

NUREG-1575, Supp. 1  
EPA 402-R-09-001  
DOE/HS-0004

# **Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual (MARSAME)**

**Department of Defense  
Department of Energy  
Environmental Protection Agency  
Nuclear Regulatory Commission**

**January 2009**

**DISCLAIMER**

This supplement was developed by four agencies of the United States Government. Neither the United States Government nor any agency or branch thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this supplement, or represents that its use by such third party would not infringe on privately owned rights.

References within this supplement to any specific commercial product, process, or service by trade name, trademark, or manufacturer does not constitute an endorsement or recommendation by the United States Government.

## ABSTRACT

The *Multi-Agency Radiation Survey and Assessment of Materials and Equipment* manual (MARSAME) is a supplement to the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) providing information on planning, conducting, evaluating, and documenting radiological disposition surveys for the assessment of materials and equipment. MARSAME is a multi-agency consensus document that was developed collaboratively by four Federal agencies having authority and control over radioactive materials: Department of Defense (DOD), Department of Energy (DOE), Environmental Protection Agency (EPA), and Nuclear Regulatory Commission (NRC). The objective of MARSAME is to provide a multi-agency approach for planning, performing, and assessing disposition surveys of materials and equipment, while at the same time encouraging an effective use of resources.



## CONTENTS

Disclaimer .....	ii
Abstract .....	iii
Acknowledgements .....	xxi
Acronyms and Abbreviations .....	xxiii
Symbols, Nomenclature, and Notations.....	xxvii
Conversion Factors .....	xxxii
Roadmap .....	RM-1
Introduction to MARSAME .....	RM-1
The Goal of the Roadmap.....	RM-1
Initial Assessment.....	RM-2
Categorization.....	RM-2
Standardized Survey Designs .....	RM-2
Develop a Decision Rule .....	RM-2
Survey Design.....	RM-3
Measurement Quality Objectives .....	RM-4
Implement the Survey Design .....	RM-5
Evaluate the Results.....	RM-5
Summary.....	RM-5
1 Introduction and Overview .....	1-1
1.1 Purpose and Scope of MARSAME.....	1-1
1.2 Understanding Key MARSAME Terminology .....	1-3
1.3 Use of MARSAME.....	1-5
1.4 Overview of MARSAME .....	1-6
1.4.1 Planning Phase.....	1-9
1.4.2 Implementation Phase.....	1-10
1.4.3 Assessment Phase .....	1-11
1.4.4 Decision-Making Phase .....	1-12
1.5 Organization of MARSAME .....	1-12
1.6 Similarities and Differences Between MARSSIM and MARSAME .....	1-14
2 Initial Assessment of Materials and Equipment .....	2-1
2.1 Introduction .....	2-1
2.2 Categorize the M&E as Impacted or Non-Impacted.....	2-1
2.2.1 Perform a Visual Inspection .....	2-3
2.2.2 Collect and Review Additional Historical Records.....	2-4
2.2.3 Assess Process Knowledge.....	2-5
2.2.4 Perform Sentinel Measurements.....	2-7
2.2.5 Decide Whether M&E are Impacted .....	2-8
2.3 Design and Implement Preliminary Surveys.....	2-9
2.4 Describe the M&E .....	2-11
2.4.1 Describe the Physical Attributes of the M&E .....	2-11
2.4.1.1 Describe the Physical Dimensions of the M&E.....	2-12

- 2.4.1.2 Describe the Complexity of the M&E ..... 2-13
- 2.4.1.3 Describe the Accessibility of the M&E ..... 2-14
- 2.4.1.4 Describe the Inherent Value of the M&E ..... 2-14
- 2.4.2 Describe the Radiological Attributes of the M&E..... 2-15
  - 2.4.2.1 Identify the Radionuclides of Potential Concern ..... 2-16
  - 2.4.2.2 Describe the Radionuclide Concentrations or Radioactivity  
Associated with the M&E ..... 2-17
  - 2.4.2.3 Describe the Distribution of Radioactivity..... 2-17
  - 2.4.2.4 Describe the Location of Radioactivity..... 2-17
- 2.4.3 Finalize the Description of the M&E..... 2-18
- 2.5 Select a Disposition Option..... 2-19
- 2.6 Document the Results of the Initial Assessment..... 2-19
  - 2.6.1 Document a Standardized Initial Assessment..... 2-20
  - 2.6.2 Document a Conceptual Model ..... 2-21
- 3 Identify Inputs to the Decision ..... 3-1
  - 3.1 Introduction ..... 3-1
  - 3.2 Select Radionuclides or Radiations of Concern..... 3-3
  - 3.3 Identify Action Levels ..... 3-3
    - 3.3.1 Identify Sources of Action Levels ..... 3-6
    - 3.3.2 Finalize Selection of Action Levels..... 3-7
    - 3.3.3 Modify Action Levels When Multiple Radionuclides are Present ..... 3-7
      - 3.3.3.1 Modify Action Levels for Non-Radionuclide-Specific Measurement  
Methods..... 3-8
      - 3.3.3.2 Modify Action Levels for Non-Radionuclide-Specific  
Measurements of Decay-Series Radionuclides ..... 3-9
      - 3.3.3.3 Modify Action Levels for Radionuclide-Specific Measurement  
Methods..... 3-11
    - 3.3.4 Evaluate Interface With Exposure Pathway Models ..... 3-13
  - 3.4 Describe the Parameter of Interest ..... 3-14
  - 3.5 Identify Alternative Actions..... 3-14
  - 3.6 Identify Survey Units ..... 3-15
    - 3.6.1 Define Initial Survey Unit Boundaries ..... 3-17
    - 3.6.2 Modify Initial Survey Unit Boundaries ..... 3-18
  - 3.7 Develop a Decision Rule..... 3-18
  - 3.8 Develop Inputs for Selection of Provisional Measurement Methods ..... 3-19
    - 3.8.1 Measurement Method Uncertainty ..... 3-21
    - 3.8.2 Detection Capability ..... 3-21
    - 3.8.3 Quantification Capability..... 3-22
    - 3.8.4 Range ..... 3-22
    - 3.8.5 Specificity ..... 3-22
    - 3.8.6 Ruggedness ..... 3-23
  - 3.9 Identify Reference Materials..... 3-24
  - 3.10 Evaluate an Existing Survey Design ..... 3-25
- 4 Develop a Survey Design..... 4-1
  - 4.1 Introduction ..... 4-1
  - 4.2 Making Decisions Using Statistics ..... 4-1

4.2.1	Null Hypothesis .....	4-2
4.2.2	Discrimination Limit .....	4-2
4.2.3	Scenario A .....	4-4
4.2.4	Scenario B.....	4-4
4.2.5	Specify Limits on Decision Errors .....	4-5
4.2.6	Develop an Operational Decision Rule .....	4-5
4.3	Classify the Materials and Equipment .....	4-6
4.3.1	Class 1.....	4-6
4.3.2	Class 2.....	4-7
4.3.3	Class 3.....	4-7
4.3.4	Other Classification Considerations .....	4-7
4.4	Design the Disposition Survey.....	4-8
4.4.1	Scan-Only Survey Designs .....	4-9
4.4.1.1	Class 1 Scan-Only Surveys .....	4-13
4.4.1.2	Class 2 Scan-Only Surveys .....	4-13
4.4.1.3	Class 3 Scan-Only Surveys .....	4-14
4.4.2	In Situ Survey Designs .....	4-15
4.4.2.1	Class 1 In situ Surveys .....	4-15
4.4.2.2	Class 2 In situ Surveys .....	4-16
4.4.2.3	Class 3 In situ Surveys .....	4-16
4.4.3	MARSSIM-Type Survey Designs .....	4-16
4.4.3.1	Class 1 MARSSIM-Type Surveys .....	4-17
4.4.3.2	Class 2 MARSSIM-Type Surveys .....	4-18
4.4.3.3	Class 3 MARSSIM-Type Surveys .....	4-18
4.4.4	Method-Based Survey Designs.....	4-18
4.4.5	Optimize the Disposition Survey Design .....	4-19
4.5	Document the Disposition Survey Design.....	4-20
4.5.1	Routine Surveys and Standard Operating Procedures .....	4-21
4.5.1.1	SOP Process .....	4-22
4.5.1.2	General Format for Disposition Survey SOPs .....	4-22
4.5.2	Case-Specific Applications.....	4-24
5	Implement the Survey Design .....	5-1
5.1	Introduction.....	5-1
5.2	Ensure Protection of Health and Safety .....	5-1
5.3	Consider Issues for Handling M&E.....	5-3
5.3.1	Prepare M&E for Survey .....	5-4
5.3.2	Provide Access.....	5-5
5.3.3	Transport the M&E.....	5-6
5.4	Segregate the M&E.....	5-6
5.5	Set Measurement Quality Objectives.....	5-7
5.6	Determine Measurement Uncertainty .....	5-9
5.7	Determine Measurement Detectability .....	5-10
5.8	Determine Measurement Quantifiability.....	5-12
5.9	Select a Measurement Technique and Instrumentation Combination.....	5-13
5.9.1	Select a Measurement Technique .....	5-14
5.9.1.1	Scanning Techniques .....	5-14

5.9.1.2	In Situ Measurements.....	5-14
5.9.1.3	Sampling .....	5-15
5.9.1.4	Smears .....	5-15
5.9.2	Select Instrumentation .....	5-16
5.9.2.1	Hand-Held Instruments .....	5-16
5.9.2.2	Volumetric Counters (Drum, Box, Barrel, 4- $\pi$ Counters).....	5-16
5.9.2.3	Conveyorized Survey Monitoring Systems .....	5-16
5.9.2.4	In Situ Gamma Spectroscopy.....	5-17
5.9.2.5	Portal Monitors.....	5-17
5.9.2.6	Laboratory Analysis.....	5-17
5.9.3	Select a Measurement Method.....	5-17
5.9.4	Measurement Performance Indicators .....	5-23
5.9.4.1	Blanks.....	5-23
5.9.4.2	Replicate Measurements .....	5-23
5.9.4.3	Spikes and Standards.....	5-24
5.9.5	Instrument Performance Indicators.....	5-24
5.9.5.1	Performance Tests.....	5-24
5.9.5.2	Functional Tests .....	5-24
5.9.5.3	Instrument Background.....	5-25
5.9.5.4	Efficiency Calibrations.....	5-25
5.9.5.5	Energy Calibrations (Spectrometry Systems) .....	5-25
5.9.5.6	Peak Resolution and Tailing (Spectrometry Systems).....	5-25
5.9.5.7	Voltage Plateaus (Gas Proportional Systems).....	5-25
5.9.5.8	Self Absorption, Backscatter, and Crosstalk.....	5-26
5.10	Report the Results .....	5-26
6	Evaluate the Survey Results .....	6-1
6.1	Introduction .....	6-1
6.2	Conduct Data Quality Assessment.....	6-1
6.2.1	Review the Data Quality Objectives and Survey Design .....	6-1
6.2.2	Conduct a Preliminary Data Review .....	6-3
6.2.2.1	Review Quality Assurance and Quality Control Reports .....	6-3
6.2.2.2	Perform a Graphical Data Review .....	6-4
6.2.2.3	Calculate Basic Statistical Quantities.....	6-5
6.2.3	Select the Statistical Tests .....	6-7
6.2.3.1	Scan-Only Surveys.....	6-7
6.2.3.2	In Situ Surveys .....	6-8
6.2.3.3	MARSSIM-Type Survey Designs.....	6-8
6.2.4	Verify the Assumptions of the Tests .....	6-9
6.2.5	Draw Conclusions from the Data .....	6-11
6.3	Compare Results to the UBGR .....	6-12
6.4	Compare Results Using an Upper Confidence Limit.....	6-12
6.4.1	Calculate the Upper Confidence Limit .....	6-13
6.4.2	Upper Confidence Limit Example: Class 1 Concrete Rubble .....	6-14
6.5	Conduct the Sign Test.....	6-16
6.5.1	Apply the Sign Test to Scenario A .....	6-17
6.5.2	Apply the Sign Test to Scenario B .....	6-17

6.5.3	Sign Test Example: Class 1 Copper Pipes.....	6-17
6.6	Conduct the Wilcoxon Rank Sum Test.....	6-19
6.6.1	Apply the WRS Test to Scenario A.....	6-19
6.6.2	Apply the WRS Test to Scenario B.....	6-19
6.6.3	WRS Test Scenario A Example: Class 2 Metal Ductwork.....	6-20
6.6.4	WRS Test Scenario B Example: Class 2 Metal Ductwork.....	6-21
6.7	Conduct the Quantile Test.....	6-23
6.8	Evaluate the Results: The Decision.....	6-23
6.8.1	Compare Results to the UBGR.....	6-26
6.8.2	Compare Results Using an Upper Confidence Limit.....	6-26
6.8.3	Compare Results for MARSSIM-Type Surveys.....	6-27
6.9	Investigate Causes for Survey Unit Failures.....	6-27
6.10	Document the Disposition Survey Results.....	6-28
7	Statistical Basis for MARSAME Surveys.....	7-1
7.1	Overview of Statistical Survey Design and Hypothesis Testing.....	7-6
7.2	Statistical Decision-Making.....	7-9
7.2.1	Null Hypothesis.....	7-9
7.2.2	Discrimination Limit.....	7-10
7.2.3	Scenario A.....	7-12
7.2.4	Scenario B.....	7-13
7.2.5	Specify Limits on Decision Errors.....	7-13
7.2.6	Develop an Operational Decision Rule.....	7-15
7.3	Set Measurement Quality Objectives.....	7-16
7.3.1	Determine the Required Measurement Method Uncertainty at the UBGR.....	7-18
7.3.1.1	Scan-Only Survey Designs.....	7-18
7.3.1.2	In Situ Survey Designs.....	7-18
7.3.1.3	MARSSIM-Type Survey Designs.....	7-19
7.3.2	Determine the Required Measurement Method Uncertainty at Concentrations Other Than the UBGR.....	7-20
7.4	Determine Measurement Uncertainty.....	7-22
7.4.1	Use Standard Terminology.....	7-23
7.4.2	Consider Sources of Uncertainty.....	7-24
7.4.3	Recommendations for Uncertainty Calculation and Reporting.....	7-26
7.5	Determine Measurement Detectability.....	7-27
7.5.1	Calculate the Critical Value.....	7-28
7.5.2	Calculate the Minimum Detectable Value of the Net Instrument Signal or Count.....	7-29
7.5.3	Calculate the Minimum Detectable Concentration.....	7-31
7.5.4	Summary of Measurement Detectability.....	7-32
7.5.5	Measurement Detectability Recommendations.....	7-34
7.6	Determine Measurement Quantifiability.....	7-34
7.6.1	Calculate the MQC.....	7-35
7.6.2	Summary of Measurement Quantifiability.....	7-36
7.7	Establish a Required Measurement Method Uncertainty.....	7-37
7.7.1	Developing a Requirement for Measurement Method Uncertainty for MARSSIM-Type Surveys.....	7-38

- 7.7.2 Developing a Requirement for Measurement Method Uncertainty When Decisions are to be Made About Individual Items ..... 7-40
- 7.8 Calculate the Combined Standard Uncertainty of a Measurement ..... 7-42
  - 7.8.1 Procedures for Evaluating Uncertainty..... 7-42
    - 7.8.1.1 Identify the Measurand,  $Y$ , and all the Input Quantities,  $X_i$ , for the Mathematical Model ..... 7-42
    - 7.8.1.2 Determine an Estimate,  $x_i$ , of the Value of Each Input Quantity,  $X_i$  ..... 7-42
    - 7.8.1.3 Evaluate the Standard Uncertainty,  $u(x_i)$ , for Each Input Estimate,  $x_i$ , Using a Type A Method, a Type B Method, or a Combination of Both ..... 7-42
    - 7.8.1.4 Evaluate the Covariances,  $u(x_i, x_j)$ , for all Pairs of Input Estimates with Potentially Significant Correlations ..... 7-45
    - 7.8.1.5 Calculate the Estimate,  $y$ , of the Measurand from the Relationship  $y = f(x_1, x_2, \dots, x_N)$  ..... 7-45
    - 7.8.1.6 Determine the Combined Standard Uncertainty,  $u_c(y)$ , of the Estimate,  $y$  ..... 7-45
    - 7.8.1.7 Optionally Multiply  $u_c(y)$  by a Coverage Factor  $k$  to Obtain the Expanded Uncertainty,  $U$  ..... 7-46
    - 7.8.1.8 Report the Result as  $y \pm U$  with the Unit of Measurement ..... 7-47
  - 7.8.2 Examples of Some Parameters that Contribute to Uncertainty ..... 7-47
    - 7.8.2.1 Instrument Background ..... 7-47
    - 7.8.2.2 Counting Efficiency ..... 7-48
    - 7.8.2.3 Digital Displays and Rounding ..... 7-51
  - 7.8.3 Example Uncertainty Calculation ..... 7-52
    - 7.8.3.1 Model Equation and Sensitivity Coefficients ..... 7-52
    - 7.8.3.2 Uncertainty Components..... 7-53
    - 7.8.3.3 Uncertainty Budget ..... 7-56
    - 7.8.3.4 Reported Result ..... 7-56
- 7.9 Calculate the Minimum Detectable Concentration ..... 7-57
  - 7.9.1 Critical Value..... 7-57
  - 7.9.2 Minimum Detectable Concentration..... 7-58
  - 7.9.3 Calculation of the Critical Value ..... 7-59
  - 7.9.4 Calculation of the Minimum Detectable Value of the Net Instrument Signal ..... 7-60
  - 7.9.5 Calculation of the Minimum Detectable Concentration ..... 7-61
- 7.10 Calculate the Minimum Quantifiable Concentration ..... 7-63
- 7.11 Calculate Scan MDCs ..... 7-66
  - 7.11.1 Calculate the Relative Fluence Rate to Exposure Rate (FRER)..... 7-67
  - 7.11.2 Calculate the Probability of Interaction ..... 7-67
  - 7.11.3 Calculate the Relative Detector Response ..... 7-69
  - 7.11.4 Relationship Between Detector Response and Exposure Rate ..... 7-69
  - 7.11.5 Relationship Between Detector Response and Radionuclide Concentration..... 7-70
  - 7.11.6 Calculation of Scan Minimum Detectable Count Rates ..... 7-72
  - 7.11.7 Calculate the Scan Minimum Detectable Concentration ..... 7-73

8	Illustrative Examples .....	8-1
8.1	Introduction .....	8-1
8.2	Mineral Processing Facility Concrete Rubble.....	8-1
8.2.1	Description.....	8-2
8.2.2	Objectives .....	8-2
8.2.3	Initial Assessment of the M&E.....	8-2
8.2.3.1	Categorize the M&E as Impacted or Non-Impacted.....	8-2
8.2.3.2	Describe the M&E.....	8-3
8.2.3.3	Design and Implement Preliminary Surveys.....	8-4
8.2.3.4	Select a Disposition Option.....	8-7
8.2.3.5	Document the Results of the Initial Assessment.....	8-8
8.2.4	Develop a Decision Rule .....	8-8
8.2.4.1	Select Radionuclides or Radiations of Concern.....	8-8
8.2.4.2	Identify Action Levels.....	8-8
8.2.4.3	Modify the Action Levels to Account for Multiple Radionuclides.....	8-10
8.2.4.4	Describe the Parameter of Interest .....	8-11
8.2.4.5	Identify Alternative Actions.....	8-12
8.2.4.6	Identify Survey Units .....	8-12
8.2.4.7	Define the Decision Rules.....	8-12
8.2.4.8	Develop Inputs for Selection of Provisional Measurement Methods.....	8-13
8.2.4.9	Identify Reference Materials.....	8-14
8.2.5	Develop a Survey Design .....	8-14
8.2.5.1	Classify the M&E.....	8-14
8.2.5.2	Design the Scanning Survey .....	8-15
8.2.5.3	Design the Sample Collection Survey.....	8-15
8.2.5.4	Develop an Operational Decision Rule.....	8-16
8.2.5.5	Document the Survey Design.....	8-16
8.2.6	Implement the Survey Design .....	8-16
8.2.6.1	Ensure Protection of Health and Safety .....	8-16
8.2.6.2	Consider Issues for Handling the M&E.....	8-18
8.2.6.3	Segregate the M&E.....	8-18
8.2.6.4	Set Measurement Quality Objectives.....	8-18
8.2.6.5	Determine Measurement Uncertainty for the Scan MDC.....	8-18
8.2.6.6	Determine Measurement Uncertainty for Concrete Samples.....	8-22
8.2.6.7	Collect Survey Data .....	8-23
8.2.7	Evaluate the Survey Results .....	8-24
8.2.7.1	Conduct a Data Quality Assessment .....	8-24
8.2.7.2	Conduct the Wilcoxon Rank Sum Test.....	8-24
8.2.8	Evaluate the Results: The Decision .....	8-25
8.3	Mineral Processing Facility Rented Equipment Baseline Survey.....	8-26
8.3.1	Description.....	8-26
8.3.2	Objectives .....	8-26
8.3.3	Initial Assessment of the M&E.....	8-26
8.3.3.1	Categorize the M&E as Impacted or Non-Impacted.....	8-26

8.3.3.2	Describe the M&E.....	8-28
8.3.3.3	Design and Implement Preliminary Surveys.....	8-30
8.3.3.4	Select a Disposition Option.....	8-30
8.3.3.5	Document the Results of the Initial Assessment.....	8-30
8.3.4	Develop a Decision Rule .....	8-30
8.3.4.1	Select Radionuclides or Radiations of Concern.....	8-30
8.3.4.2	Identify Action Levels.....	8-31
8.3.4.3	Describe the Parameter of Interest .....	8-31
8.3.4.4	Identify Alternative Actions.....	8-31
8.3.4.5	Develop a Decision Rule.....	8-31
8.3.4.6	Identify Survey Units .....	8-31
8.3.4.7	Develop Inputs for Selection of Provisional Measurement Methods.....	8-31
8.3.4.8	Reference Materials .....	8-32
8.3.5	Develop a Survey Design .....	8-33
8.3.5.1	Select a Null Hypothesis .....	8-33
8.3.5.2	Set the Discrimination Limit.....	8-33
8.3.5.3	Specify the Limits on Decision Errors .....	8-33
8.3.5.4	Select a Measurement Technique.....	8-34
8.3.5.5	Finalize Selection of Radiations to be Measured.....	8-35
8.3.5.6	Develop an Operational Decision Rule.....	8-35
8.3.5.7	Classify the M&E.....	8-35
8.3.5.8	Select a Measurement Method .....	8-35
8.3.5.9	Optimize the Disposition Survey Design.....	8-37
8.3.5.10	Document the Disposition Survey Design .....	8-37
8.3.6	Implement the Survey Design .....	8-37
8.3.6.1	Ensure Protection of Health and Safety .....	8-37
8.3.6.2	Consider Issues for Handling M&E.....	8-37
8.3.6.3	Segregate the M&E.....	8-38
8.3.6.4	Determine the Measurement Detectability for the Scan Survey .	8-38
8.3.6.5	Determine the Measurement Detectability for the Investigation Survey .....	8-38
8.3.6.6	Determine Measurement Uncertainty for the Investigation Survey MDC.....	8-39
8.3.6.7	Perform Quality Control Measurements .....	8-41
8.3.6.8	Collect Survey Data .....	8-41
8.3.7	Evaluate the Survey Results .....	8-41
8.3.7.1	Conduct a Data Quality Assessment.....	8-41
8.3.7.2	Conduct a Preliminary Data Review.....	8-41
8.3.7.3	Conduct the Statistical Tests .....	8-41
8.3.8	Evaluate the Results: The Decision .....	8-42
8.4	Mineral Processing Facility Rented Equipment Disposition Survey .....	8-42
8.4.1	Description.....	8-42
8.4.2	Objectives .....	8-42
8.4.3	Initial Assessment of the M&E.....	8-42
8.4.3.1	Categorize the M&E as Impacted or Non-Impacted.....	8-42

8.4.3.2	Describe the M&E.....	8-43
8.4.3.3	Select a Disposition Option.....	8-44
8.4.3.4	Document the Results of the Initial Assessment.....	8-44
8.4.4	Develop a Decision Rule .....	8-44
8.4.4.1	Identify Action Levels.....	8-44
8.4.4.2	Evaluate an Existing Survey Design .....	8-44
8.4.5	Develop a Survey Design .....	8-44
8.4.5.1	Select the Null Hypothesis .....	8-44
8.4.5.2	Set the Discrimination Limit.....	8-45
8.4.5.3	Specify Limits on Decision Errors.....	8-45
8.4.5.4	Classify the M&E.....	8-45
8.4.5.5	Optimize the Existing Survey Design.....	8-45
8.4.5.6	Document the Disposition Survey Design .....	8-46
8.4.6	Implement the Survey Design .....	8-46
8.4.7	Evaluate the Survey Results .....	8-46
8.4.7.1	Conduct a Data Quality Assessment .....	8-46
8.4.7.2	Conduct the Statistical Tests .....	8-47
8.4.8	Evaluate the Results: The Decision .....	8-47
Appendix A	Statistical Tables and Procedures.....	A-1
A.1	Normal Distribution .....	A-1
A.2	Sample Sizes for Statistical Tests .....	A-2
A.3	Critical Values for the Sign Test.....	A-4
A.4	Critical Values for the WRS Test .....	A-6
A.5	Critical Values for the Quantile Test .....	A-10
Appendix B	Sources of Background Radioactivity .....	B-1
B.1	Introduction.....	B-1
B.2	Environmental Radioactivity .....	B-1
B.2.1	Terrestrial Radioactivity .....	B-2
B.2.2	Anthropogenic Radioactive Materials .....	B-3
B.2.3	Cosmic Radiation and Cosmogenic Radionuclides .....	B-4
B.3	Inherent Radioactivity .....	B-4
B.4	Instrument Background.....	B-5
B.5	Technologically Enhanced Naturally Occurring Radioactive Material .....	B-5
B.6	Orphan Sources .....	B-6
Appendix C	Examples of Common Radionuclides.....	C-1
Appendix D	Instrumentation and Measurement Techniques .....	D-1
D.1	Introduction.....	D-1
D.2	General Detection Instrumentation .....	D-1
D.2.1	Gas-Filled Detectors .....	D-1
D.2.1.1	Ionization Chamber Detectors.....	D-2
D.2.1.2	Gas-Flow Proportional Detectors.....	D-2
D.2.1.3	Geiger-Mueller Detectors.....	D-3
D.2.2	Scintillation Detectors.....	D-4
D.2.2.1	Zinc Sulfide Scintillation Detectors .....	D-4
D.2.2.2	Sodium Iodide Scintillation Detectors .....	D-4

- D.2.2.3 Cesium Iodide Scintillation Detectors..... D-4
      - D.2.2.4 Plastic Scintillation Detectors ..... D-5
    - D.2.3 Solid State Detectors..... D-5
  - D.3 Counting Electronics..... D-5
  - D.4 Hand-Held Instruments ..... D-6
    - D.4.1 Instruments..... D-6
    - D.4.2 Temporal Issues ..... D-6
    - D.4.3 Spatial Issues..... D-7
    - D.4.4 Radiation Types ..... D-7
    - D.4.5 Range ..... D-8
    - D.4.6 Scale..... D-8
    - D.4.7 Ruggedness ..... D-8
  - D.5 Volumetric Counters (Drum, Box, Barrel, Four-Pi Counters)..... D-9
    - D.5.1 Instruments..... D-9
    - D.5.2 Temporal Issues ..... D-10
    - D.5.3 Spatial Issues..... D-10
    - D.5.4 Radiation Types ..... D-10
    - D.5.5 Range ..... D-10
    - D.5.6 Scale..... D-11
    - D.5.7 Ruggedness ..... D-11
  - D.6 Conveyorized Survey Monitoring Systems ..... D-11
    - D.6.1 Instruments..... D-11
    - D.6.2 Temporal Issues ..... D-12
    - D.6.3 Spatial Issues..... D-12
    - D.6.4 Radiation Types ..... D-13
    - D.6.5 Range ..... D-13
    - D.6.6 Scale..... D-13
    - D.6.7 Ruggedness ..... D-13
  - D.7 In Situ Gamma Spectroscopy..... D-14
    - D.7.1 Instruments..... D-14
    - D.7.2 Temporal Issues ..... D-14
    - D.7.3 Spatial Issues..... D-15
    - D.7.4 Radiation Types ..... D-15
    - D.7.5 Range ..... D-15
    - D.7.6 Scale..... D-15
    - D.7.7 Ruggedness ..... D-16
  - D.8 Hand-Held Radionuclide Identifiers ..... D-16
    - D.8.1 Instruments..... D-16
    - D.8.2 Temporal Issues ..... D-16
    - D.8.3 Spatial Issues..... D-16
    - D.8.4 Radiation Types ..... D-17
    - D.8.5 Range ..... D-17
    - D.8.6 Scale..... D-17
    - D.8.7 Ruggedness ..... D-17
  - D.9 Portal Monitors ..... D-17
    - D.9.1 Instruments..... D-17

D.9.2	Temporal Issues .....	D-18
D.9.3	Spatial Issues.....	D-18
D.9.4	Radiation Types .....	D-19
D.9.5	Range .....	D-19
D.9.6	Scale.....	D-19
D.9.7	Ruggedness .....	D-19
D.10	Sample with Laboratory Analysis.....	D-19
D.10.1	Instruments .....	D-20
D.10.1.1	Instruments for the Detection of Alpha Radiation .....	D-20
D.10.1.2	Instruments for the Detection of Beta Radiation.....	D-21
D.10.1.3	Instruments for the Detection of Gamma or X-Radiation.....	D-21
D.10.2	Temporal Issues .....	D-21
D.10.3	Spatial Issues .....	D-22
D.10.3.1	Alpha Spectroscopy with Multi-Channel Analyzer .....	D-22
D.10.3.2	Gas-Flow Proportional Counter .....	D-22
D.10.3.3	Liquid Scintillation Spectrometer .....	D-23
D.10.3.4	Low-Resolution Alpha Spectroscopy.....	D-23
D.10.3.5	High-Purity Germanium Detector with Multi-Channel Analyzer .....	D-23
D.10.3.6	Sodium Iodide Detector with Multi-Channel Analyzer .....	D-23
D.10.3.7	Alpha Scintillation Detectors .....	D-23
D.10.4	Radiation Types .....	D-24
D.10.5	Range .....	D-24
D.10.6	Scale.....	D-25
D.10.7	Ruggedness .....	D-26
Appendix E	Disposition Criteria.....	E-1
E.1	Department of Energy .....	E-1
E.1.1	10 CFR 835 (Non-Exhaustive Excerpts) .....	E-1
E.1.1.1	§ 835.405 Receipt of Packages Containing Radioactive Material .....	E-1
E.1.1.2	§ 835.605 Labeling Items and Containers.....	E-2
E.1.1.3	§ 835.606 Exceptions to Labeling Requirements .....	E-2
E.1.1.4	§ 835.1101 Control of Material and Equipment .....	E-2
E.1.1.5	§ 835.1102 Control of Areas.....	E-3
E.1.2	Appendix D to 10 CFR 835 – Surface Contamination Values .....	E-3
E.1.3	DOE Guidance and Similar Documents .....	E-5
E.2	International Organizations.....	E-7
E.2.1	International Atomic Energy Agency (IAEA).....	E-7
E.2.2	European Commission.....	E-7
E.3	Nuclear Regulatory Commission .....	E-8
E.3.1	§ 20.2003 Disposal by Release into Sanitary Sewerage.....	E-8
E.3.2	§ 20.2005 Disposal of Specific Wastes .....	E-8
E.3.3	§ 35.92 Decay-in-Storage .....	E-9
E.3.4	§ 35.315 Safety Precautions .....	E-9
E.3.5	§ 36.57 Radiation Surveys.....	E-9
E.3.6	Appendix A to Part 40–Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or	

	Concentration of Source Material from Ores Processed Primarily for Their Source Material Content .....	E-9
E.3.7	§ 71.4 Definitions .....	E-9
E.3.8	§ 71.14 Exemption for Low-Level Materials .....	E-11
E.3.9	§ 110.22 General License for the Export of Source Material .....	E-12
E.3.10	§ 110.23 General License for the Export of Byproduct Material .....	E-12
E.3.11	Policies and Practices .....	E-13
E.3.12	Issues Related to International Trade .....	E-14
References	.....	Ref-1
Glossary	.....	GL-1

## LIST OF FIGURES

Roadmap Figure 1	Overview of MARSAME Process.....	RM-6
Roadmap Figure 2	The Data Life Cycle Applied to Disposition Surveys .....	RM-7
Roadmap Figure 3	The Categorization Process as Part of Initial Assessment.....	RM-8
Roadmap Figure 4	Assessing Adequacy of Information for Designing .....	RM-9
Roadmap Figure 5	Assessing the Applicability of Existing SOPs.....	RM-10
Roadmap Figure 6	Identify Inputs to the Decision .....	RM-11
Roadmap Figure 7	Identify Action Levels .....	RM-12
Roadmap Figure 8	Developing Survey Unit Boundaries (Apply to All Impacted M&E for each set of Action Levels Identified in Section 3.3).....	RM-13
Roadmap Figure 9	Flow Diagram for Developing a Disposition Survey Design.....	RM-14
Roadmap Figure 10	Flow Diagram for Identifying the Number of Data Points for a MARSSIM-Type Disposition Survey .....	RM-15
Roadmap Figure 11	Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units for MARSSIM-Type Disposition Surveys.....	RM-16
Roadmap Figure 12	Implementation of Disposition Surveys .....	RM-17
Roadmap Figure 13	Assess the Results of the Disposition Survey.....	RM-18
Roadmap Figure 14	Interpretation of Survey Results for Scan-Only and In Situ Surveys..	RM-19
Roadmap Figure 15	Interpretation of Survey Results for MARSSIM-Type Surveys .....	RM-20
Figure 1.1	The Data Life Cycle Applied to Disposition Surveys .....	1-8
Figure 2.1	The Categorization Process as Part of Initial Assessment .....	2-2
Figure 2.2	Assessing Adequacy of Information for Designing Disposition Surveys .....	2-10
Figure 2.3	Documentation of the Initial Assessment .....	2-20
Figure 3.1	Identifying Inputs to the Decision.....	3-2
Figure 3.2	Identifying Action Levels .....	3-4
Figure 3.3	Developing Survey Unit Boundaries .....	3-16
Figure 4.1	Relative Shift, $\Delta/\sigma$ , Comparison for Scenario A: $\sigma$ is Large, but the Large $\Delta$ Results in a Large $\Delta/\sigma$ and Fewer Samples .....	4-3
Figure 4.2	Relative Shift, $\Delta/\sigma$ , Comparison for Scenario A: $\sigma$ is Small, but the Small $\Delta$ Results in a Small $\Delta/\sigma$ and More Samples.....	4-3
Figure 4.3	Illustration of Scenario A.....	4-4
Figure 4.4	Illustration of Scenario B .....	4-4
Figure 4.5	Flow Diagram for a Disposition Survey Design.....	4-10
Figure 4.6	Flow Diagram for Identifying the Number of Data Points for a MARSSIM-Type Disposition Survey.....	4-11
Figure 4.7	Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units for MARSSIM-Type Disposition Surveys.....	4-12
Figure 4.8	Relationship Between the Relative Shift and the Amount of M&E to be Scanned .....	4-13
Figure 5.1	Implementation of Disposition Surveys.....	5-2

Figure 5.2 The Critical Value ( $S_c$ ) and the Minimum Detectable Value ( $S_D$ ) of the Net Instrument Signal (or Count) ..... 5-11

Figure 6.1 The Assessment Phase of the Data Life Cycle ..... 6-2

Figure 6.2 Frequency Plot of Concrete Rubble Data ..... 6-15

Figure 6.3 Screen Capture of Output from ProUCL Software for the Sample Data Set..... 6-16

Figure 6.4 Interpretation of Survey Results for Scan-Only and In Situ Surveys ..... 6-24

Figure 6.5 Statistical Interpretation of Results for MARSSIM-Type Surveys ..... 6-25

Figure 7.1 Relative Shift,  $\Delta/\sigma$ , Comparison for Scenario A:  $\sigma$  is Large, but the Large  $\Delta$  Results in a Large  $\Delta/\sigma$  and Fewer Samples ..... 7-11

Figure 7.2 Relative Shift,  $\Delta/\sigma$ , Comparison for Scenario A:  $\sigma$  is Small, but the Small  $\Delta$  Results in a Small  $\Delta/\sigma$  and More Samples..... 7-11

Figure 7.3 Illustration of Scenario A..... 7-12

Figure 7.4 Illustration of Scenario B ..... 7-13

Figure 7.5 Example of the Required Measurement Uncertainty at Concentrations other than the UBGR. In this Example the UBGR Equals the Action Level ..... 7-21

Figure 7.6 The Critical Value of the Net Instrument Signal ( $S_c$ ) and the Minimum Detectable Net Signal ( $S_D$ ) ..... 7-31

Figure 7.7 Relationship Between the Critical Value of the Net Count, the Minimum Detectable Net Counts and the MDC..... 7-33

Figure 7.8 Probability of Detection as a Function of Net Count (Lower X-Axis) and Concentration (Upper X-Axis) ..... 7-33

Figure 7.9 Relationships Among the Critical Value, the MDC, the MQC, and the Probability of Exceeding the Critical Value..... 7-37

Figure 8.1 Frequency Plot of Illustrative Example Data..... 8-25

Figure 8.2 Cumulative Frequency Plot of Illustrative Example Data ..... 8-25

Figure 8.3 Front Loader..... 8-27

Figure D.1 Example Volumetric Counter (Thermo 2005)..... D-9

Figure D.2 Example Conveyorized Survey Monitoring System (Laurus 2001)..... D-12

Figure D.3 Example Portal Monitor (Canberra 2005b) ..... D-18

## LIST OF TABLES

Table 1.1	The Data Life Cycle Used to Support Disposition Survey Design.....	1-7
Table 1.2	Similarities Between MARSSIM and MARSAME.....	1-15
Table 1.3	Differences Between MARSSIM and MARSAME .....	1-16
Table 2.1	Physical Attributes Used to Describe M&E .....	2-12
Table 2.2	Radiological Attributes Used to Describe M&E .....	2-15
Table 3.1	Example Detector Efficiency Calculation ( $^{232}\text{Th}$ in Complete Equilibrium with its Decay Products) Using a Gas Proportional Detector.....	3-11
Table 3.2	Example Alternative Actions.....	3-15
Table 3.3	Examples of Consensus Standards for Evaluating Ruggedness .....	3-24
Table 5.1	Potential Applications for Instrumentation and Measurement Technique Combinations .....	5-18
Table 5.2	Survey Unit Size and Quantity Restrictions for Instrumentation and Measurement Technique Combinations .....	5-18
Table 5.3	Advantages and Disadvantages of Instrumentation and Measurement Technique Combinations .....	5-20
Table 6.1	Issues and Assumptions Underlying the Evaluation Method .....	6-10
Table 6.2	Summary of Evaluation Methods and Statistical Tests .....	6-11
Table 6.3	Sign Test Example Data.....	6-18
Table 6.4	Scenario A WRS Test Example Data .....	6-21
Table 6.5	Scenario B WRS Test Example Data.....	6-22
Table 7.1	Notation for DQOs and MQOs .....	7-2
Table 7.2	Notation for Uncertainty Calculations .....	7-3
Table 7.3	Notation for MDC Calculations.....	7-4
Table 7.4	Notation for MQC Calculations.....	7-5
Table 7.5	Recommended Approaches for Calculating the Critical Value of the Net Instrument Signal (Count), $S_C$ .....	7-28
Table 7.6	Recommended Approaches for Calculating the Minimum Detectable Net Instrument Signal or Count.....	7-30
Table 7.7	Uncertainty Budget for the Efficiency Example.....	7-56
Table 7.8	Calculation of Detector Response to Natural Uranium .....	7-68
Table 7.9	Calculation of Detector Response for Natural Thorium .....	7-69
Table 7.10	Detector Response to Natural Uranium .....	7-71
Table 7.11	Detector Response to Natural Thorium .....	7-71
Table 7.12	Scan MDCs for FIDLER .....	7-74
Table 8.1	Physical Attributes of the Concrete Rubble.....	8-4
Table 8.2	Radiological Attributes of the Concrete Rubble.....	8-5
Table 8.3	Preliminary Alpha Spectrometry Results for Uranium Series Radionuclides .....	8-6
Table 8.4	Preliminary Alpha Spectrometry Results for Thorium Series Radionuclides .....	8-6
Table 8.5	Preliminary Gamma Spectroscopy Results for Uranium Series Radionuclides ..	8-7
Table 8.6	Preliminary Gamma Spectroscopy Results for Thorium Series Radionuclides ..	8-7
Table 8.7	Radionuclide-Specific Action Levels .....	8-9
Table 8.8	Calculation of the Gross Gamma Action Level.....	8-11

Table 8.9	Job Safety Analysis for Surveying Concrete Rubble.....	8-17
Table 8.10	Radionuclide-Specific Required Relative Measurement Method Uncertainties	8-23
Table 8.11	Sentinel Measurement Results.....	8-27
Table 8.12	Physical Attributes Used to Describe the Front Loader.....	8-28
Table 8.13	Radiological Attributes Used to Describe the Front Loader.....	8-29
Table 8.14	Potential Discrimination Limits.....	8-33
Table 8.15	Detector Efficiency for the Mineral Processing Facility ( <sup>232</sup> Th in Complete Equilibrium with its Progeny) using a Gas Proportional Detector .....	8-36
Table 8.16	Sentinel Measurement Results.....	8-43
Table A.1	Cumulative Normal Distribution Function $\Phi(z)$ .....	A-1
Table A.2a	Sample Sizes for Sign Test .....	A-2
Table A.2b	Sample Sizes for Wilcoxon Rank Sum Test.....	A-3
Table A.3	Critical Values for the Sign Test Statistic $S^+$ .....	A-4
Table A.4	Critical Values for the WRS Test .....	A-6
Table A.5a	Values of $r$ and $k$ for the Quantile Test When $\alpha$ Is Approximately 0.01 .....	A-10
Table A.5b	Values of $r$ and $k$ for the Quantile Test When $\alpha$ Is Approximately 0.025 .....	A-11
Table A.5c	Values of $r$ and $k$ for the Quantile Test When $\alpha$ Is Approximately 0.05 .....	A-12
Table A.5d	Values of $r$ and $k$ for the Quantile Test When $\alpha$ Is Approximately 0.10.....	A-13
Table B.1	Typical Average Concentration Ranges of Terrestrial Radionuclides .....	B-2
Table C.1	Examples of Common Radionuclides at Selected Types of Facilities .....	C-1
Table D.1	Potential Applications for Common Hand-Held Instruments.....	D-7
Table D.2	Typical Preparation and Counting Times .....	D-22
Table D.3	Radiation Applications for Laboratory Instruments and Methods .....	D-24
Table D.4	Typical Energy Ranges and Maximum Activities .....	D-25
Table D.5	Typical Liquid and Solid Sample Sizes.....	D-25
Table E.1	Surface Contamination Values <sup>1</sup> in dpm/100 cm <sup>2</sup> as Reported in Appendix D to 10 CFR 835 .....	E-4
Table E.2	Figure IV-1, from DOE Order 5400.5, as Supplemented in November, 1995 Memorandum: Surface Activity Guidelines – Allowable Total Residual Surface Activity (dpm/100 cm <sup>2</sup> ) .....	E-6
Table E.3	Summary of NRC Disposition Criteria from Current Practices for the Release of Materials and Equipment .....	E-14

## ACKNOWLEDGEMENTS

The *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) and the *Multi-Agency Radiation Survey and Assessment of Materials and Equipment* manual (MARSAME) supplement came about as a result of individuals—at the management level—within the Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), Department of Energy (DOE), and Department of Defense (DOD) who recognized the necessity for a standardized guidance document for investigating radioactively contaminated sites. The creation of MARSSIM and MARSAME was facilitated by the cooperation of subject matter specialists from these agencies with management's support and a willingness to work smoothly together toward reaching the common goal of creating a workable and user-friendly guidance manual. Special appreciation is extended to Robert A. Meck of the NRC and Anthony Wolbarst of EPA for developing the concept of a multi-agency workgroup and bringing together representatives from the participating agencies.

MARSAME could not have been possible without the technical workgroup members who contributed their time, talent, and efforts to develop this consensus guidance document:

CAPT Colleen F. Petullo, U.S. Public Health Service, EPA, Chair

DOD David P. Alberth (Army)	EPA Kathryn Snead
Dennis Chambers, CHP (Army, Retired)	Nidal Azzam
Gerald Faló, Ph.D., CHP (Army)	Lindsey Bender
Steven Doremus, Ph.D. (Navy)	Vicki Lloyd
CAPT Vincent DeInnocentiis (Navy)	Eugene Jablonowski
Ramachandra Bhat, Ph.D., CHP (Air Force)	
Lt Col Craig Bias, Ph.D., CHP (Air Force)	
Lt Col Daniel Caputo, Ph.D. (Air Force Reserve)	
DOE W. Alexander Williams, Ph.D.	NRC Robert A. Meck, Ph.D.
Emile Boulos	George E. Powers, Ph.D.
Harold T. Peterson, Jr., CHP (Retired)	Joseph DeCicco, CHP
Amanda Anderson	Anthony Huffert, CHP
Wayne Glines, CHP	
	DHS Carl V. Gogolak, Ph.D. (Retired)

Special mention is extended to the Federal Agency contractors for their assistance in developing the MARSAME supplement:

Scott Hay (Cabrera Services, Inc.)  
 Carl V. Gogolak (Environmental Management Support, Inc.)  
 Nicholas Berliner (Cabrera Services, Inc.)  
 Robert Coleman (Oak Ridge National Laboratory)  
 Deborah Schneider (S. Cohen & Associates, Inc.)  
 Kerri Wachter (S. Cohen & Associates, Inc.)

A special thank you is extended to Mary Clark (EPA), Schatzi Fitz-James (EPA), Paul Giardina (EPA), Bonnie Gitlin (EPA), Sally Hamlin (EPA), David Kappelman (EPA), Sophie Kastner

(EPA), Joseph LaFornara (EPA), Juan Reyes (EPA), Colby Stanton (EPA), Dennisses Valdes (EPA), Jean-Claude Dehmel (NRC), MAJ David Pugh, CHP (Air Force), Brian Renaghan (Air Force), Andrew Wallo III (DOE), Ethel Jacob (DHS), Kevin Miller (DHS), Peter Shebell (DHS), Jenny Goodman (NJ Bureau of Environmental Radiation), Nancy Stanley (NJ Bureau of Environmental Radiation), and Eric Abelquist (Oak Ridge Institute for Science and Education).

The Workgroup would also like to thank EPA's Science Advisory Board Radiation Advisory Committee for their consultations and peer review supporting development of the MARSAME supplement:

#### Chair

Bernd Kahn, Ph.D., Georgia Institute of Technology

Jill Lipoti, Ph.D., New Jersey Department of Environmental Protection (Past Chair)

#### Members

Thomas B. Borak, Ph.D., Colorado State University

Antone L. Brooks, Ph.D., Washington State University Tri-Cities

Faith G. Davis, Ph.D., University of Illinois at Chicago

Brian Dodd, Ph.D., Consultant

Shirley A. Fry, Ph.D., Consultant

William C. Griffith, Ph.D., University of Washington

Jonathan M. Links, Ph.D., Johns Hopkins University

Bruce A. Napier, Pacific Northwest National Laboratory

Daniel O. Stram, Ph.D., University of Southern California

Richard J. Vetter, Ph.D., Mayo Clinic

#### SAB Consultants

Bruce W. Church, BWC Enterprises, Inc.

Kenneth Duvall, Environmental Scientist/Consultant

Janet A. Johnson, Ph.D., Consultant

Paul J. Merges, Ph.D., Environment & Radiation Specialists, Inc.

#### Science Advisory Board Staff

K. Jack Kooyoomjian, Ph.D., Designated Federal Officer, EPA

The Workgroup acknowledges the interest of the NRC's Advisory Committee on Nuclear Waste and Materials in the development of MARSAME.

## ACRONYMS AND ABBREVIATIONS

AL	action level
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
BKGD	background
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
cpm	counts per minute
cps	counts per second
CSM	conceptual site model
CSU	combined standard uncertainty
CZT	cadmium zinc telluride
DAC	derived air concentration
DCGL	derived concentration guideline level
DL	discrimination limit
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
dpm	disintegrations per minute
DQA	data quality assessment
DQO	data quality objective
EMC	elevated measurement comparison
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EU	European Union
EZ	exclusion zone
FIDLER	field instrument for the detection of low-energy radiation
FRER	fluence rate to exposure rate
GM	Geiger Mueller
HASP	health and safety plan
HEU	high-enriched uranium
HPGe	high-purity germanium
HPS	Health Physics Society
HSA	Historical Site Assessment
HPSR	Health Physics Society Report
HWP	hazard work permit
IA	initial assessment
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical & Electronics Engineers
ISGS	in situ gamma spectroscopy
ISO	International Organization for Standardization

JSA	job safety analysis
LBGR	lower bound of the gray region
LEU	low-enriched uranium
LSA	low specific activity
LSC	liquid scintillation cocktail
M&E	materials and equipment
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols manual
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCA	multi-channel analyzer
MDC	minimum detectable concentration
MDCR	minimum detectable count rate
MDCR <sub>surveyor</sub>	MDCR by a less than ideal surveyor
MDER	minimum detectable exposure rate
MQC	minimum quantifiable concentration
MQO	measurement quality objective
NARM	naturally occurring and accelerator-produced radioactive material
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Science and Technology
NJBER	New Jersey Bureau of Environmental Radiation
NORM	naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
NUREG	Nuclear Regulatory Commission technical report prepared by NRC staff
NUREG/CR	Nuclear Regulatory Commission technical report prepared by NRC contractor
ORISE	Oak Ridge Institute for Science and Education
OSHA	Occupational Safety and Health Administration
OSWER	EPA Office of Solid Waste and Emergency Response
PCB	polychlorinated biphenyl
pH	hydrogen ion concentration (acidity or basicity)
PIC	pressurized ion chamber
PPE	personal protective equipment
PVC	polyvinylchloride
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RCA	radiological control area
RCRA	Resource Conservation and Recovery Act
RCSU	relative combined standard uncertainty
RDR	relative detector response
RESRAD	<u>RE</u> Sidual <u>RA</u> Dioactivity computer code (exposure pathway model)
ROC	radionuclide of concern
RTG	Radioisotopic Thermoelectric Generator

RWP	radiation work permit
SCO	surface-contaminated object
SI	International System of Units (Système International d'Unités)
SOP	standard operating procedure
TEDE	total effective dose equivalent
TENORM	technologically enhanced naturally occurring radioactive material
TRU	transuranic
UBGR	upper bound of the gray region
UCL	upper confidence limit
UMTRCA	Uranium Mill Tailings Radiation Control Act
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USEPA	United States Environmental Protection Agency
U.S.	United States
WRS	Wilcoxon Rank Sum



## SYMBOLS, NOMENCLATURE, AND NOTATIONS

<	less than
>	greater than
≤	less than or equal to
≥	greater than or equal to
°	degrees (angle or temperature)
%	percent
1-β	statistical power of a hypothesis test
α	Type I decision-error rate
α <sub>Q</sub>	quantile test (α <sub>Q</sub> = α/2)
a	half-width of a rectangular or triangular probability distribution
A	area
A	overall sensitivity of a measurement
Ac	actinium (isotope listed: <sup>228</sup> Ac)
AL <sub>i</sub>	action level value an individual radionuclide (i = 1, 2, ..., n)
AL <sub>meas,mod</sub>	modified action level for the radionuclide being measured when it is used as a surrogate for other radionuclide(s)
AL <sub>meas</sub>	action level for the radionuclide being measured
AL <sub>infer</sub>	action level for the inferred radionuclide (in surrogate measurements)
Am	americium (isotope listed: <sup>241</sup> Am)
β	Type II decision-error rate
b	background count rate
b <sub>i</sub>	the average number of counts in the background interval (scanning)
Be	beryllium (isotope listed: <sup>7</sup> Be)
Bi	bismuth (isotopes listed: <sup>210</sup> Bi, <sup>212</sup> Bi, <sup>214</sup> Bi)
Bq	becquerel
C	carbon (isotope listed: <sup>14</sup> C)
C	radionuclide concentration or activity
Ci	curie
C <sub>i</sub>	concentration value an individual radionuclide (i = 1, 2, ..., n)
c <sub>i</sub>	sensitivity coefficient
c <sub>i</sub> μ(x <sub>i</sub> )	component of the uncertainty in y due to x <sub>i</sub>
C <sub>infer</sub> /C <sub>meas</sub>	ratio of amount of the inferred radionuclide to that of the measured surrogate radionuclide
°C	degrees Celsius
cm	centimeter
cm <sup>2</sup>	square centimeter
cm <sup>3</sup>	cubic centimeter
Cd	cadmium (isotope listed: <sup>109</sup> Cd)
Co	cobalt (isotopes listed: <sup>57</sup> Co, <sup>60</sup> Co)
Cs	cesium (isotope listed: <sup>137</sup> Cs)
CsI(Tl)	cesium iodide (thallium activated)
Δ	shift (width of the gray region, UBGR–LBGR)

$\Delta/\sigma$	relative shift
$d$	parameter in the Stapleton Equation for the critical net signal
$d'$	detectability index (scanning)
$\varepsilon_i$	instrument efficiency
$\varepsilon_s$	surface efficiency for surveyed media
eV	electron-volt
$E_\gamma$	energy of a gamma photon of concern in kiloelectron-volts (keV)
$E_i$	energy of a photon of interest
$^\circ\text{F}$	degrees Fahrenheit
$f_i$	relative fraction of activity contributed by radionuclide $i$ to the total
ft	foot (feet)
ft <sup>3</sup>	cubic foot (feet)
Fe	iron (isotope listed: <sup>55</sup> Fe)
g	gram
GBq	gigabecquerel ( $1 \times 10^9$ becquerels)
$GG_{AL}$	gross gamma action level
h	hour
H	hydrogen (isotope listed: <sup>3</sup> H [tritium])
H <sub>0</sub>	null hypothesis
H <sub>1</sub>	alternative hypothesis
$i$	observation time interval length (scanning)
I	iodine (isotopes listed: <sup>123</sup> I, <sup>125</sup> I, <sup>131</sup> I)
in	inch
Ir	iridium (isotope listed: <sup>192</sup> Ir)
$k$	coverage factor for the expanded uncertainty, $U$
K	potassium (isotope listed: <sup>40</sup> K)
kBq	kilobecquerel ( $1 \times 10^3$ becquerels)
keV	kiloelectron-volt ( $1 \times 10^3$ electron-volts)
kg	kilogram
$k_Q$	multiple of the standard deviation defining $y_Q$ , usually chosen to be 10
$L$	grid size spacing
L	liter
lb	pound
$\mu$	micro ( $10^{-6}$ )
$\mu$	theoretical mean of a population distribution
$(\mu_{en}/\rho)_{\text{air}}$	mass energy absorption coefficient in air centimeters squared per gram ( $\text{cm}^2/\text{g}$ )
$\mu\text{R}$	microroentgen ( $1 \times 10^{-6}$ roentgen)
$m$	number of reference measurements (WRS test or Quantile test)
m	meter
m <sup>2</sup>	square meter
MeV	megaelectron-volt ( $1 \times 10^6$ electron-volt)
mrem	millirem ( $1 \times 10^{-3}$ rem)

mSv	milliseivert ( $1 \times 10^{-3}$ Sv)
$n$	number of survey unit measurements (WRS test or Quantile test)
$N$	sample size, i.e. number of data points (or samples) for the Sign test
$n_{EA}$	survey unit area divided by the maximum area corresponding to the area factor, which yields the number of measurements needed so the scan MDC is adequate
Na	sodium (isotope listed: $^{22}\text{Na}$ )
NaI(Tl)	sodium iodide (thallium activated)
Ni	nickel (isotope listed: $^{63}\text{Ni}$ )
Np	neptunium (isotope listed: $^{237}\text{Np}$ )
$\zeta_B$	non-Poisson variance component of the background count rate correction
$p$	coverage probability for expanded uncertainty, also used for efficiency of a less than ideal surveyor (scanning)
$P$	probability of interaction between radiation and a detector
Pa	protactinium (isotopes listed: $^{234}\text{Pa}$ , $^{234m}\text{Pa}$ )
PA	probe area
Pb	lead (isotopes listed: $^{212}\text{Pb}$ , $^{214}\text{Pb}$ )
PC	personal computer
pCi	picocurie ( $1 \times 10^{-12}$ curies)
Pm	promethium (isotope listed: $^{147}\text{Pm}$ )
Po	polonium (isotopes listed: $^{210}\text{Po}$ , $^{212}\text{Po}$ , $^{214}\text{Po}$ , $^{216}\text{Po}$ )
Pu	plutonium (isotopes listed: $^{238}\text{Pu}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{241}\text{Pu}$ )
$q$	critical value for statistical tests (Table A.3, Table A.4)
$\rho$	density
$\rho(X_i, X_j)$	correlation coefficient for two input quantities, $X_i$ and $X_j$
$R$	ratio
R	roentgen (exposure rate)
Ra	radium (isotopes listed: $^{224}\text{Ra}$ , $^{226}\text{Ra}$ , $^{228}\text{Ra}$ )
$R_B$	mean background count rate
$R_I$	mean interference count rate
Rn	radon (isotopes listed: $^{220}\text{Rn}$ , $^{222}\text{Rn}$ )
$r(x_i, x_j)$	correlation coefficient for two input estimates, $x_i$ and $x_j$
$\sigma$	theoretical total standard deviation of the population distribution being sampled
$\sigma_M$	theoretical measurement standard deviation of the population distribution being sampled, estimated by the combined standard uncertainty of the measurement
$\sigma_M^2$	theoretical measurement variance of the population distribution being sampled
$\sigma_{MR}$	required measurement method standard deviation (upper limit)
$\sigma_s$	theoretical sampling standard deviation of the population distribution being sampled
$\sigma_s^2$	theoretical sampling variance of the population distribution being sampled
$\sigma(\hat{R}_I)$	standard deviation of the measured interference count rate
$\sigma(y Y = y_Q)$	variance of the estimator $y$ given the true concentration $Y$ equals $y_Q$
$\sigma(X_i, X_j)$	covariance for two input quantities, $X_i$ and $X_j$

$S+$	Sign test statistic
$s(x)$	sample standard deviation of the input estimate, $x_i$
$S_C$	critical value of the net instrument signal
$S_D$	mean value of the net signal that gives a specified probability, $1-\beta$ , of yielding an observed signal greater than its critical value $S_C$
$s_i$	minimum detectable number of net source counts in the observation interval (scanning)
$s_{i,surveyor}$	minimum detectable number of net source counts in the observation interval by a less than ideal surveyor (scanning)
<b>Sr</b>	strontium (isotope listed: $^{90}\text{Sr}$ )
<b>Sv</b>	seivert
<b>Tc</b>	technicium (isotopes listed: $^{99}\text{Tc}$ , $^{99m}\text{Tc}$ )
<b>Th</b>	thorium (isotopes listed: $^{228}\text{Th}$ , $^{230}\text{Th}$ , $^{232}\text{Th}$ , $^{234}\text{Th}$ )
<b>Tl</b>	thallium (isotopes listed: $^{201}\text{Tl}$ , $^{208}\text{Tl}$ )
$t_B$	count time for the background
$t_S$	count time for the source
$U$	expanded uncertainty
<b>U</b>	uranium (isotopes listed: $^{234}\text{U}$ , $^{235}\text{U}$ , $^{238}\text{U}$ )
$u(x_i)$	standard uncertainty of the input estimate, $x_i$
$u(x_i)/x_i$	relative standard uncertainty of $x_i$
$u(x_i, x_j)$	covariance of two input estimates, $x_i$ and $x_j$
$u_c(y)$	combined standard uncertainty of $y$
$u_c(y)/y$	relative combined standard uncertainty of the output quantity for a particular measurement
$u_c^2(y)$	combined variance of $y$
$u_i(y)$	component of the combined standard uncertainty, $u_c(y)$ , generated by the standard uncertainty of the input estimate $x_i$ , $u(x_i)$ , multiplied by the sensitivity coefficient, $c_i$
$u_M$	measurement method uncertainty
$u_{MR}$	required measurement method uncertainty
$\varphi_{MR}$	required relative measurement method uncertainty
$\phi_A^2$	relative variance of the measured sensitivity
$\varphi(x_i)$	relative standard uncertainty of a nonzero input estimate, $x_i$ , for a particular measurement. $\varphi(x_i) = u(x_i)/x_i$
$\Phi(z)$	cumulative normal distribution function
$W_r$	sum of the ranks of the (adjusted) reference measurements (WRS test)
$W_s$	sum of the ranks of the (adjusted) sample measurements (WRS test)
$WS$	weighted instrument sensitivity
$x$	estimate of the input quantity, $X$
$X_i$	an input quantity
$x_C$	the critical value of the response variable, $x$
$x_Q$	minimum quantifiable value of the response variable, $x$
$y$	year

$y$	estimate of the output quantity for a particular measurement, $Y$
$Y$	output quantity, measurand
$y_C$	critical value of the concentration
$y_D$	minimum detectable concentration (MDC)
$y_Q$	minimum quantifiable concentration (MQC)
yd	yard
yd <sup>3</sup>	cubic yard
Z	atomic number
$z_{1-\alpha}$	(1 - $\alpha$ )-quantile of the standard normal distribution
$z_{1-\beta}$	(1 - $\beta$ )-quantile of the standard normal distribution
ZnS(Ag)	zinc sulfide (silver activated)

## CONVERSION FACTORS

To Convert From	To	Multiply "From" Quantity By	To Convert From	To	Multiply By
acre	hectare	0.405	meter (m)	inch	39.4
	sq. meter (m <sup>2</sup> )	4,050	sq. meter (m <sup>2</sup> )	mile	0.000621
	sq. feet (ft <sup>2</sup> )	43,600		acre	0.000247
becquerel (Bq)	curie (Ci)	$2.7 \times 10^{-11}$	m <sup>3</sup>	hectare	0.0001
	dps	1		sq. feet (ft <sup>2</sup> )	10.8
	pCi	27		sq. mile	$3.86 \times 10^{-7}$
Bq/kg	pCi/g	0.027	mrem	liter	1,000
Bq/m <sup>2</sup>	dpm/100 cm <sup>2</sup>	0.60		mSv	0.01
Bq/m <sup>3</sup>	Bq/L	0.001		mrem/y	mSv/y
centimeter (cm)	pCi/L	0.027	mSv	mrem	100
	inch	0.394	mSv/y	mrem/y	100
	Ci	Bq	ounce (oz)	liter (L)	0.0296
dps	pCi	$3.70 \times 10^{10}$	pCi	Bq	0.037
	dpm	$1 \times 10^{12}$	pCi/g	dpm	2.22
	pCi	60	pCi/L	Bq/kg	37
dpm	dps	0.0167	rad	Bq/m <sup>3</sup>	37
	pCi	0.451	rem	Gy	0.01
	Bq/m <sup>2</sup>	1.67	seivert (Sv)	mrem	1,000
gray (Gy)	rad	mSv		10	
hectare	acre	2.47		Sv	0.01
liter (L)	cm <sup>3</sup>	1000	mrem	mrem	100,000
	m <sup>3</sup>	0.001		mSv	1,000
	ounce (fluid)	33.8		rem	100