5   IMPLEMENT THE SURVEY DESIGN

5.1   Introduction

This chapter discusses the implementation phase of the data life cycle and focuses on controlling measurement uncertainty and associated MQOs. The information in this chapter describes approaches for safely implementing the final disposition survey design developed in Chapter 4, methods for controlling uncertainty, and techniques to determine whether the measurement results achieve the survey objectives. Figure 5.1 illustrates the implementation phase of the data life cycle.

Similar to MARSSIM, MARSAME excludes specific recommendations for implementing disposition surveys. Instead, MARSAME provides recommendations and information to assist the user in selecting measurement techniques for implementing the survey design. This approach encourages consideration of innovative measurement techniques and emphasizes the flexibility of the information in MARSAME.

Implementation begins with health and safety considerations for the disposition survey (Section 5.2). Section 5.3 provides information on handling M&E, while Section 5.4 discusses segregating M&E based on physical and radiological attributes. Section 5.5 continues the discussion of measurement quality objectives (MQOs) from Chapters 3 and 4. Measurement uncertainty (Section 5.6), detectability (Section 5.7), and quantifiability (Section 5.8), are three MQOs that are described in greater detail. Combining an instrument with a measurement technique to ensure the MQOs are achieved is discussed in Section 5.9. Section 5.10 provides information on quality control (QC), and information on data reporting is provided in Section 5.11.

5.2   Ensure Protection of Health and Safety

Health and safety is emphasized as an issue potentially affecting the implementation of MARSAME disposition surveys. The focus of minimizing hazards is shifted away from environmental hazards (e.g., confined spaces, unstable surfaces, heat and cold stress) and towards scenarios where health and safety issues may affect how a disposition survey is designed and performed. Work areas and procedures that present potential safety hazards must be identified and evaluated to warn personnel of potential hazards. Personnel must be trained with regard to potential physical and chemical safety hazards (e.g., inhalation, adsorption, ingestion, injection/puncturing) and the potential for injury (e.g., slips, trips, falls, burns).

A job safety analysis (JSA) should be performed prior to implementing a disposition survey. The JSA offers an organized approach to the task of locating problem areas for material handling safety (OSHA 2002). The JSA should be used to identify hazards and provide inputs for drafting a health and safety plan (HASP). The HASP will address the potential hazards associated with M&E handling and movement and should be prepared concurrently with the survey design. The HASP identifies methods to minimize the threats posed by the potential hazards. The information in the HASP may influence the selection of a measurement technique and disposition survey procedures. Radiation work permits (RWPs) may be established to control access to
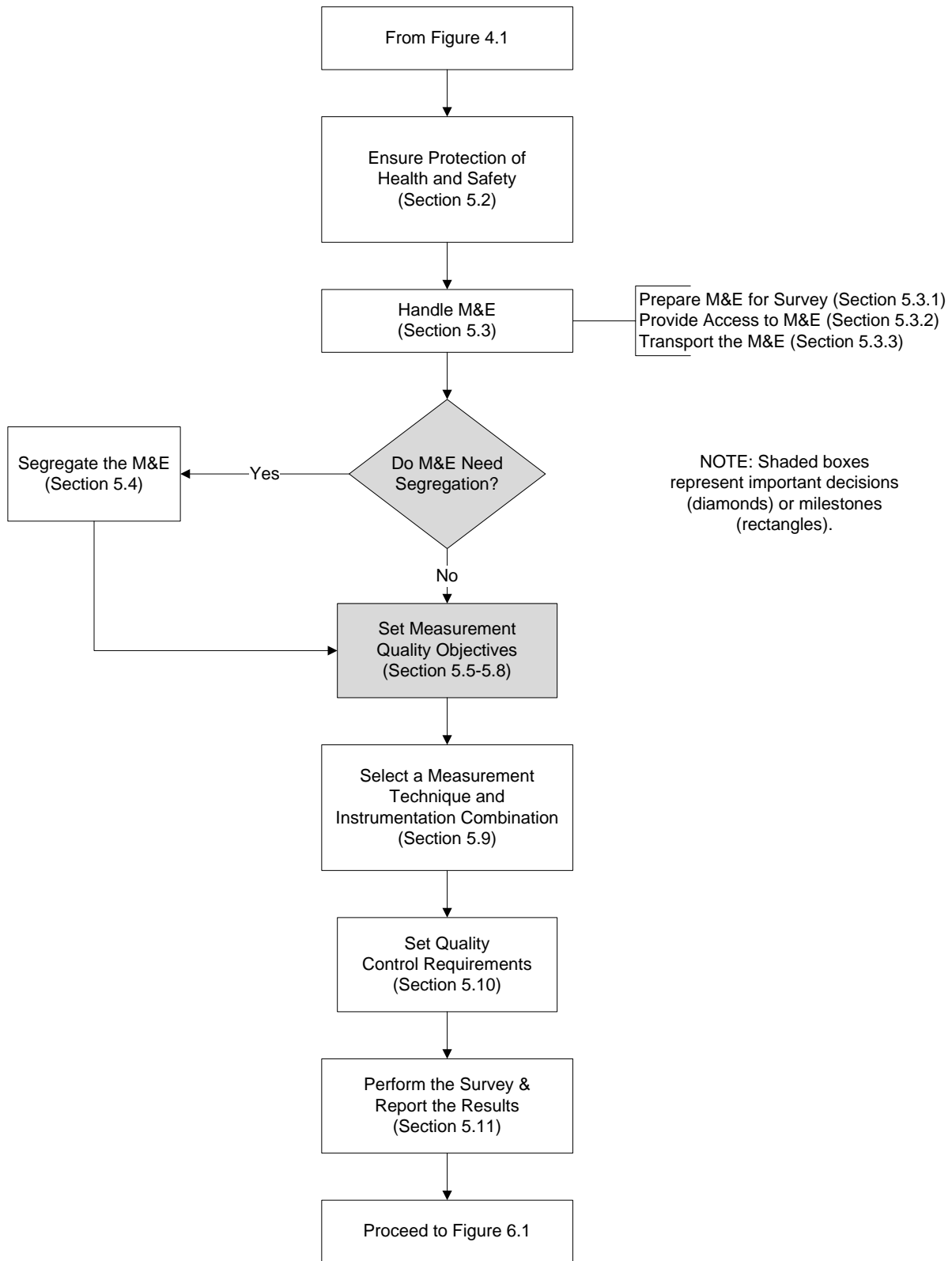
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                    ┌─────────────────────┐
                    │   From Figure 4.1   │
                    └─────────────────────┘
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                    │ Ensure Protection of│
                    │  Health and Safety  │
                    │    (Section 5.2)    │
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                    ┌─────────────────────┐     ┌──────────────────────────────────────────┐
                    │    Handle M&E       │     │ Prepare M&E for Survey (Section 5.3.1)   │
                    │   (Section 5.3)     ├─────┤ Provide Access to M&E (Section 5.3.2)    │
                    └─────────────────────┘     │ Transport the M&E (Section 5.3.3)        │
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  ┌──────────────────┐      ╱◇╲                      NOTE: Shaded boxes
  │ Segregate the M&E│ Yes ◇   ◇  Do M&E Need       represent important decisions
  │  (Section 5.4)   │◄────◇     ◇ Segregation?      (diamonds) or milestones
  └──────────────────┘      ╲◇╱                           (rectangles).
           │                  │
           │                  │ No
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           │       ┌─────────────────────┐
           │       │  Set Measurement    │
           └──────►│ Quality Objectives  │
                   │  (Section 5.5-5.8)  │
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                    ┌─────────────────────┐
                    │ Select a Measurement│
                    │    Technique and    │
                    │Instrumentation Combi-│
                    │nation (Section 5.9) │
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                               │
                               ▼
                    ┌─────────────────────┐
                    │   Set Quality       │
                    │Control Requirements │
                    │   (Section 5.10)    │
                    └─────────────────────┘
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                    │ Perform the Survey &│
                    │  Report the Results │
                    │   (Section 5.11)    │
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                    │ Proceed to Figure 6.1│
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Figure 5.1 Implementation of Disposition Surveys

radiologically controlled areas. RWPs contain requirements from the JSA, such as dosimetry and personal protective equipment (PPE), as well as survey maps illustrating predicted dose rates and related radiological concerns (e.g., removable or airborne radioactivity). Hazard work permits (HWPs) may be used in place of RWPs at sites with primarily physical or chemical hazards. The mineral processing facility concrete rubble example presented in Chapter 8 (see Table 8.9) provides an example of a JSA.

The JSA systematically carries out the basic strategy of accident prevention through the recognition, evaluation, and control of hazards associated with a given job as well as the determination of the safest, most efficient method of performing that job. This process creates a framework for deciding among engineering controls, administrative controls, and PPE for the purpose of controlling or correcting unsafe conditions (Hatch 1978). Examples of these controls include—

- Engineering controls, which are physical changes in processes or machinery (e.g., installing guards to restrict access to moving parts during operation), storage configuration (e.g., using shelves in place of piles or stacks);
- Administrative controls, which are changes in work practices and organization (e.g., restricted areas where it is not safe to eat, drink, smoke, etc.) including the placement of signs to warn personnel of hazards; and
- Personal protective equipment, which are clothing or devices worn by employees to protect against hazards (e.g., gloves, respirator, full-body suits).

Correction measures may incorporate principles of all of the controls listed above. The preferred method of control is through engineering controls, followed by administrative controls, and then personal protective equipment.

Proper handling procedures for hazardous M&E are documented in site-specific health and safety plans. Compliance with all control requirements is mandatory to maintain a safe working environment. Personnel must regard control requirements as a framework to facilitate health and safety, while still taking responsibility for their own well being. Being wary of safety hazards remains an individual responsibility and personnel must be aware of their surroundings at all times in work areas.

5.3   Consider Issues for Handling M&E

Materials and equipment handling is addressed in this document as a process control issue. M&E handling requirements are determined by the final integrated survey design (Section 4.4) and the combination of instrumentation and measurement technique used to perform the survey (Section 5.9). M&E may also require handling to more closely match the assumptions used to develop instrument calibrations used to determine measurement uncertainty (Section 5.6), measurement detectability (see Section 5.7), and measurement quantifiability (Section 5.8). Typically, M&E will be handled to—

- Prepare a measurement grid or arrange M&E to perform a survey,
- Provide access for performing measurements, and

- Transport the M&E to a different location.

5.3.1   Prepare M&E for Survey

Depending on the survey design, or assumptions used to develop the survey design, it may be necessary to prepare the M&E for survey. The amount of preparation required is determined by the DQOs and MQOs, and ranges from identifying measurement locations to adjusting the physical characteristics of the M&E (e.g., disassembly, segregation, physical arrangement).

The performance of a MARSSIM-type survey requires determining the location where the measurements are to be performed. The DQOs will determine the level of effort required to identify, mark, and record measurement locations.

Identifying measurement locations can be problematic because MARSSIM-type surveys recommend samples to be located either randomly (Class 3) or on a systematic grid (Class 1 and Class 2). Class 2 and Class 3 scan-only and in situ surveys do not require 100% of the M&E to be measured, so a method of identifying which portions will be measured is required.

Bulk materials or M&E consisting of many small, regularly shaped objects can be spread out in a uniform layer, and a two-dimensional grid can be superimposed on the surface to identify measurement locations. However, it is virtually impossible to identify random or systematic locations on M&E that consist of relatively few, large, irregularly shaped objects. The reason is that it is virtually impossible to establish a reference grid for these M&E. It is important to note that the objective for random locations is to allow every portion of the survey unit the same opportunity to be measured. Alternatively, the objective of systematic locations is to distribute the measurement locations equally. It is only necessary to establish a reference grid to sufficiently identify the measurement locations to meet the survey objectives.

One way to approximate a reference grid for locating measurements is to establish a grid in the area where the survey will be performed. The M&E to be surveyed are laid out in a single layer within the grid. The grid can then be used to identify measurement locations. Another option for locating measurements involves superimposing a grid on top of the M&E. A net could be laid over the M&E to be surveyed, ropes could be laid over the M&E to form a grid, or lights on a grid could be directed onto the M&E to approximate a grid and identify measurement locations. If measurement locations cannot be identified with a grid, there may be no alternative but to perform biased measurements. Measurements would be performed preferentially in locations more likely to contain radionuclides or radioactivity, based on the results of the initial assessment (IA) (Section 2.5). This process involves professional judgment and may result in overestimating the average radionuclide concentration or level of radioactivity. In all cases, it is important to document the criteria used for identifying measurement locations and to document that these criteria were followed.

Marking measurement locations, once they have been identified, should be done in a way that will not interfere with the measurement. For example, using paint to mark the location of an alpha measurement could end up masking the presence of alpha activity. Using arrows, marking

borders, or using an alternate method for marking locations (e.g., encircling with chalk) should be considered for these types of situations.

Recording measurement locations may be required as part of the survey objectives if the measurements may need to be repeated. For example, a large piece of equipment is surveyed prior to use on a decommissioning or cleanup project. If the exact same locations will be surveyed at the completion of the project, it will be necessary to record the measurement locations. Permanent or semi-permanent markings can be used to identify the measurement locations. Video or photographic records of measurement locations can also be used to return to a specific measurement location.

5.3.2 Provide Access

Large pieces of equipment may require special handling considerations. Large, mobile equipment (e.g., front loader, bulldozer, or crane) typically requires a specially trained operator. The operator may need to be available during the disposition survey to provide access to all areas requiring survey (e.g., move the equipment to provide access to the bottom of tires or treads). Other large items may require special equipment (e.g., a crane or lift) to provide access to all areas requiring survey. Special health and safety issues (Section 5.2) may be required to ensure protection of survey personnel from physical hazards (e.g., personnel or items falling from heights, or large items dropping on personnel or equipment). It may be necessary to partially or totally disassemble large pieces of equipment to provide access and ensure measurability.

Piles of M&E may involve special handling precautions. Piles of dispersible M&E (e.g., excavated soil or concrete rubble) may need to be rearranged to match the assumptions used to develop the instrument efficiency. For example, a conical pile of excavated soil may need to be flattened to a uniform thickness to ensure measurability. If the M&E consists of or contains a significant amount of dust, precautions against generating an airborne radiation hazard may be necessary. Because many dust control systems use liquids to prevent the dust from becoming airborne, it may be necessary to account for dust control impacts on measurability of the M&E. For example, adding water to control dust will make it more difficult to measure alpha radioactivity. Piles of scrap may also present other health and safety concerns along with issues related to measurability. Sharp edges, pinch points, and unstable piles are examples of handling problems that may need to be addressed.

Small pieces of M&E may be surveyed individually or combined into groups for survey. Care should be taken when combining items to prevent mixing impacted and non-impacted items, or mixing items with different physical or radiological attributes (see Section 2.2 and Section 5.4). The moving of materials at a given site may require labeling as a quality control measure to ensure M&E movement is tracked and documented. Labeling will help avoid the commingling of impacted and non-impacted materials, and facilitate the staging and storage of impacted and non-impacted M&E in appropriate areas.

5.3.3   Transport the M&E

Identification of impacted and non-impacted areas within a facility will assist in selecting areas for storing, staging, and surveying impacted M&E. In general, impacted M&E should be stored, staged, and surveyed in impacted areas. Care should be taken when moving or handling impacted M&E to prevent the spread of radionuclides to non-impacted areas. M&E in areas with airborne radioactivity issues should be moved to protect the personnel conducting surveys and reduce the possibility of contaminating survey instruments.

Disposition surveys can be performed with the M&E in place, or the M&E can be moved to another location. For example, work areas with high levels of radioactivity may make it difficult or resource intensive to meet the MQOs for measurement detectability (Sections 5.7 and 7.5) or quantifiability (Sections 5.8 and 7.6). Moving the M&E to areas with lower levels of radioactivity will help reduce radiation exposure for personnel conducting surveys and facilitate meeting the survey objectives.

5.4   Segregate the M&E

The purpose of segregation is to separate M&E based on the estimated total measurement uncertainty, ease of handling, and disposition options. Segregation is based on the physical and radiological attributes determined during the IA (Chapter 2), not only on radionuclide concentrations or radiation levels (i.e., classification).

In general, segregation based on measurement uncertainty should consider the physical and radiological attributes that affect efficiency (i.e., geometry and fluence rate). M&E with simple geometries, such as drums (cylinder) and flat surfaces (plane), should be separated from M&E with complex geometries. Fluence rate is affected by location of the radioactivity (i.e., surficial or volumetric) as well as surface effects (e.g., rough or smooth), density of the M&E, and type and energy of radiation. High fluence rates are associated with surface radioactivity with high energy on flat smooth surfaces made from materials with high atomic number (due to increased backscatter). Volumetric activity, shielded surfaces, alpha or low energy or beta radiations, irregular shapes, or rough surfaces can cause lower fluence rates. All of these factors should be considered when segregating M&E.

Segregation of M&E should be performed conservatively. This means that the user should separate M&E when they are not obviously similar. It is always possible to combine M&E but it is not always practical or possible, to separate M&E once they have been combined. For example, consider a facility where all the waste materials (e.g., paper, wood, metal, broken equipment) are combined into a single "trash pile." When the planning team considers different measurement methods and disposition options, they identify an innovative measurement method that only applies to non-ferrous scrap metal. This would allow for recycling of these materials with significant cost recovery as opposed to disposal. If the cost of re-segregating the M&E is not offset by the value of recycling these materials, it may not be practical to segregate the non-ferrous metals.

It is important to note that segregation does not require physical separation. Consider a generic large box geometry, such as an empty shipping container or railroad car. The large, flat sides could be considered separate survey units from the corners. Therefore, separate surveys would be designed for the corners and the sides even though the entire railroad car would remain intact throughout implementation of the disposition survey. Alternatively (or additionally), obvious flaws, corrosion areas, or damaged areas could be segregated from the areas in good condition. Even if the entire object is eventually surveyed using a single in situ measurement (e.g., in situ gamma spectroscopy) it is important to segregate the M&E (at least conceptually) so an adequate evaluation of alternate measurement methods can be performed (Section 5.9).

Handling of M&E during disposition surveys should also be considered during segregation (Section 5.3). Physical characteristics of the M&E should be considered when segregating based on handling requirements. Small, light items are easier to move and gain access to all surfaces than large, massive items. M&E that will require preparation (e.g., disassembly, crushing, chopping) prior to survey should be segregated from M&E that can be surveyed in their present form. Disposition options should also be considered when segregating M&E. M&E that can be reused or recycled should be segregated from M&E that is being considered for disposal. Selection of disposition options is discussed in Section 2.4.

5.5   Set Measurement Quality Objectives

A number of terms with specific statistical meanings are used in this and subsequent sections. These terms are defined in Chapter 7. The concept of Measurement Quality Objectives (MQOs) and in particular the required measurement method uncertainty is introduced in Section 3.8.1. These ideas are discussed in greater detail in the *Multi-Agency Radiological Laboratory Analytical Protocols* manual (MARLAP 2004) Chapter 3 and Appendix C. While MARLAP is focused on radioanalytical procedures, these concepts are applicable on a much broader scale and will be used in MARSAME to guide the selection of measurement methods for disposition surveys for materials and equipment.

Section 4.2 discusses the DQO process for developing statistical hypothesis tests for the implementation of disposition decision rules using measurement data. These concepts are further developed in Chapter 7. This includes formulating the null and alternative hypotheses, defining the gray region using the action level and discrimination limit, and setting the desired limits on potential Type I and Type II decision error probabilities that a decision-maker is willing to accept for project results. Decision errors are possible, at least in part, because measurement results have uncertainties. Because DQOs apply to both sampling and measurement activities, method performance characteristics specifically for the measurement process of a particular project are needed from a measurement perspective. These method performance characteristics (Section 3.8) are the measurement quality objectives (MQOs).

DQOs define the performance criteria that limit the probabilities of making decision errors by—

- Considering the purpose of collecting the data,
- Defining the appropriate type of data needed, and
- Specifying tolerable probabilities of making decision errors.

DQOs apply to both sampling and measurement activities. MQOs can be viewed as the measurement portion of the overall project DQOs (Section 3.8). MQOs are—

- The part of the project DQOs that apply to the measured result and its associated uncertainty,
- Statements of measurement performance objectives or requirements for a particular measurement method performance characteristic (e.g., measurement method uncertainty and detection capability),
- Used initially for the selection and evaluation of measurement methods, and
- Used subsequently for the ongoing and final evaluation of the measurement data.

Measurement method uncertainty refers to the *predicted* uncertainty of a measured value that would be calculated if the method were applied to a hypothetical sample with a specified concentration. Measurement method uncertainty is a characteristic of the measurement method and the measurement process. Measurement uncertainty, as opposed to sampling uncertainty, is a characteristic of an individual measurement.

The true measurement method standard deviation, σ_M, is a theoretical quantity and is never known exactly, but it may be estimated using the methods described in Section 7.4. The estimated value of σ_M will be denoted here by σ_M and called the "measurement method uncertainty." The measurement method uncertainty, when estimated by uncertainty propagation, is the predicted value of the combined standard uncertainty ("one-sigma" uncertainty) of the measurement for material with concentration equal to the upper bound of the gray region (UBGR). Note that the term "measurement method uncertainty" and the symbol u_M actually apply not just to the measurement method but also to the entire measurement process: it should include uncertainties in how the measurement method is actually implemented. This definition of measurement method uncertainty is independent of the null hypothesis and applies to both Scenario A and Scenario B.

The true standard deviation of the measurement method, σ_M, is unknown, but the required measurement method uncertainty, σ_{MR}, is intended to be an upper bound for σ_M. In practice, σ_M is actually used as an upper bound for the method uncertainty, σ_M, which is an estimate of σ_M. Therefore, the estimated value of σ_{MR} will be called the "required measurement method uncertainty" and denoted by u_{MR}. Note that when referring to a theoretical population standard deviation, the symbol σ is used. Estimates of the value of σ in specific cases are denoted by the symbol u, for uncertainty. An uncertainty is not a standard deviation because its evaluation involves concepts from metrology as well as statistics, however, in many cases it is treated mathematically as if it were a standard deviation.

The principal MQOs in any project will be defined by the required measurement method uncertainty, u_{MR}, at and below the UBGR and the relative required measurement method uncertainty, φ_{MR}, at and above the UBGR:

$$\varphi_{MR} = \frac{u_{MR}}{UBGR} \tag{5-1}$$

Section 7.7 provides the rationale and guidance for establishing project-specific MQOs for controlling u_M.

Note: When making decisions about individual measurement results, u_{MR} usually should be about 0.3Δ, and when making decisions about the mean of several measurement results, u_{MR} usually should be about 0.1Δ, where Δ is the width of the gray region, $\Delta = \text{UBGR} - \text{LBGR}$. These rules of thumb require certain assumptions as discussed in Chapter 7.

This check of measurement quality against the required measurement method uncertainty relies on having realistic estimates of the measurement uncertainty. Often reported measurement uncertainties are underestimated, particularly if they are confined to the estimated Poisson counting uncertainty (Section 7.8). Tables of results are sometimes presented with a column listing simply "±" without indicating how these numbers were obtained. Often it is found that they simply represent the square root of the number of counts obtained during the measurement. The method for calculating measurement uncertainty, approved by both the International Organization for Standardization (ISO) and the National Institute of Standards and Technology (NIST) is discussed in the next section.

5.6   Determine Measurement Uncertainty

This section discusses the evaluation and reporting of measurement uncertainty. Measurements always involve uncertainty, which must be considered when measurement results are used as part of a basis for making decisions. Every measured and reported result should be accompanied by an explicit uncertainty estimate. One purpose of this section is to give users of data an understanding of the causes of measurement uncertainty and of the meaning of uncertainty statements; another is to describe procedures that can be used to estimate uncertainties. Much of this material is derived from MARLAP Chapter 19.

In 1980, the Environmental Protection Agency published a report entitled "Upgrading Environmental Radiation Data," which was produced by an ad hoc committee of the Health Physics Society (EPA 1980). Two of the recommendations of this report were that–

1. Every reported measurement result (x) should include an estimate of its overall uncertainty (u_x) that is based on as nearly a complete assessment as possible, and
2. The uncertainty assessment should include every significant source of inaccuracy in the result.

The concept of traceability is also defined in terms of uncertainty. Traceability is defined as the "property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties" (ISO 1996). Thus, to realistically make the claim that a measurement result is "traceable" to a standard, there must be a chain of comparisons (each measurement having its own associated uncertainty) connecting the result of the measurement to that standard.

This section considers only the measurement standard deviation, σ_M. Reducing sampling standard deviation, σ_S, by segregating M&E was discussed in Section 5.4. The sampling standard deviation is often larger than the measurement standard deviation. Although this statement may be true in some cases, this is not an argument for failing to perform a full evaluation of the measurement uncertainty, u_M, to evaluate σ_M. A realistic estimate of the measurement uncertainty is one of the most useful data quality indicators for a result (Section 3.8).

Although the need for reporting uncertainty has been recognized, often it consists of only the estimated component due to Poisson counting statistics. This is done because it is easier than a full uncertainty analysis, but it can be misleading because it is at best only a lower bound on the uncertainty and may lead to incorrect decisions based on overconfidence in the measurement. Software is available to perform the mathematical operations for uncertainty evaluation and propagation, eliminating much of the difficulty in implementing the mathematics of uncertainty calculations. There are several examples of such software (McCroan 2006, GUM Workbench 2006, Kragten 1994, Vetter 2006).

The methods, terms, and symbols recommended by MARSAME for evaluating and expressing measurement uncertainty are described in the *Guide to the Expression of Uncertainty in Measurement*, or GUM, which was published by ISO (ISO 1995). The ISO methodology is summarized in the NIST Technical Note TN-1297 (NIST 1994). The details of applying this methodology are given in Section 7.4 and 7.8.

5.7   Determine Measurement Detectability

This section is a summary of issues related to measurement detection capabilities. Much of this material is derived from the MARLAP Chapter 20. More detail may be found in Section 7.9. Radioactivity measurements may involve material with very small amounts of the radionuclide of interest. Measurement uncertainty often makes it difficult to distinguish such small amounts from zero. Therefore, an important MQO of a measurement process is its detection capability, which is usually expressed as the smallest concentration of radioactivity that can be reliably distinguished from zero. Effective project planning requires knowledge of the detection capabilities of the measurement method that will be or could be used. This section explains an MQO called the minimum detectable concentration (MDC) and describes radioactivity detection capabilities, as well as methods for calculating it.

The method most often used to make a detection decision about radiation or radioactivity involves the principles of statistical hypothesis testing. It is a specific example of a Scenario B hypothesis testing procedure described in Section 7.2.4. To "detect" the radiation or radioactivity requires a decision on the basis of the measurement data that the radioactivity is present. The detection decision involves a choice between the null hypothesis (H_0): There is no radiation or radioactivity present (above background), and the alternative hypothesis (H_1): There is radiation or radioactivity present (above background). Making the choice between these hypotheses requires the calculation of a critical value. If the measurement result exceeds this critical value, the null hypothesis is rejected and the decision is that radiation or radioactivity is present. If the null hypothesis is rejected when it is true, a Type I decision error is made. In this case, a sample with no additional radiation or radioactivity above background is deemed to actually contain

such. The rate at which this decision error occurs is denoted by α. The critical value depends directly on the value of α. The planning team has to make a choice about the establishment of the acceptable rate for mischaracterizing a background count for a real detection count, i.e., establish a Type I error rate, α, for mistakenly deciding a background measurement is really a detection of additional radiation or radioactivity.

Radioactivity measurements are often recorded as counts or count rates. Radiation exposure measurements are often expressed in different terms, e.g., ionization current. The term "instrument signal" is used in the following so that all types of measurement are included.[1]

The relationship between the critical value of the net instrument signal (or count), S_C, and the minimum detectable net instrument signal, S_D, is shown in Figure 5.2. More detail on the calculation of the minimum detectable value of the net instrument signal (or count), S_D, is given in Section 7.9. The net instrument signal obtained for a blank sample will usually be distributed around zero as shown. Occasionally, a net instrument signal above S_C may be obtained by chance. The probability that this happens is controlled by the value of α, the Type I decision error rate, shown as the lightly shaded area in Figure 5.2. Smaller values of α result in larger values of S_C and vice versa. The minimum detectable value of the net instrument signal S_D is that value of the mean net instrument signal that results in a detection decision with probability $1 - \beta$. That is, there is only a probability β, the Type II decision error rate shown as the more darkly shaded area in Figure 5.2, of yielding an observed instrument signal less than S_C. Smaller values of β result in larger values of S_D and vice versa. The planning team has to decide what an acceptable value of β should be, i.e. when additional radiation or radioactivity is present, at what rate is it acceptable to mistakenly attribute the measurement result to only background. Note that S_D depends on the values of both α and β.
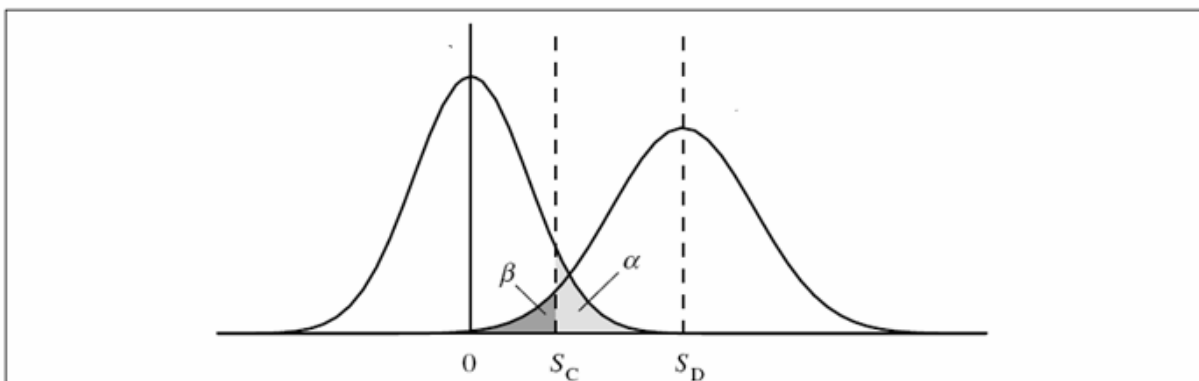

Figure 5.2 The Critical Value (S_C) and the Minimum Detectable Value (S_D) of the Net Instrument Signal (or Count)

The MDC is usually obtained from the minimum detectable value of the net instrument signal (or count), S_D. The MDC is by definition an estimate of the true concentration of the radiation or radioactivity required to give a specified high probability that the measured response will be

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[1] "Net instrument signal," is used here as a general term, because many radiation-detection instruments may have output other than "counts" (e.g., current for ionization chambers). In cases where the instrument output *is* in counts, the term "net counts" can be substituted for the term "net instrument signal."

greater than S_C. The common practice of comparing a measured concentration to the MDC, instead of S_C, to make a detection decision is incorrect.

To calculate the MDC, the minimum detectable value of the net instrument signal, S_D, must first be converted to the detectable value of the net instrument signal rate (often a count rate), S_D/t_S (s^{-1}), where t_S is the duration of the measurement in seconds. This in turn must be divided by the instrument efficiency, ε (s^{-1}/Bq) to get the minimum detectable activity, y_D. Finally, the minimum detectable activity can be divided by the sample volume or mass to obtain the MDC. At each stage in this process, additional uncertainty may be introduced by the uncertainties in time, efficiency, volume, mass, etc. Prudently conservative values of these factors should be used so that the desired detection power, $1 - \beta$, at the MDC is maintained. Another approach would be to recognize that y_D itself has an uncertainty which can be calculated using the methods of Section 7.8. Thus, any input quantity that is used to convert from S_D to y_D that has significant uncertainty, can be incorporated to assess the overall uncertainty in the MDC.

MARSAME recommends that when a detection decision is required, it generally should be made by comparing the net instrument signal to its corresponding critical value. Expressions for S_C and S_D should be chosen that are appropriate for the structure and statistics of the measurement process. An appropriate background should be used to predict the instrument signal produced when there is no radioactivity present in the sample. The MDC should be used only as a MQO for the measurement method. To make a detection decision, a measurement result should be compared to S_C and never to the MDC. Finally, additional discussion of the calculation of the MDCs is given in Section 7.9.

5.8   Determine Measurement Quantifiability

This section discusses issues related to measurement quantifiability. Much of this material is derived from the MARLAP Chapter 20.

Action levels are frequently stated in terms of a quantity or concentration of radioactivity, rather than in simply in terms of whether radioactivity is detected. In these cases, project planners may need to know the quantification capability of a measurement method, or its capability for precise measurement. The quantification capability is expressed as the smallest concentration of radiation or radioactivity that can be measured with a specified relative measurement standard deviation. This section explains an MQO called the *minimum quantifiable concentration* (MQC), which may be used to describe quantification capabilities.

The MQC, y_Q, is defined as the concentration at which the measurement process gives results with a specified relative standard deviation, $1/k_Q$, where k_Q is usually chosen to be 10 for comparability. Thus, the MQC is generally the concentration at which the relative measurement uncertainty is 10%.

Historically much attention has been given to the detection capabilities of radiation and radioactivity measurement processes, but less attention has been given to quantification capabilities. For some projects, quantification capability may be a more relevant issue. For example, suppose the purpose of a project is to determine whether the ^{226}Ra concentration on

material at a site is below an action level. Because ^{226}Ra can be found in almost any type of naturally occurring material, it may be assumed to be present in every sample, making detection decisions unnecessary. The MDC of the measurement process obviously should be less than the action level, but a more important question is whether the MQC is less than the action level.

A common practice in the past has been to select a measurement method based on the MDC, which is defined in Section 5.7 and Section 7.5. For example, MARSSIM says:

> During survey design, it is generally considered good practice to select a measurement system with an MDC between 10-50% of the DCGL [action level].

Such guidance implicitly recognizes that for cases when the decision to be made concerns the mean of a population that is represented by multiple measurements, criteria based on the MDC may not be sufficient and a somewhat more stringent requirement is needed. The requirement that the MDC (approximately 3–5 times σ_M) be 10% to 50% of the action level is tantamount to requiring that σ_M be 0.02 to 0.17 times the action level. In other words, the relative measurement standard deviation should be approximately 10% at the action level. However, the concentration at which the relative measurement standard deviation is 10% of the MQC when k_Q assumes its conventional value of 10. Thus, a requirement that is often stated in terms of the MDC may be more naturally expressed in terms of the MQC (e.g., by saying that the MQC should not exceed the action level). Further details on calculating the MQC can be found in Section 7.10.

5.9   Select a Measurement Technique and Instrumentation Combination

The combination of a measurement technique with instrumentation, or measurement method, is selected to implement a disposition survey design based on the ability to meet the MQOs (see Sections 3.3.2 and 5.5). Note that measurement techniques are separate from survey designs. The relationship between the two is explained in Sections 5.9.1.1, 5.9.1.2, and 5.9.1.3. A realistic determination of the measurement method uncertainty (Section 5.6) is critical to demonstrating a method meets the MQOs. Other considerations when selecting a measurement method include—

- Health and safety concerns (Section 5.2),
- M&E handling issues (Section 5.3),
- Segregation (Section 5.4),
- Measurement detectability (Section 5.7), and
- Measurement quantifiability (Section 5.8).

The measurement techniques discussed in Section 5.9.1 all can be classified as scanning measurements (constant motion involved in the surveying procedure) or fixed measurements (surveying discrete locations without motion). Fixed measurements consist of in situ measurements (the detection instrument moves to the M&E or measures the M&E in its entirety), and sampling (removing part of the M&E for separate analysis).

Instrumentation for performing radiological measurements is varied and constantly being improved. Section 5.9.2 provides an overview of some commonly used types of instruments and how they might be applied to disposition surveys. The purpose of the discussions on

instrumentation is not to provide an exhaustive list of acceptable instruments, but to provide examples of how instrumentation and measurement techniques can be combined to meet the survey objectives. Additional information on instrumentation is found in Appendix D. Section 5.9.3 provides information on selecting a combination of measurement technique and instrumentation to provide a measurement method. It is necessary that the selected measurement method meet the MQOs established during survey design (Section 3.8). Selection of instrumentation can be an iterative process. The appropriate MQO (e.g., MDC, MQC) may not be attainable with some measurement methods. In some cases selection of a different instrument may be all that is necessary, while in other cases a different measurement technique or an entirely different measurement method will need to be considered.

5.9.1   Select a Measurement Technique

A measurement technique describes how a measurement is performed. The detector can be moved relative to the M&E (i.e., scanning), used to perform static measurements of the M&E in place (i.e., in situ or direct measurements), or some representative portion of the M&E can be taken to a different location for analysis (i.e., sampling). These three measurement techniques are described in Sections 5.9.1.1, 5.9.1.2, and 5.9.1.3, respectively. Smears are a type of sampling, where a portion of the removable radioactivity is collected (Section 5.9.1.4).

5.9.1.1   Scanning Techniques

Scanning techniques generally consist of moving portable radiation detectors at a specified distance above the physical surface of a survey unit at some specified speed to meet the MQOs. Alternatively, the M&E can be moved past a stationary instrument at a specified distance and speed (e.g., conveyorized systems or certain portal monitors). Scanning techniques can be used alone to demonstrate compliance with a disposition criterion (i.e., scan-only surveys, Section 4.4.1), or combined with sampling in a MARSSIM-type survey design (Section 4.4.3). Scanning is used in MARSSIM-type surveys to locate radiation anomalies by searching for variations in readings, indicating gross radioactivity levels that may require further investigation or action. Scanning techniques can more readily provide thorough coverage of a given survey unit and are often relatively quick and inexpensive to perform. Scanning often represents the simplest and most practical approach for performing MARSAME disposition surveys.

Maintaining the specified distance and speed during scanning can be difficult, especially with hand-held instruments and irregularly shaped M&E. Variations in source-to-detector distance and scan speed can result in increased total measurement method uncertainty. Determining a calibration function for situations other than surficial radionuclides uniformly distributed on a plane can be complicated, and may also contribute to the total measurement method uncertainty.

5.9.1.2   In Situ Measurements

In situ measurements are taken by placing the instrument in a fixed position at a specified distance[2] from the surface of a given survey unit of M&E and taking a discrete measurement for

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[2]Measurements at several distances may be needed. Near-surface or surface measurements provide the best indication of the size of the area of elevated radionuclide concentrations or radioactivity, and are useful for model

a pre-determined time interval. Single in situ measurements can be performed on individual objects or groups of M&E. Multiple in situ measurements can be combined to provide several different views of the same object, or used to provide measurements for a specified fraction of the M&E. In situ measurements can also be performed at random or systematic locations, combined with scanning measurements, in a MARSSIM-type survey design. In situ measurements are used generally to provide an estimate of the average radionuclide concentration or level of radioactivity over a certain area or volume defined by the calibration function.

Determining a calibration function for situations other than radionuclides uniformly distributed on a plane or through a regularly shaped volume (e.g., a disk or cylinder) can be complicated and may contribute to the total measurement method uncertainty. In situ techniques are not typically used to identify small areas or volumes of elevated radionuclide concentration or activity.

5.9.1.3   Sampling

Sampling consists of removing a portion of the M&E for separate laboratory analysis. This measurement technique, when combined with laboratory analysis, surpasses the detection capabilities of measurement techniques that may be implemented with the M&E left in place. This facilitates the analysis of complicated radioisotope mixtures, difficult-to-measure radionuclides, and extremely low concentrations of residual radioactivity. Sampling is used to provide an estimate of the average radionuclide concentration or level of radioactivity for a specified area or volume. The sample locations may be located using a random or systematic grid, depending on the objectives of the survey. Sampling is typically combined with scanning in a MARSSIM-type survey design, where sampling is used to evaluate the average concentration or activity and scanning is used to identify small areas or volumes with elevated radionuclide concentrations or radioactivity. Sampling may also be used to validate data collected using other measurement techniques.

Sampling (combined with laboratory analysis) typically requires the most time for data generation of all the surveying techniques discussed in this chapter and is often the most expensive. Sampling is not an effective technique for identifying small areas or volumes of elevated radionuclide concentrations or levels of radioactivity.

5.9.1.4   Smears

Smears are used to provide an estimate of removable surface radioactivity. Smears are also referred to as smear tests, swipes, or wipes. Smears are a type of sample where a filter paper or other substance is used to wipe a specified area of a surface. The filter paper or other substance is then tested for the presence of radioactivity.

Individual smear results collected by hand usually have a high uncertainty because the fraction of surface radioactivity transferred to the smear is unknown and variable and the surface area

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implementation. Gamma measurements at one meter provide a good estimate of potential direct external exposure (MARSSIM 2002).

covered by the smear is variable. In addition, the results may vary with time due to environmental factors or interactions of surface activity with the surface itself. Action levels for removable activity based on smear measurements may include assumptions about the fraction of surface radioactivity transferred to a single smear or specify a surface area to be smeared. For example, DOT surface contamination guidelines assume that 10% of the surface radioactivity is transferred to a single smear. Also, DOE Order 5400.5 Figure IV-1 (DOE 1993) provides instructions for using smears to measure removable radioactivity. These instructions specify wiping an area of 100 cm^2 with a dry filter or soft absorbent paper while applying moderate pressure. The instructions also discuss how to account for minor variations from the procedure.

Determining a collection or removal fraction for smears can be complicated. The uncertainty and variability in the removal fraction estimate and surface area smeared can result in increased total measurement method uncertainty. Using a template or cutout with a known area can help control the variability in the area covered by a smear. Using a tool that applies consistent pressure while collecting smears can reduce the variability in the fraction of radioactivity removed. Implementing a protocol for preparing surfaces and sorting materials prior to survey can reduce variability in surface textures and conditions resulting in lower variability in smear collection conditions.

5.9.2   Select Instrumentation

This section briefly describes the typical types of instrumentation that may be used to conduct MARSAME disposition surveys. More detailed information relevant to each type of instrument and measurement method is provided in Appendix D.

5.9.2.1   Hand-Held Instruments

Hand-held instruments typically are composed of a detection probe (utilizing a single detector) and an electronic instrument to provide power to the detector and to interpret data from the detector to provide a measurement display. They may be used to perform scanning surveys or in situ measurements. Hand-held measurements also allow the user the flexibility to constantly vary the source-to-detector geometry for obtaining data from difficult-to-measure areas.

5.9.2.2   Volumetric Counters (Drum, Box, Barrel, 4-π Counters)

Box counting systems typically consist of a counting chamber, an array of detectors configured to provide 4-π counting geometry, and microprocessor-controlled electronics that allow programming of system parameters and data-logging. Volumetric counters are used to perform in situ measurements on entire pieces of small M&E.

5.9.2.3   Conveyorized Survey Monitoring Systems

Conveyorized survey monitoring systems automate the routine scanning of M&E. Conveyorized survey monitoring systems typically perform scanning surveys by moving M&E through a detector array on a conveyor belt. Conveyorized survey monitoring systems may be utilized to

take in situ measurements by halting the conveyor and continuing the measurement to improve the detection efficiency.

5.9.2.4   In Situ Gamma Spectroscopy

Some in situ gamma spectroscopy (ISGS) systems consist of a small hand-held unit that incorporates the detector and counting electronics into a single package. Other ISGS systems consist of a semiconductor detector, a cryostat, a multi-channel analyzer (MCA) electronics package that provides amplification and analysis of the energy pulse heights, and a computer system for data collection and analysis. ISGS systems typically are applied to perform in situ measurements, but they may be incorporated into innovative detection equipment set-ups to perform scanning surveys.

5.9.2.5   Portal Monitors

Portal monitors utilize a fixed detector array through which M&E are passed to typically perform scanning surveys (objects may also remain stationary within the detector array to perform in situ measurements). Portal monitors typically are used to perform scanning surveys of vehicles.[3] In situ measurements may be utilized with portal monitors by taking motionless measurements to improve the detection efficiency.

5.9.2.6   Laboratory Analysis

Laboratory analysis consists of analyzing a portion or sample of the M&E. The laboratory will generally have recommendations or requirements concerning the amount and types of samples that can be analyzed for radionuclides or radiations. Communications should be established between the field team collecting the samples and the laboratory analyzing the samples. More information on sampling is provided in Section 5.9.1.3. Laboratory analyses can be developed for any radionuclide with any material, given sufficient resources. Laboratory analyses typically require more time to complete than field analyses. The laboratory may be located onsite or offsite. The quality of laboratory data typically is greater than data collected in the field because the laboratory is better able to control sources of measurement method uncertainty. The planning team should consider the resources available for laboratory analysis (e.g., time, money), the sample collection requirements or recommendations, and the requirements for data quality (e.g., MDC, MQC) during discussions with the laboratory.

5.9.3   Select a Measurement Method

Table 5.1 and Table 5.2 illustrate the potential applications and associated size restrictions for combinations of the instrument and measurement techniques discussed in Sections 5.9.1 and 5.9.2, respectively. Sampling followed by laboratory analysis is not included in these tables, but is considered "GOOD" for all applications. Please note the following qualifiers:

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[3] Specialized vehicle monitors are available that monitor rates of change in ambient background to account for differences in vehicles being scanned to improve measurement detectability.

GOOD   The measurement technique is well-suited for performing this application
FAIR   The measurement technique can adequately perform this application
POOR   The measurement technique is poorly suited for performing this application
NA   The measurement technique cannot perform this application
Few   A relatively small number, usually three or less
Many   A relatively large number, usually more than three

Table 5.1 illustrates that most measurement techniques can be applied to almost any M&E and type of radioactivity. The quantity of M&E to be surveyed becomes a major factor for the selection of measurement instruments and techniques described in this chapter. Hand-held measurements and techniques generally are the most efficient technique for surveying small quantities of M&E.

Table 5.1 Potential Applications for Instrumentation and Measurement Technique Combinations

Radiation Type	Hand-Held Instruments	Volumetric Counters	Portal Monitors	In Situ Gamma Spectroscopy	Conveyorized Survey Monitoring Systems
In Situ Measurements					
Alpha	FAIR	FAIR	POOR	NA	FAIR
Beta	GOOD	FAIR	FAIR	NA	GOOD
Photon	GOOD	GOOD	GOOD	GOOD	GOOD
Neutron	GOOD	FAIR	GOOD	NA	GOOD
Scanning Surveys					
Alpha	POOR	NA	POOR	NA	POOR
Beta	GOOD	NA	FAIR	NA	FAIR
Photon	GOOD	NA	GOOD	GOOD	GOOD
Neutron	FAIR	NA	FAIR	NA	FAIR

Table 5.2 Survey Unit Size and Quantity Restrictions for Instrumentation and Measurement Technique Combinations

Size of Items	Number of Survey Units or Items	Hand-Held Instruments	Volumetric Counters	Portal Monitors	In Situ Gamma Spectroscopy	Conveyorized Survey Monitoring Systems
In Situ Measurements						
> 10 m^3	Few	GOOD	NA	FAIR	GOOD	POOR
> 10 m^3	Many	POOR	NA	FAIR	GOOD	POOR
1 to 10 m^3	Few	GOOD	FAIR	FAIR	GOOD	FAIR
1 to 10 m^3	Many	POOR	FAIR	FAIR	GOOD	FAIR
< 1 m^3	Few	GOOD	GOOD	POOR	GOOD	GOOD
< 1 m^3	Many	FAIR	GOOD	POOR	GOOD	GOOD

Table 5.2 Survey Unit Size and Quantity Restrictions for Instrumentation and Measurement Technique Combinations (Continued)

Size of Items	Number of Survey Units or Items	Hand-Held Instruments	Volumetric Counters	Portal Monitors	In Situ Gamma Spectroscopy	Conveyorized Survey Monitoring Systems
Scanning Surveys						
$> 10 \text{ m}^3$	Few	GOOD	NA	GOOD	FAIR	POOR
	Many	FAIR	NA	GOOD	FAIR	POOR
$1 \text{ to } 10 \text{ m}^3$	Few	GOOD	NA	FAIR	FAIR	FAIR
	Many	FAIR	NA	FAIR	FAIR	FAIR
$< 1 \text{ m}^3$	Few	GOOD	NA	POOR	FAIR	GOOD
	Many	GOOD	NA	POOR	FAIR	GOOD

Facilities that conduct routine surveys on substantial quantities of specific types of M&E may benefit financially from investing in measurement instruments and techniques that require less manual labor to conduct disposition surveys. For example, it will require significantly more time for a health physics technician to survey a toolbox of tools and equipment used in a radiologically controlled area using hand-held surveying techniques and instruments than the time to complete the surveying using a box counting system. Use of such automated systems will also reduce the potential for ergonomic injuries, and attendant costs, associated with routine, repetitive surveys performed using hand-held instruments.

Hand-held surveying remains the more economical choice for a small quantity of tools and toolboxes, but as the quantity of tools and toolboxes increases, the cost of a box counting system becomes an increasingly worthwhile investment to reduce manual labor costs associated with surveying. Note that some M&E have no survey design options that are described as "GOOD" in these two tables (e.g., a large quantity of M&E impacted with residual alpha radioactivity with survey unit sizes greater than 10 m³). The planning team should revisit earlier DQO selections to see if a different approach is more acceptable (e.g., review selection of disposition options in Section 2.4).

Each type of measurement technique has associated advantages and disadvantages, some of which are summarized in Table 5.3. All the measurement techniques described in this table include source-to-detector geometry and sampling variability as common disadvantages.

Table 5.3 Advantages and Disadvantages of Instrumentation and Measurement Technique Combinations

Instrument	Measurement Technique	Advantages	Disadvantages
Hand-Held Instruments	In Situ	• Generally allows flexibility in media to be measured • Detection equipment is usually portable • Detectors are available to efficiently measure alpha, beta, gamma, x-ray, and neutron radiation • Generally acceptable for performing measurements in difficult-to-measure areas • Measurement equipment is relatively low cost • May provide a good option for small quantities of M&E	• Requires a relatively large amount of manual labor as a surveying technique; may make surveying large quantities of M&E labor-intensive • Detector windows may be fragile • Most do not provide nuclide identification
Hand-Held Instruments	Scanning	• Generally allows flexibility in media to be measured • Detection equipment is usually portable • Detectors are available to efficiently measure beta, gamma, x-ray, and neutron radiation • Generally good for performing measurements in difficult-to-measure areas • Measurement equipment is relatively low cost • May provide a good option for small quantities of M&E	• Requires a relatively large amount of manual labor as a surveying technique; may make surveying large quantities of M&E labor-intensive • Detector windows may be fragile • Most do not provide nuclide identification • Incorporates more potential sources of uncertainty than most instrument and measurement technique combinations • Potential ergonomic injuries and attendant costs associated with repetitive surveys.
Hand-Held Instruments	Smear	• Only measurement technique for assessing removable radioactivity • Removable radioactivity can be transferred and assessed in a low background counting area.	• Instrument background may not be sufficiently low. • Detectors with counting sensitive region larger than the smear surface area may require counting adjustments to account for inherent backgrounds associated with other media located under the detector sensitive region.

Table 5.3 Advantages and Disadvantages of Instrumentation and Measurement Technique Combinations (Continued)

Instrument	Measurement Technique	Advantages	Disadvantages
Volumetric Counters	In situ	• Able to measure small items • Designs are available to efficiently measure gamma, x-ray, and alpha radiation • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E	• May not be suited for measuring radioactivity in difficult-to-measure areas • Size of instrumentation may discourage portability
Portal Monitors	In situ	• Able to measure large objects • Designs are available to efficiently measure gamma, x-ray, and neutron radiation • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E	• Not ideal for measuring alpha or beta radioactivity • May not be ideal for measuring radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability
Portal Monitors	Scanning	• Able to measure large objects • Efficient designs available for gamma, x-ray, and neutron radiation • Residence times generally are short • May not require objects to remain stationary during counting • Requires relatively small amount of labor • May be cost-effective for measuring large quantities of M&E	• Not ideal for measuring alpha or beta radioactivity • Source geometry is an important consideration • May not be ideal for measuring radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability
In Situ Gamma Spectroscopy (ISGS)	In situ	• Provides quantitative measurements with flexible calibration • Generally requires a moderate amount of labor • May be cost-effective for measuring large quantities of M&E	• Instrumentation may be expensive and difficult to set up and maintain • May require liquid nitrogen supply (with ISGS semiconductor systems) • Size of detection equipment may discourage portability
In Situ Gamma Spectroscopy (ISGS)	Scanning	• Provides quantitative measurements with flexible calibration • Generally requires a moderate amount of labor • May be cost-effective for measuring large quantities of M&E	• Instrumentation may be expensive and difficult to set up and maintain • May require liquid nitrogen supply (with ISGS semiconductor systems) • Size of detection equipment may discourage portability

Table 5.3 Advantages and Disadvantages of Instrumentation and Measurement Technique Combinations (Continued)

Instrument	Measurement Technique	Advantages	Disadvantages
Conveyorized Survey Monitoring Systems	In situ	• Requires relatively small amount of labor after initial set up • May be cost-effective for measuring large quantities of M&E	• Instrumentation may be expensive and difficult to set up and maintain • May not be ideal for assessing radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability • Typically does not provide nuclide identification
Conveyorized Survey Monitoring Systems	Scanning	• Requires relatively small amount of labor after initial set up • May be cost-effective for measuring large quantities of M&E	• Instrumentation may be expensive and difficult to set up and maintain • May not be ideal for assessing radioactivity in difficult-to-measure areas • Size of detection equipment may discourage portability • Typically does not provide nuclide identification
Laboratory Analysis	Sampling	• Generally provides the lowest MDCs and MQCs, even for difficult-to-measure radionuclides • Allows positive identification of radionuclides without gammas	• Most costly and time-consuming measurement technique • May incur increased overhead costs while personnel are waiting for analytical results • Great care must be taken to ensure samples are representative • Detector windows may be fragile
Laboratory Analysis	Smear	• Only measurement technique for assessing removable radioactivity • Removable radioactivity can be transferred and assessed in a low background counting area.	• Instrument background may not be sufficiently low. • Detectors with counting sensitive region larger than the smear surface area may require counting adjustments to account for inherent backgrounds associated with other media located under the detector sensitive region.

5.9.4   Measurement Performance Indicators

Measurement performance indicators are used to evaluate the performance of the measurement method. These indicators describe how the measurement method is performing to ensure the survey results are of sufficient quality to meet the survey objectives.

5.9.4.1   Blanks

Blanks are measurements of materials with little or no radioactivity and none of the radionuclide(s) of concern present, and performed to determine whether the measurement process introduces any increase in instrument signal rate that could impact the measurement method detection capability. Blanks should be representative of all measurements performed using a specific method (i.e., combination of instrumentation and measurement technique). When practical, the blank should consist of the same or equivalent material(s) as the M&E being surveyed.

Blanks typically are performed before and after a series of measurements to demonstrate the measurement method was performing adequately throughout the survey. At a minimum, blanks should be performed at the beginning and end of each shift. When large quantities of data are collected (e.g., scanning measurements) or there is an increased potential for radionuclide contamination of the instrument (e.g., removable or airborne radionuclides), blanks may be performed more frequently. In general, a blank should be collected whenever enough measurements have been performed such that it is not practical to repeat those measurements if a problem is identified.

A sudden change in a blank result indicates a condition requiring immediate attention. Sudden changes are caused by the introduction of a radionuclide, a change in ambient background, or instrument instability. Gradual changes in blank values indicate a need to inspect all survey areas for sources of radionuclides or radioactivity. Gradual build up of removable radionuclides over time or instrument drift and deterioration can result in slowly increasing blank values. High variability in blank values can result from instrument instability or improper classification (i.e., high activity and low activity M&E combined into a single survey unit. It is important to correct any problems with blanks to ensure measurement detectability (see Sections 5.7 and 7.5) is not compromised.

5.9.4.2   Replicate Measurements

Replicate measurements are two or more measurements performed on the same M&E, and performed primarily to provide an estimate of precision for the measurement method. The reproducibility of measurement results should be evaluated by replicates to establish this component of measurement uncertainty (see Sections 5.6 and 7.4).

Replicates typically are performed at specified intervals during a survey (e.g., 5% of all measurements or once per day), and should be used to evaluate each batch of data used to support a disposition decision (e.g., one replicate per survey unit). For single measurement

surveys or scan-only surveys where decisions are made based on every measurement, typically 5% of all measurements are replicated.

Precision exhibits a range of values and depends in part on the material being measured and the activity level. Small changes in precision are expected, and the acceptable range of variability should be established prior to initiating data collection activities. The main causes for lack of precision include problems with repeating measurements on irregularly shaped M&E, the material being measured, counting statistics when the activity levels are low, and instrument contamination.

5.9.4.3 Spikes and Standards

Spikes and standards are materials with known composition and radioactivity, used to evaluate bias in the measurement method, and typically performed periodically during a survey (e.g., 5% of all measurements or once per day). When spikes and standards are available, they should be used to evaluate each batch of data used to support a disposition decision (i.e., at least one spike or standard per survey unit).

M&E cover a broad range of physical forms and materials that can change a measurement method's expected bias. Tracking results of measurements with known activity can provide an indication of the magnitude of bias. In general, activity levels near the action levels (or discrimination limits in Scenario B) will provide adequate information on the performance of the measurement system.

5.9.5   Instrument Performance Indicators

Instrument performance indicators provide information on how an instrument is performing. Evaluation of these indicators provides information on the operation of the instruments.

5.9.5.1 Performance Tests

Performance tests should be performed periodically and after maintenance to ensure that the instruments continue to meet performance requirements for measurements. An example of a performance test is a test for response time. Performance requirements should be met as specified in the applicable sections of ANSI N323A (ANSI 1997), ANSI N42.17A (ANSI 2003b), and ANSI N42.17C (ANSI 1989). These tests may be conducted as part of the calibration procedure.

5.9.5.2 Functional Tests

Functional tests should be performed prior to initial use of an instrument. These functional tests should include—

- General condition,
- Battery condition,

- Verification of current calibration (i.e., check to see that the date due for calibration has not passed),
- Source and background response checks (and other tests as applicable to the instrument), and
- Constancy check.

The effects of environmental conditions (temperature, humidity, etc.) and interfering radiation on an instrument should be established prior to use. The performance of functional tests should be appropriately documented. This may be as simple as a checklist on a survey sheet, or may include more detailed statistical evaluation such as a chi-square test.

5.9.5.3   Instrument Background

All radiation detection instruments have a background response, even in the absence of a sample or radiation source (Section 3.4.2). Inappropriate background correction will result in measurement error and increase the uncertainty of data interpretation.

5.9.5.4   Efficiency Calibrations

Detector efficiency is critical for converting the instrument response to activity (MARSAME Section 7.8.2.2, MARSSIM Section 6.5.4, MARLAP Chapter 16). Routine performance checks may be used to demonstrate the system's operational parameters are within acceptable limits, and these measurements typically are included in the assessment of bias. The system's operational parameters may be tracked using control charts.

5.9.5.5   Energy Calibrations (Spectrometry Systems)

Spectrometry systems identify radionuclides based on the energy of the detected radiations. A correct energy calibration is critical to accurately identify radionuclides. An incorrect energy calibration may result in misidentification of peaks, or failure to identify radionuclides present in the M&E being investigated.

5.9.5.6   Peak Resolution and Tailing (Spectrometry Systems)

The shape of the full energy peak is important for identifying radionuclides and quantifying their activity with spectrometry systems. Poor peak resolution and peak tailing may result in larger measurement uncertainty, or in failure to identify the presence of peaks based on shape. Consistent problems with peak resolution indicate the presence of an analytical bias.

5.9.5.7   Voltage Plateaus (Gas Proportional Systems)

The accuracy of results using a gas proportional system can be affected if the system is not operated with its detector high voltage adjusted such that it is on a stable portion of the operating plateau.

5.9.5.8 Self Absorption, Backscatter, and Crosstalk

Alpha and beta measurement results can be affected by the M&E through self-absorption and backscatter. Measurement systems simultaneously detecting alpha and beta particles using an electronic discriminator (e.g., gas flow proportional detectors) can be affected by crosstalk (i.e., identification of alpha particles as beta particles and vice versa). Accurate differentiation between alpha and beta activity depends on the assessment and maintenance of information on self-absorption and crosstalk.

5.10   Report the Results

Once the instruments have been checked to ensure proper operation, the data should be collected in a manner consistent with the survey design. Any field changes and deviations from survey design should be documented and described in sufficient detail to enable an independent recreation and evaluation at some future time.

The reported measurements should comprise raw data that includes background radioactivity (i.e., gross measurement data). Electronic instruments with data logging capabilities should be used when applicable. Electronic data should be exported and backed up periodically to minimize the chance of losing data and the need for re-surveying.

Use of a measurement identification system should be considered. If required by the objectives of the survey, the identification system should be developed and used such that each measurement is assigned and labeled with a unique (preferably sequential) identifying number, the collection date and time, the measurement location, and any applicable comments.

While MARSAME does not make specific recommendations with regard to approved media formats for storing documentation, some users of MARSAME (e.g., private industry nuclear power plants) may be required to retain documentation in media formats prescribed by State and Federal rules of evidence. Similarly, State and Federal rules of evidence may specify retention periods for documentation that exceed internal facility requirements. Compliance with State and Federal rules of evidence is intrinsic to maintaining legally defensible records for insurance and litigation-related purposes.

Projects at large, complex facilities often occur over relatively long time frames (e.g., years or decades). In many cases the project is divided into smaller sub-projects that are performed as resources and information become available. Retention of records, data compatibility, data accessibility, and transfer of data between sub-projects should be considered during the performance of individual surveys.

Documentation of the survey measurements should provide a complete and unambiguous record of the data collected. Documentation should also include descriptions of variability and other conditions pertaining to the M&E that may have affected the measurement capabilities of the survey procedure, and photographs where applicable. The documentation itself should be clear, legible, retained, retrievable, and to the level of detail required.

Negative results (net activity below zero) can be obtained when an instrument background is subtracted from the measurement of a low activity sample. In the case where the activity is close to zero, the measurement uncertainty will result in a distribution of results where approximately one-half are less than zero and one-half are greater than zero. As long as the magnitude of negative values is comparable to the estimated measurement uncertainties and there is no discernible negative bias, negative results should be accepted as legitimate estimates of radionuclide concentrations or levels of radioactivity associated with the M&E. A preponderance of negative results, even if they are close to zero may indicate a bias or systematic error.

The inclusion of the information described above is important in creating comprehensive documentation to make disposition surveys technically and legally defensible. The collection of all necessary data prepares the MARSAME user to assess the results of the disposition survey, which is discussed in Chapter 6.