissioning process.

_______ Identify the radionuclides of concern. Determine whether the radionuclides of concern exist in background. This will determine whether one-sample or two-sample tests are performed to demonstrate compliance. Two-sample tests are performed when radionuclides are present in the natural background; one-sample tests may be performed if the radionuclide is not present in background.

_______ Segregate the site into Class 1, Class 2, and Class 3 areas, based on contamination potential.

_______ Identify survey units.

_______ Select representative reference (background) areas for both indoor and outdoor survey areas. Reference areas are selected from non-impacted areas and

 _______ are free of contamination from site operations,

 _______ exhibit similar physical, chemical, and biological characteristics of the survey area,

 _______ have similar construction, but have no history of radioactive operations.

_______ Select survey instrumentation and survey techniques. Determine MDCs (select instrumentation based on the radionuclides present) and match between instrumentation and DCGLs—the selected instruments should be capable of detecting the contamination at 10-50% of the DCGLs.

_______ Prepare area if necessary—clear and provide access to areas to be surveyed.

_______ Establish reference coordinate systems (as appropriate).

SURVEY DESIGN

_______ Enumerate DQOs: State objective of survey, state the null and alternative hypotheses, specify the acceptable decision error rates (Type I (α) and Type II (β)).

_______ Specify sample collection and analysis procedures.

_______ Determine numbers of data points for statistical tests, depending on whether or not the radionuclide is present in background.

- _______ Specify the number of samples/measurements to be obtained based on the statistical tests.

- _______ Evaluate the power of the statistical tests to determine that the number of samples is appropriate.

- _______ Ensure that the sample size is sufficient for detecting areas of elevated activity.

- _______ Add additional samples/measurements for QC and to allow for possible loss.

_______ Specify sampling locations.

_______ Provide information on survey instrumentation and techniques. The decision to use portable survey instrumentation or *in situ* techniques, and/or a combination of both, depends on whether or not the radiation levels are elevated compared to natural background, and whether or not the residual radioactivity is present at some fraction of background levels.

_______ Specify methods of data reduction and comparison of survey units to reference areas.

_______ Provide quality control procedures and QAPP for ensuring validity of survey data:

- _______ properly calibrated instrumentation,

- _______ necessary replicate, reference and blank measurements,

- _______ comparison of field measurement results to laboratory sample analyses.

_______ Document the survey plan (*e.g.*, QAPP, SOPs, *etc.*)

CONDUCTING SURVEYS

________ Perform reference (background) area measurements and sampling.

Conduct survey activities:

- ________ Perform surface scans of the Class 1, Class 2, and Class 3 areas.
- ________ Conduct surface activity measurements and sampling at previously selected sampling locations.
- ________ Conduct additional direct measurements and sampling at locations based on professional judgment.

________ Perform and document any necessary investigation activities, including survey unit reclassification, remediation, and resurvey.

________ Document measurement and sample locations; provide information on measurement system MDC and measurement errors.

________ Document any observations, abnormalities, and deviations from the QAPP or SOPs

EVALUATING SURVEY RESULTS

________ Review DQOs.

________ Analyze samples.

________ Perform data reduction on survey results.

________ Verify assumptions of statistical tests.

________ Compare survey results with regulatory DCGLs:

- ________ Conduct elevated measurement comparison.
- ________ Determine area-weighted average, if appropriate.
- ________ Conduct WRS or Sign tests.

________ Prepare final status survey report.

________ Obtain an independent review of the report.