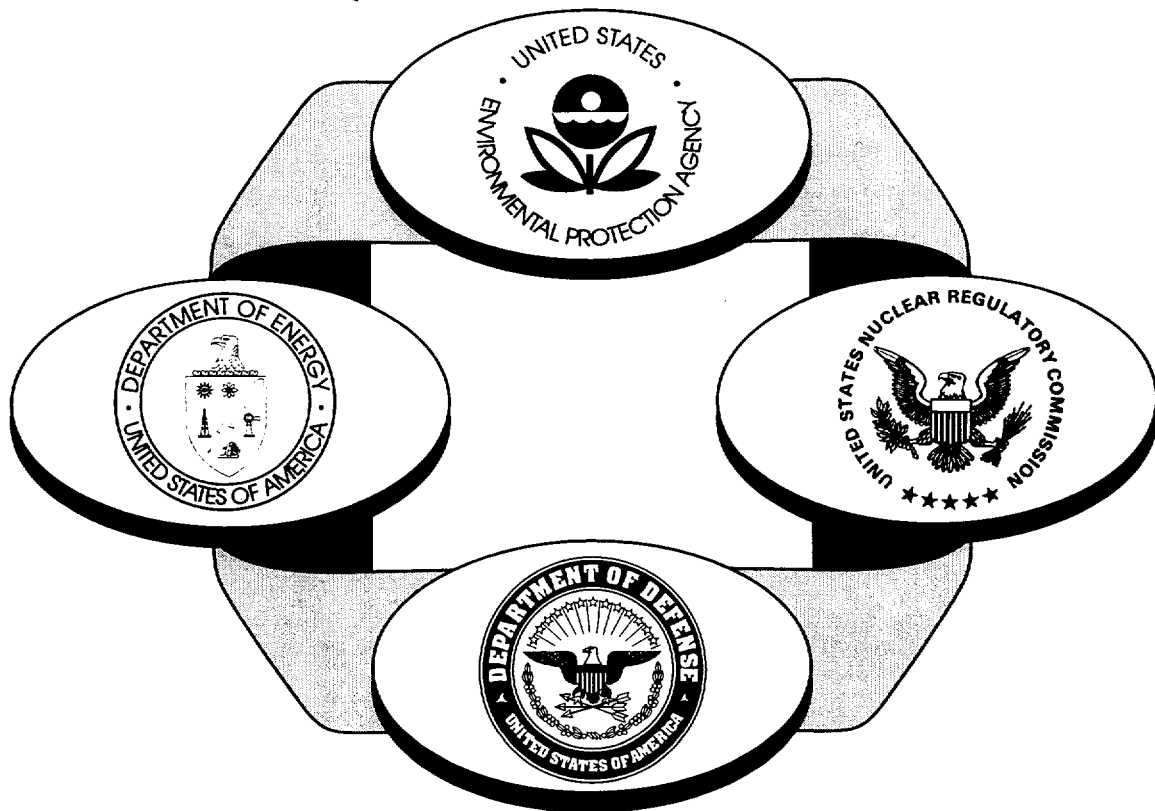


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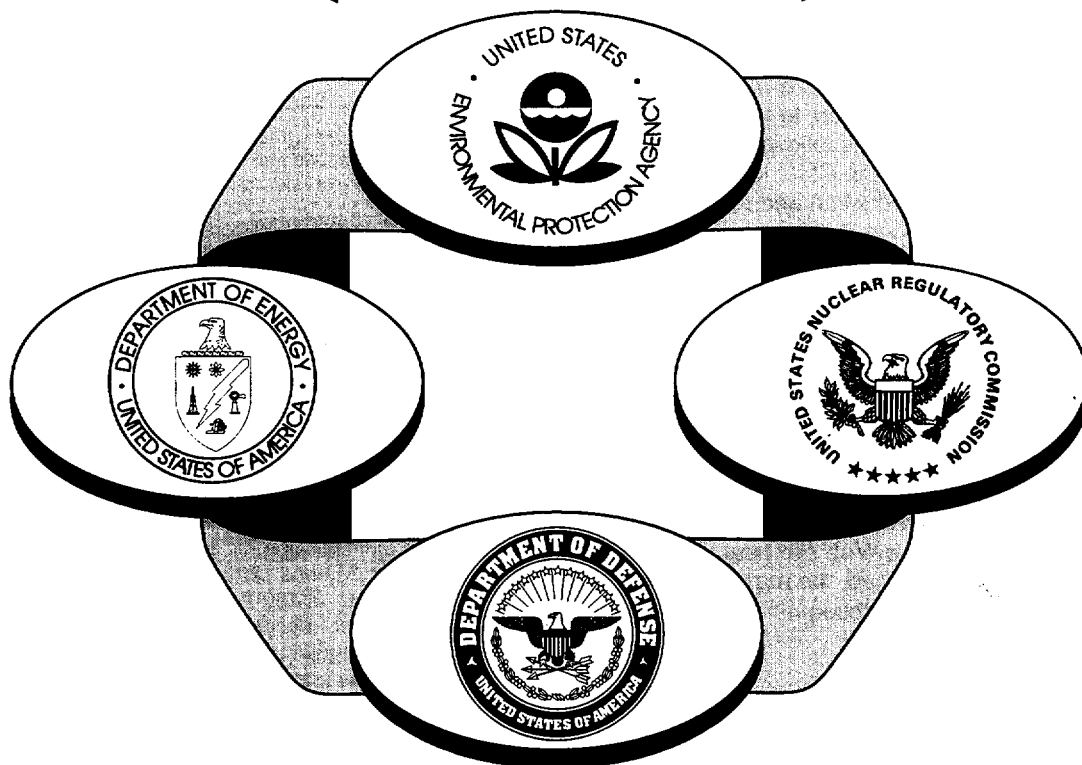


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Submit written comments arising from the review or use of MARSSIM to EITHER the U.S. Environmental Protection Agency, ATTN: Air and Radiation Docket, Mail Stop 6102, Air Docket No. A-96-44, First Floor Waterside Mall (geographic address at 401 M Street, SW.), mailing address 1200 Pennsylvania Ave., NW., Washington D.C. 20460-2001 or the Chief, Rules and Directives Branch, Division of Administrative Services, U.S. Nuclear Regulatory Commission, Washington DC 20555-0001. As appropriate, revised pages of MARSSIM will be posted on the Internet at: <http://www.epa.gov/radiation/marssim>.

ABSTRACT

The MARSSIM provides information on planning, conducting, evaluating, and documenting building surface and surface soil final status radiological surveys for demonstrating compliance with dose or risk-based regulations or standards. The MARSSIM 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 MARSSIM's objective is to describe a consistent approach for planning, performing, and assessing building surface and surface soil final status surveys to meet established dose or risk-based release criteria, while at the same time encouraging an effective use of resources.

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CONTENTS

| | <u>Page</u> |
|---|---------------|
| Abstract | iii |
| Disclaimer | iv |
| Acknowledgments | xix |
| Abbreviations | xxiii |
| Conversion Factors | xxvii |
| April 2000 Errata and Addenda | xxviii |
| Roadmap | Roadmap-1 |
| 1. Introduction | 1-1 |
| 1.1 Purpose and Scope of MARSSIM | 1-1 |
| 1.2 Structure of the Manual | 1-4 |
| 1.3 Use of the Manual | 1-6 |
| 1.4 Missions of the Federal Agencies Producing MARSSIM | 1-7 |
| 1.4.1 Environmental Protection Agency | 1-7 |
| 1.4.2 Nuclear Regulatory Commission | 1-7 |
| 1.4.3 Department of Energy | 1-7 |
| 1.4.4 Department of Defense | 1-8 |
| 2. Overview of the Radiation Survey and Site Investigation Process | 2-1 |
| 2.1 Introduction | 2-1 |
| 2.2 Understanding Key MARSSIM Terminology | 2-2 |
| 2.3 Making Decisions Based on Survey Results | 2-6 |
| 2.3.1 Planning Effective Surveys—Planning Phase | 2-8 |
| 2.3.2 Estimating the Uncertainty in Survey Results— Implementation Phase | 2-11 |
| 2.3.3 Interpreting Survey Results—Assessment Phase | 2-11 |
| 2.3.4 Uncertainty in Survey Results | 2-12 |
| 2.3.5 Reporting Survey Results | 2-13 |
| 2.4 Radiation Survey and Site Investigation Process | 2-14 |
| 2.4.1 Site Identification | 2-16 |
| 2.4.2 Historical Site Assessment | 2-22 |
| 2.4.3 Scoping Survey | 2-22 |
| 2.4.4 Characterization Survey | 2-23 |
| 2.4.5 Remedial Action Support Survey | 2-23 |
| 2.4.6 Final Status Survey | 2-24 |
| 2.4.7 Regulatory Agency Confirmation and Verification | 2-25 |
| 2.5 Demonstrating Compliance With a Dose- or Risk-Based Regulation | 2-25 |
| 2.5.1 The Decision To Use Statistical Tests | 2-25 |
| 2.5.2 Classification | 2-28 |
| 2.5.3 Design Considerations for Small Areas of Elevated Activity | 2-29 |

CONTENTS

| | <u>Page</u> |
|--|-------------|
| 2.5.4 Design Considerations for Relatively Uniform Distributions of Contamination | 2-30 |
| 2.5.5 Developing an Integrated Survey Design | 2-31 |
| 2.6 Flexibility in Applying MARSSIM Guidance | 2-33 |
| 2.6.1 Alternate Statistical Methods | 2-34 |
| 2.6.2 Alternate Null Hypothesis | 2-39 |
| 2.6.3 Integrating MARSSIM with Other Survey Designs | 2-39 |
| 3. Historical Site Assessment | 3-1 |
| 3.1 Introduction | 3-1 |
| 3.2 Data Quality Objectives | 3-2 |
| 3.3 Site Identification | 3-4 |
| 3.4 Preliminary Historical Site Assessment Investigation | 3-4 |
| 3.4.1 Existing Radiation Data | 3-7 |
| 3.4.2 Contracts and Interviews | 3-9 |
| 3.5 Site Reconnaissance | 3-9 |
| 3.6 Evaluation of Historical Site Assessment Data | 3-10 |
| 3.6.1 Identify Potential Contaminants | 3-11 |
| 3.6.2 Identify Potentially Contaminated Areas | 3-12 |
| 3.6.3 Identify Potentially Contaminated Media | 3-13 |
| 3.6.4 Develop a Conceptual Model of the Site | 3-21 |
| 3.6.5 Professional Judgment | 3-22 |
| 3.7 Determining the Next Step in the Site Investigation Process | 3-24 |
| 3.8 Historical Site Assessment Report | 3-24 |
| 3.9 Review of the Historical Site Assessment | 3-25 |
| 4. Preliminary Survey Considerations | 4-1 |
| 4.1 Introduction | 4-1 |
| 4.2 Decommissioning Criteria | 4-1 |
| 4.3 Identify Contaminants and Establish Derived Concentration Guideline Levels . | 4-3 |
| 4.3.1 Direct Application of DCGLs | 4-4 |
| 4.3.2 DCGLs and the Use of Surrogate Measurements | 4-4 |
| 4.3.3 Use of DCGLs for Sites With Multiple Radionuclides | 4-8 |
| 4.3.4 Integrated Surface and Soil Contamination DCGLs | 4-8 |
| 4.4 Classify Areas by Contamination Potential | 4-11 |
| 4.5 Select Background Reference Areas | 4-13 |
| 4.6 Identify Survey Units | 4-14 |

CONTENTS

| | <u>Page</u> |
|---|-------------|
| 4.7 Select Instruments and Survey Techniques | 4-16 |
| 4.7.1 Selection of Instruments | 4-16 |
| 4.7.2 Selection of Survey Techniques | 4-17 |
| 4.7.3 Criteria for Selection of Sample Collection and Direct Measurement Methods | 4-19 |
| 4.8 Site Preparation | 4-22 |
| 4.8.1 Consent for Survey | 4-22 |
| 4.8.2 Property Boundaries | 4-22 |
| 4.8.3 Physical Characteristics of Site | 4-22 |
| 4.8.4 Clearing To Provide Access | 4-24 |
| 4.8.5 Reference Coordinate System | 4-27 |
| 4.9 Quality Control | 4-32 |
| 4.9.1 Precision and Systematic Errors (Bias) | 4-33 |
| 4.9.2 Number of Quality Control Measurements | 4-34 |
| 4.9.3 Controlling Sources of Error | 4-38 |
| 4.10 Health and Safety | 4-38 |
| 5. Survey Planning and Design | 5-1 |
| 5.1 Introduction | 5-1 |
| 5.2 Scoping Surveys | 5-1 |
| 5.2.1 General | 5-1 |
| 5.2.2 Survey Design | 5-2 |
| 5.2.3 Conducting Surveys | 5-3 |
| 5.2.4 Evaluating Survey Results | 5-3 |
| 5.2.5 Documentation | 5-4 |
| 5.3 Characterization Surveys | 5-7 |
| 5.3.1 General | 5-7 |
| 5.3.2 Survey Design | 5-8 |
| 5.3.3 Conducting Surveys | 5-9 |
| 5.3.4 Evaluating Survey Results | 5-14 |
| 5.3.5 Documentation | 5-15 |
| 5.4 Remedial Action Support Surveys | 5-18 |
| 5.4.1 General | 5-18 |
| 5.4.2 Survey Design | 5-18 |
| 5.4.3 Conducting Surveys | 5-19 |
| 5.4.4 Evaluating Survey Results | 5-19 |
| 5.4.5 Documentation | 5-19 |

CONTENTS

| | <u>Page</u> |
|--|-------------|
| 5.5 Final Status Surveys | 5-21 |
| 5.5.1 General | 5-21 |
| 5.5.2 Survey Design | 5-21 |
| 5.5.3 Developing an Integrated Survey Strategy | 5-46 |
| 5.5.4 Evaluating Survey Results | 5-52 |
| 5.5.5 Documentation | 5-52 |
| 6. Field Measurement Methods and Instrumentation | 6-1 |
| 6.1 Introduction | 6-1 |
| 6.2 Data Quality Objectives | 6-2 |
| 6.2.1 Identifying Data Needs | 6-2 |
| 6.2.2 Data Quality Indicators | 6-3 |
| 6.3 Selecting a Service Provider to Perform Field Data Collection Activities | 6-8 |
| 6.4 Measurement Methods | 6-10 |
| 6.4.1 Direct Measurements | 6-10 |
| 6.4.2 Scanning Surveys | 6-13 |
| 6.5 Radiation Detection Instrumentation | 6-15 |
| 6.5.1 Radiation Detectors | 6-15 |
| 6.5.2 Display and Recording Equipment | 6-17 |
| 6.5.3 Instrument Selection | 6-18 |
| 6.5.4 Instrument Calibration | 6-20 |
| 6.6 Data Conversion | 6-28 |
| 6.6.1 Surface Activity | 6-29 |
| 6.6.2 Soil Radionuclide Concentration and Exposure Rates | 6-31 |
| 6.7 Detection Sensitivity | 6-31 |
| 6.7.1 Direct Measurement Sensitivity | 6-32 |
| 6.7.2 Scanning Sensitivity | 6-37 |
| 6.8 Measurement Uncertainty (Error) | 6-49 |
| 6.8.1 Systematic and Random Uncertainties | 6-50 |
| 6.8.2 Statistical Counting Uncertainty | 6-52 |
| 6.8.3 Uncertainty Propagation | 6-52 |
| 6.8.4 Reporting Confidence Intervals | 6-53 |
| 6.9 Radon Measurements | 6-55 |
| 6.9.1 Direct Radon Measurements | 6-58 |
| 6.9.2 Radon Progeny Measurements | 6-59 |
| 6.9.3 Radon Flux Measurements | 6-60 |
| 6.10 Special Equipment | 6-61 |
| 6.10.1 Positioning Systems | 6-61 |
| 6.10.2 Mobile Systems with Integrated Positioning Systems | 6-62 |
| 6.10.3 Radar, Magnetometer, and Electromagnetic Sensors | 6-63 |
| 6.10.4 Aerial Radiological Surveys | 6-66 |

CONTENTS

| | <u>Page</u> |
|---|-------------|
| 7. Sampling and Preparation for Laboratory Measurements | 7-1 |
| 7.1 Introduction | 7-1 |
| 7.2 Data Quality Objectives | 7-1 |
| 7.2.1 Identifying Data Needs | 7-2 |
| 7.2.2 Data Quality Indicators | 7-2 |
| 7.3 Communications with the Laboratory | 7-7 |
| 7.3.1 Communications During Survey Planning | 7-8 |
| 7.3.2 Communications Before and During Sample Collection | 7-8 |
| 7.3.3 Communications During Sample Analysis | 7-9 |
| 7.3.4 Communications Following Sample Analysis | 7-9 |
| 7.4 Selecting a Radioanalytical Laboratory | 7-10 |
| 7.5 Sampling | 7-11 |
| 7.5.1 Surface Soil | 7-12 |
| 7.5.2 Building Surfaces | 7-15 |
| 7.5.3 Other Media | 7-16 |
| 7.6 Field Sample Preparation and Preservation | 7-16 |
| 7.6.1 Surface Soil | 7-17 |
| 7.6.2 Building Surfaces | 7-17 |
| 7.6.3 Other Media | 7-17 |
| 7.7 Analytical Procedures | 7-17 |
| 7.7.1 Photon Emitting Radionuclides | 7-21 |
| 7.7.2 Beta Emitting Radionuclides | 7-21 |
| 7.7.3 Alpha Emitting Radionuclides | 7-22 |
| 7.8 Sample Tracking | 7-23 |
| 7.8.1 Field Tracking Considerations | 7-24 |
| 7.8.2 Transfer of Custody | 7-24 |
| 7.8.3 Laboratory Tracking | 7-25 |
| 7.9 Packaging and Transporting Samples | 7-25 |
| 7.9.1 U.S. Nuclear Regulatory Commission Regulations | 7-27 |
| 7.9.2 U.S. Department of Transportation Regulations | 7-27 |
| 7.9.3 U.S. Postal Service Regulations | 7-28 |
| 8. Interpretation of Survey Results | 8-1 |
| 8.1 Introduction | 8-1 |
| 8.2 Data Quality Assessment | 8-1 |
| 8.2.1 Review the Data Quality Objectives and Sampling Design | 8-2 |
| 8.2.2 Conduct a Preliminary Data Review | 8-2 |
| 8.2.3 Select the Tests | 8-6 |

CONTENTS

| | <u>Page</u> |
|--|-------------|
| 8.2.4 Verify the Assumptions of the Tests | 8-7 |
| 8.2.5 Draw Conclusions From the Data | 8-8 |
| 8.2.6 Example | 8-10 |
| 8.3 Contaminant Not Present in Background | 8-11 |
| 8.3.1 One-Sample Statistical Test | 8-11 |
| 8.3.2 Applying the Sign Test | 8-12 |
| 8.3.3 Sign Test Example: Class 2 Exterior Soil Survey Unit | 8-12 |
| 8.3.4 Sign Test Example: Class 3 Exterior Soil Survey Unit | 8-14 |
| 8.4 Contaminant Present in Background | 8-17 |
| 8.4.1 Two-Sample Statistical Test | 8-17 |
| 8.4.2 Applying the Wilcoxon Rank Sum Test | 8-18 |
| 8.4.3 Wilcoxon Rank Sum Test Example: Class 2 Interior Drywall Survey Unit | 8-19 |
| 8.4.4 Wilcoxon Rank Sum Test Example: Class 1 Interior Concrete Survey Unit | 8-21 |
| 8.4.5 Multiple Radionuclides | 8-21 |
| 8.5 Evaluating the Results: The Decision | 8-21 |
| 8.5.1 Elevated Measurement Comparison | 8-21 |
| 8.5.2 Interpretation of Statistical Test Results | 8-23 |
| 8.5.3 If the Survey Unit Fails | 8-23 |
| 8.5.4 Removable Activity | 8-25 |
| 8.6 Documentation | 8-25 |
| 9. Quality Assurance and Quality Control | 9-1 |
| 9.1 Introduction | 9-1 |
| 9.2 Development of a Quality Assurance Project Plan | 9-3 |
| 9.3 Data Assessment | 9-5 |
| 9.3.1 Data Verification | 9-6 |
| 9.3.2 Data Validation | 9-7 |
| References | Ref-1 |
| Appendix A Example of MARSSIM Applied to a Final Status Survey | A-1 |
| A.1 Introduction | A-1 |
| A.2 Survey Preparations | A.1 |
| A.3 Survey Design | A-7 |
| A.4 Conducting Surveys | A-14 |
| A.5 Evaluating Survey Results | A-15 |

CONTENTS

| | <u>Page</u> |
|--|-------------|
| Appendix B Simplified Procedure for Certain Users of Sealed Sources, Short Half-Life Materials, and Small Quantities | B-1 |
| Appendix C Site Regulations and Requirements Associated With Radiation Surveys and Site Investigations | C-1 |
| C.1 EPA Statutory Authorities | C-1 |
| C.2 DOE Regulations and Requirements | C-4 |
| C.3 NRC Regulations and Requirements | C-12 |
| C.4 DOD Regulations and Requirements | C-15 |
| C.5 State and Local Regulations and Requirements | C-20 |
| Appendix D The Planning Phase of the Data Life Cycle | D-1 |
| D.1 State the Problem | D-4 |
| D.2 Identify the Decision | D-5 |
| D.3 Identify the Inputs to the Decision | D-5 |
| D.4 Define the Boundaries of the Study | D-6 |
| D.5 Develop a Decision Rule | D-8 |
| D.6 Specify Limits on Decision Errors | D-13 |
| D.7 Optimize the Design for Collecting Data | D-28 |
| Appendix E The Assessment Phase of the Data Life Cycle | E-1 |
| E.1 Review DQOs and Survey Design | E-1 |
| E.2 Conduct a Preliminary Data Review | E-3 |
| E.3 Select the Statistical Test | E-4 |
| E.4 Verify the Assumptions of the Statistical Test | E-4 |
| E.5 Draw Conclusions from the Data | E-5 |
| Appendix F The Relationship Between the Radiation Survey and Site Investigation Process, the CERCLA Remedial or Removal Process, and the RCRA Correction Action Process | F-1 |
| Appendix G Historical Site Assessment Information Sources | G-1 |
| Appendix H Description of Field Survey and Laboratory Analysis Equipment | H-1 |
| H.1 Introduction | H-3 |
| H.2 Field Survey Equipment | H-5 |
| H.3 Laboratory Instruments | H-38 |

CONTENTS

| | <u>Page</u> |
|--|-------------|
| Appendix I Statistical Tables and Procedures | I-1 |
| I.1 Normal Distribution | I-1 |
| I.2 Sample Sizes for Statistical Tests | I-2 |
| I.3 Critical Values for the Sign Test | I-4 |
| I.4 Critical Values for the WRS Test | I-6 |
| I.5 Probability of Detecting an Elevated Area | I-11 |
| I.6 Random Numbers | I-14 |
| I.7 Stem and Leaf Display | I-17 |
| I.8 Quantile Plots | I-18 |
| I.9 Power Calculations for the Statistical Tests | I-25 |
| I.10 Spreadsheet Formulas for the Wilcoxon Rank Sum Test | I-30 |
| I.11 Example WRS Test for Two Radionuclides | I-31 |
| Appendix J Derivation of Alpha Scanning Equations Presented in Section 6.7.2.2 | J-1 |
| Appendix K Comparison Tables Between Quality Assurance Documents | K-1 |
| Appendix L Regional Radiation Program Managers | L-1 |
| L.1 Department of Energy | L-2 |
| L.2 Environmental Protection Agency | L-3 |
| L.3 Nuclear Regulatory Commission | L-5 |
| L.4 Department of the Army | L-6 |
| L.5 Department of the Navy | L-7 |
| L.6 Department of the Air Force | L-8 |
| Appendix M Sampling Methods: A List of Sources | M-1 |
| M.1 Introduction | M-1 |
| M.2 List of Sources | M-1 |
| Appendix N Data Validation Using Data Descriptors | N-1 |
| N.1 Reports to Decision Maker | N-1 |
| N.2 Documentation | N-2 |
| N.3 Data Sources | N-4 |
| N.4 Analytical Method and Detection Limit | N-4 |
| N.5 Data Review | N-5 |
| N.6 Data Quality Indicators | N-6 |
| Glossary | GL-1 |
| Index | Index-1 |

CONTENTS

LIST OF TABLES

| | <u>Page</u> |
|--|-------------|
| 1.1 Scope of MARSSIM | 1-8 |
| 2.1 The Data Life Cycle used to Support the Radiation Survey and Site Investigation Process | 2-16 |
| 2.2 Recommended Conditions for Demonstrating Compliance Based on Survey Unit Classification for a Final Status Survey | 2-32 |
| 2.3 Examples of Alternate Statistical Tests | 2-35 |
| 3.1 Questions Useful for the Preliminary HSA Investigation | 3-5 |
| 4.1 Selection of Direct Measurement Techniques Based on Experience | 4-20 |
| 4.2 Example of DQO Planning Considerations | 4-21 |
| 4.3 Upper Confidence Limits for the True Variance as a Function of the Number of QC Measurements used to Determine the Estimated Variance | 4-36 |
| 5.1 Values of P_r for Given Values of the Relative Shift, Δ/σ , when the Contaminant is Present in Background | 5-28 |
| 5.2 Percentiles Represented by Selected Values of α and β | 5-28 |
| 5.3 Values of $N/2$ for Use with the Wilcoxon Rank Sum Test | 5-30 |
| 5.4 Values of Sign p for Given Values of the Relative Shift, Δ/σ , when the Contaminant is Not Present in Background | 5-32 |
| 5.5 Values of N for Use with the Sign Test | 5-34 |
| 5.6 Illustrative Examples of Outdoor Area Dose Factors | 5-37 |
| 5.7 Illustrative Examples of Indoor Area Dose Factors | 5-37 |
| 5.8 Example Final Status Survey Investigation Levels | 5-45 |
| 5.9 Recommended Survey Coverage for Structures and Land Areas | 5-47 |
| 6.1 Radiation Detectors With Applications to Alpha Surveys | 6-20 |
| 6.2 Radiation Detectors With Applications to Beta Surveys | 6-21 |
| 6.3 Radiation Detectors With Applications to Gamma Surveys | 6-22 |
| 6.4 Examples of Estimated Detection Sensitivities for Alpha and Beta Survey Instrumentation | 6-36 |
| 6.5 Values of d' for Selected True Positive and False Positive Proportions | 6-40 |
| 6.6 Scanning Sensitivity (MDCR) of the Ideal Observer for Various Background Levels | 6-41 |

LIST OF TABLES

| | <u>Page</u> |
|--|-------------|
| 6.7 NaI(Tl) Scintillation Detector Scan MDCs for Common Radiological Contaminants | 6-47 |
| 6.8 Probability of Detecting 300 dpm/100 cm ² of Alpha Activity While Scanning with Alpha Detectors Using an Audible Output | 6-49 |
| 6.9 Areas Under Various Intervals About the Mean of a Normal Distribution | 6-54 |
| 6.10 Radiation Detectors with Applications to Radon Surveys | 6-57 |
| 6.11 Typical Radar Penetration Depths for Various Geologic Materials | 6-64 |
| 7.1 Soil Sampling Equipment | 7-14 |
| 7.2 Examples of References for Routine Analytical Methods. | 7-18 |
| 7.3 Typical Measurement Sensitivities for Laboratory Radiometric Procedures | 7-20 |
| 8.1 Methods for Checking the Assumptions of Statistical Tests | 8-8 |
| 8.2 Summary of Statistical Tests | 8-9 |
| 8.3 Final Status Survey Parameters for Example Survey Units | 8-10 |
| 8.4 Example Sign Analysis: Class 2 Exterior Soil Survey Unit | 8-14 |
| 8.5 Sign Test Example Data for Class 3 Exterior Survey Unit | 8-16 |
| 8.6 WRS Test for Class 2 Interior Drywall Survey Unit | 8-20 |
| 9.1 The Elements of a Quality System Related to the Data Life Cycle | 9-2 |
| 9.2 Examples of QAPP Elements for Site Surveys and Investigations | 9-4 |
| 9.3 Suggested Content or Consideration, Impact if Not Met, and Corrective Actions for Data Descriptors | 9-8 |
| A.1 Class 1 Interior Concrete Survey Unit and Reference Area Data | A-15 |
| A.2 Stem and Leaf Displays for Class 1 Interior Concrete Survey Unit | A-16 |
| A.3 WRS Test for Class 1 Interior Concrete Survey Unit | A-18 |
| C.1 DOE Authorities, Orders and Regulations Related to Radiation Protection | C-5 |
| C.2 Agreement States | C-21 |
| C.3 States that Regulate Diffuse NORM | C-21 |
| D.1 Example Representation of Decision Errors for a Final Status Survey | D-15 |
| F.1 Program Comparison | F-5 |
| F.2 Data Elements for Site Visits | F-10 |
| F.3 Comparison of Sampling Emphasis Between Remedial Site Assessment and Removal Assessment | F-10 |
| G.1 Site Assessment Information Sources (Organized by Information Needed) | G-2 |
| G.2 Site Assessment Information Sources (Organized by Information Source) | G-7 |

LIST OF TABLES

| | <u>Page</u> |
|--|-------------|
| H.1 Radiation Detectors with Applications to Alpha Surveys | H-50 |
| H.2 Radiation Detectors with Applications to Beta Surveys | H-52 |
| H.3 Radiation Detectors with Applications to Gamma Surveys | H-53 |
| H.4 Radiation Detectors with Applications to Radon Surveys | H-55 |
| H.5 Systems that Measure Atomic Mass or Emissions | H-56 |
| | |
| I.1 Cumulative Normal Distribution Function $\Phi(z)$ | I-1 |
| I.2a Sample Sizes for Sign Test | I-2 |
| I.2b Sample Sizes for Wilcoxon Rank Sum Test | I-3 |
| I.3 Critical Values for the Sign Test Statistic S^+ | I-4 |
| I.4 Critical Values for the WRS Test | I-6 |
| I.5 Risk that an Elevated Area with Length L/G and Shape S will not be Detected and the Area (%) of the Elevated Area Relative to a Triangular Sample Grid Area of $0.866 G^2$ | I-11 |
| I.6 1,000 Random Numbers Uniformly Distributed between Zero and One | I-14 |
| I.7 Data for Quantile Plot | I-19 |
| I.8 Ranked Reference Area Concentrations | I-22 |
| I.9 Interpolated Ranks for Survey Unit Concentrations | I-23 |
| I.10 Values of P_r and p_2 for Computing the Mean and Variance of W_{MW} | I-28 |
| I.11 Spreadsheet Formulas Used in Table 8.6 | I-30 |
| I.12 Example WRS Test for Two Radionuclides | I-35 |
| | |
| K.1 Comparison of EPA QA/R-5 and EPA QAMS-005/80 | K-2 |
| K.2 Comparison of EPA QA/R-5 and ASME NQA-1 | K-3 |
| K.3 Comparison of EPA QA/R-5 and DOE Order 5700.6c | K-4 |
| K.4 Comparison of EPA QA/R-5 and MIL-Q-9858A | K-5 |
| K.5 Comparison of EPA QA/R-5 and ISO 9000 | K-6 |
| | |
| N.1 Use of Quality Control Data | N-7 |
| N.2 Minimum Considerations for Precision, Impact if Not Met, and Corrective Actions | N-9 |
| N.3 Minimum Considerations for Bias, Impact if Not Met, and Corrective Actions | N-10 |
| N.4 Minimum Considerations for Representativeness, Impact if Not Met, and Corrective Actions | N-13 |
| N.5 Minimum Considerations for Comparability, Impact if Not Met, and Corrective Actions | N-15 |
| N.6 Minimum Considerations for Completeness, Impact if Not Met, and Corrective Actions | N-16 |

CONTENTS

LIST OF FIGURES

| | <u>Page</u> |
|--|-------------|
| 1.1 Compliance Demonstration | 1-2 |
| 2.1 The Data Life Cycle | 2-7 |
| 2.2 The Data Quality Objectives Process | 2-10 |
| 2.3 The Assessment Phase of the Data Life Cycle | 2-12 |
| 2.4 The Radiation Survey and Site Investigation Process in Terms of Area Classification | 2-17 |
| 2.5 The Historical Site Assessment Portion of the Radiation Survey and Site Investigation Process | 2-18 |
| 2.6 The Scoping Survey Portion of the Radiation Survey and Site Investigation Process | 2-19 |
| 2.7 The Characterization and Remedial Action Support Survey Portion of the Radiation Survey and Site Investigation Process | 2-20 |
| 2.8 The Final Status Survey Portion of the Radiation Survey and Site Investigation Process | 2-21 |
| 3.1 Example Showing How a Site Might Be Classified Prior to Cleanup Based on the Historical Site Assessment | 3-23 |
| 3.2 Example of a Historical Site Assessment Report Format | 3-26 |
| 4.1 Sequence of Preliminary Activities Leading to Survey Design | 4-2 |
| 4.2 Flow Diagram for Selection of Field Survey Instrumentation for Direct Measurements and Analysis of Samples | 4-18 |
| 4.3 Indoor Grid Layout With Alphanumeric Grid Block Designation | 4-28 |
| 4.4 Example of a Grid System for Survey of Site Grounds Using Compass Directions .. | 4-29 |
| 4.5 Example of a Grid System for Survey of Site Grounds Using Distances Left or Right of the Baseline | 4-30 |
| 5.1 Flow Diagram Illustrating the Process for Identifying Measurement Locations | 5-22 |
| 5.2 Flow Diagram for Identifying the Number of Data Points, N, for Statistical Tests ... | 5-23 |
| 5.3 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units | 5-24 |
| 5.4 Example of a Random Measurement Pattern | 5-41 |
| 5.5 Example of a Random-Start Triangular Grid Measurement Pattern | 5-43 |
| 6.1 The Physical Probe Area of a Detector | 6-29 |
| 6.2 Graphically Represented Probabilities for Type I and Type II Errors in Detection Sensitivity for Instrumentation With a Background Response | 6-33 |

LIST OF FIGURES

| | <u>Page</u> |
|--|-------------|
| 8.1 Examples of Posting Plots | 8-4 |
| 8.2 Example of a Frequency Plot | 8-5 |
| 9.1 Example of a QAPP Format | 9-5 |
| A.1 Plot Plan for the Specialty Source Manufacturing Company | A-3 |
| A.2 Building Floor Plan | A-4 |
| A.3 Examples of Scanning Patterns for Each Survey Unit Classification | A-6 |
| A.4 Reference Coordinate System for the Class 1 Interior Concrete Survey Unit | A-8 |
| A.5 Power Chart for the Class 1 Interior Concrete Survey Unit | A-9 |
| A.6 Prospective Power Curve for the Class 1 Interior Concrete Survey Unit | A-12 |
| A.7 Measurement Grid for the Class 1 Interior Concrete Survey Unit | A-13 |
| A.8 Quantile-Quantile Plot for the Class 1 Interior Concrete Survey Unit | A-17 |
| A.9 Retrospective Power Curve for the Class 1 Interior Concrete Survey Unit | A-20 |
| D.1 The Data Quality Objectives Process | D-2 |
| D.2 Repeated Applications of the DQO Process Throughout the Radiation Survey and Site Investigation Process | D-3 |
| D.3 Example of the Parameter of Interest for the 1-Sample Case | D-11 |
| D.4 Example of the Parameter of Interest for the 2-Sample Case | D-12 |
| D.5 Possible Statement of the Null Hypothesis for the Final Status Survey Addressing the Issue of Compliance | D-18 |
| D.6 Possible Statement of the Null Hypothesis for the Final Status Survey Addressing the Issue of Indistinguishability from Background | D-19 |
| D.7 Geometric Probability of Sampling at Least One Point of an Area of Elevated Activity as a Function of Sample Density with Either a Square or Triangular Sampling Pattern | D-24 |
| D.8 Example of a Power Chart Illustrating the Decision Rule for the Final Status Survey | D-25 |
| D.9 Example of an Error Chart Illustrating the Decision Rule for the Final Status Survey | D-27 |
| E.1 The Assessment Phase of the Data Life Cycle | E-2 |
| F.1 Comparison of the Radiation Survey and Site Investigation Process with the CERCLA Superfund Process and the RCRA Corrective Action Process | F-2 |

LIST OF FIGURES

| | <u>Page</u> |
|---|-------------|
| I.1 Example of a Stem and Leaf Display | I-18 |
| I.2 Example of a Quantile Plot | I-20 |
| I.3 Quantile Plot for Example Class 2 Exterior Survey Unit of Section 8.3.3 | I-21 |
| I.4 Example Quantile-Quantile Plot | I-24 |
| I.5 Retrospective Power Curve for Class 3 Exterior Survey Unit | I-26 |
| I.6 Retrospective Power Curve for Class 2 Interior Drywall Survey Unit | I-29 |
| | |
| J.1 Probability (P) of Getting One or More Counts When Passing Over a 100 cm ² Area Contaminated at 500 dpm/100 cm ² Alpha | J-5 |
| J.2 Probability (P) of Getting One or More Counts When Passing Over a 100 cm ² Area Contaminated at 1,000 dpm/100 cm ² Alpha | J-6 |
| J.3 Probability (P) of Getting One or More Counts When Passing Over a 100 cm ² Area Contaminated at 5,000 dpm/100 cm ² Alpha | J-7 |
| J.4 Probability (P) of Getting Two or More Counts When Passing Over a 100 cm ² Area Contaminated at 500 dpm/100 cm ² Alpha | J-8 |
| J.5 Probability (P) of Getting Two or More Counts When Passing Over a 100 cm ² Area Contaminated at 1,000 dpm/100 cm ² Alpha | J-9 |
| J.6 Probability (P) of Getting Two or More Counts When Passing Over a 100 cm ² Area Contaminated at 5,000 dpm/100 cm ² Alpha | J-10 |
| | |
| N.1 Measurement Bias and Random Measurement Uncertainty | N-11 |

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ABBREVIATIONS

| | |
|---------------------|--|
| AEA | Atomic Energy Act |
| AEC | Atomic Energy Commission |
| AFI | Air Force Instructions |
| ALARA | as low as reasonably achievable |
| AMC | Army Material Command |
| ANSI | American National Standards Institute |
| AR | Army Regulations |
| ASTM | American Society of Testing and Materials |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| CAA | Clean Air Act |
| Capt. | Captain (Air Force) |
| CAPT | Captain (Navy) |
| CDR | Commander |
| CEDE | committed effective dose equivalent |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CERCLIS | Comprehensive Environmental Response, Compensation, and Liability Information System |
| CFR | Code of Federal Regulations |
| CHP | Certified Health Physicist |
| CPM | counts per minute |
| DARA | Department of the Army Radioactive Material Authorization |
| DCF | dose conversion factor |
| DCGL | derived concentration guideline level |
| DCGL _{EMC} | DCGL for small areas of elevated activity, used with the EMC |
| DCGL _w | DCGL for average concentrations over a wide area, used with statistical tests |
| DEFT | Decision Error Feasibility Trials |
| DLC | Data Life Cycle |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DOT | Department of Transportation |
| DQA | Data Quality Assessment |
| DQO | Data Quality Objectives |
| EERF | Eastern Environmental Radiation Facility |
| Ehf | human factors efficiency |
| EMC | elevated measurement comparison |
| EML | Environmental Measurements Laboratory |
| EMMI | Environmental Monitoring Methods Index |
| EPA | Environmental Protection Agency |
| EPIC | Environmental Photographic Interpretation Center |
| ERAMS | Environmental Radiation Ambient Monitoring System |

ABBREVIATIONS

| | |
|---------|--|
| FEMA | Federal Emergency Management Agency |
| FIRM | Flood Insurance Rate Maps |
| FRDS | Federal Reporting Data System |
| FSP | Field Sampling Plan |
| FWPCA | Federal Water Pollution Control Act |
| FUSRAP | Formerly Utilized Sites Remedial Action Program |
| GEMS | Geographical Exposure Modeling System |
| GM | Geiger-Mueller |
| GPS | global positioning system |
| GRIDS | Geographic Resources Information Data System |
| GWSI | Ground Water Site Inventory |
| H_0 | null hypothesis |
| H_a | alternative hypothesis |
| HSA | Historical Site Assessment |
| HSWA | Hazardous and Solid Waste Amendments |
| ISI | Information System Inventory |
| L_c | critical level |
| L_D | detection limit |
| LBGR | lower bound of the gray region |
| LCDR | Lieutenant Commander |
| LLRWPA | Low Level Radioactive Waste Policy Act as Amended |
| LT | Lieutenant |
| MARLAP | Multi-Agency Radiation Laboratory Analytical Protocols (Manual) |
| MARSSIM | Multi-Agency Radiation Survey and Site Investigation Manual |
| MCA | multichannel analyzer |
| MDC | minimum detectable concentration |
| MDCR | minimum detectable count rate |
| MED | Manhattan Engineering District |
| NARM | naturally occurring or accelerator produced radioactive material |
| NCAPS | National Corrective Action Prioritization System |
| NCRP | National Council on Radiation Protection and Measurements |
| NCP | National Contingency Plan |
| NIST | National Institute of Standards and Technology |
| NORM | naturally occurring radioactive material |
| NPDC | National Planning Data Corporation |

ABBREVIATIONS

| | |
|-----------|---|
| NPDES | National Pollutant Discharge Elimination System |
| NRC | Nuclear Regulatory Commission |
| NWPA | Nuclear Waste Policy Act |
| NWWA | National Water Well Association |
| ODES | Ocean Data Evaluation System |
| ORNL | Oak Ridge National Laboratory |
| ORISE | Oak Ridge Institute for Science and Education |
| PERALS | photon electron rejecting alpha liquid scintillator |
| PIC | pressurized ionization chamber |
| QA | quality assurance |
| QAPP | Quality Assurance Project Plan |
| QC | quality control |
| QMP | Quality Management Plan |
| RASP | Radiological Affairs Support Program |
| RAGS/HHEM | Risk Assessment Guidance for Superfund/Human Health Evaluation Manual |
| RC | release criterion |
| RCRA | Resource Conservation and Recovery Act |
| RCRIS | Resource Conservation and Recovery Information System |
| RI/FS | Remedial Investigation/Feasibility Study |
| ROD | Record of Decision |
| RODS | Records of Decision System |
| RSSI | Radiation Survey and Site Investigation |
| SARA | Superfund Amendments and Reauthorization Act |
| SAP | Sampling and Analysis Plan |
| SDWA | Safe Drinking Water Act |
| SFMP | Surplus Facilities Management Program |
| SOP | Standard Operating Procedures |
| STORET | Storage and Retrieval of U.S. Waterways Parametric Data |
| TEDE | total effective dose equivalent |
| TLD | thermoluminescence dosimeter |
| TRU | transuranic |
| TSCA | Toxic Substances Control Act |

ABBREVIATIONS

| | |
|----------|--|
| UMTRCA | Uranium Mill Tailings Radiation Control Act |
| USGS | United States Geological Survey |
| USPHS | United States Public Health Service |
| USRADS | Ultrasonic Ranging and Data System |
| WATSTORE | National Water Data Storage and Retrieval System |
| WL | working level |
| WRS | Wilcoxon rank sum |
| WSR | Wilcoxon signed ranks |
| WT | Wilcoxon test |

CONVERSION FACTORS

| To Convert From | To | Multiply By | To Convert From | To | Multiply By |
|-------------------|-----------------------------|-----------------------------|-----------------------------|-------------------|-------------|
| acre | hectare | 0.405 | meter (m) | inch | 39.4 |
| | sq. meter (m ²) | 4,050 | | mile | 0.000621 |
| | sq. feet (ft ²) | 43,600 | sq. meter (m ²) | acre | 0.000247 |
| becquerel (Bq) | curie (Ci) | 2.7x10 ⁻¹¹ | | hectare | 0.0001 |
| dps | 1 | sq. feet (ft ²) | | 10.8 | |
| pCi | 27 | sq. mile | 3.86x10 ⁻⁷ | | |
| Bq/kg | pCi/g | 0.027 | m ³ | liter | 1,000 |
| Bq/m ² | dpm/100 cm ² | 0.60 | mrem | mSv | 0.01 |
| Bq/m ³ | Bq/L | 0.001 | mrem/y | mSv/y | 0.01 |
| | pCi/L | 0.027 | mSv | mrem | 100 |
| centimeter (cm) | inch | 0.394 | mSv/y | mrem/y | 100 |
| Ci | Bq | 3.70x10 ¹⁰ | ounce (oz) | liter (L) | 0.0296 |
| | pCi | 1x10 ¹² | pCi | Bq | 0.037 |
| dps | dpm | 60 | pCi/L | dpm | 2.22 |
| | pCi | 27 | | Bq/m ³ | 37 |
| dpm | dps | 0.0167 | rad | Gy | 0.01 |
| | pCi | 0.451 | rem | mrem | 1,000 |
| gray (Gy) | rad | 100 | | mSv | 10 |
| hectare | acre | 2.47 | | Sv | 0.01 |
| liter (L) | cm ³ | 1000 | seivert (Sv) | mrem | 100,000 |
| | m ³ | 0.001 | | mSv | 1,000 |
| | ounce (fluid) | 33.8 | | rem | 100 |

AUGUST 2000 ERRATA AND ADDENDA

In response to comments received on the December 1997 Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), minor modifications were made to individual pages. Modifications to the manual that correct errors are listed as errata, while modifications made to clarify guidance or provide additional information are referred to as addenda. The pages affected by these modifications are listed here. A complete list of comments and resolutions is available on the MARSSIM web site at:

<http://www.epa.gov/radiation/marssim/>

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ROADMAP

Introduction to MARSSIM


The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides detailed guidance for planning, implementing, and evaluating environmental and facility radiological surveys conducted to demonstrate compliance with a dose- or risk-based regulation. The MARSSIM guidance focuses on the demonstration of compliance during the final status survey following scoping, characterization, and any necessary remedial actions.

The process of planning the survey, implementing the survey plan, and assessing the survey results prior to making a decision is called the Data Life Cycle. MARSSIM Chapter 2 and Appendix D provide detailed guidance on developing appropriate survey designs using the Data Quality Objectives (DQO) Process to ensure that the survey results are of sufficient quality and quantity to support the final decision. The survey design process is described in MARSSIM Chapters 3, 4, and 5. Guidance on selecting appropriate measurement methods (*i.e.*, scan surveys, direct measurements, samples) and measurement systems (*i.e.*, detectors, instruments, analytical methods) is provided in MARSSIM Chapters 6 and 7 and Appendix H. Data Quality Assessment (DQA) is the process of assessing the survey results, determining that the quality of the data satisfies the objectives of the survey, and interpreting the survey results as they apply to the decision being made. The DQA process is described in MARSSIM Chapter 2 and Appendix E and is applied in MARSSIM Chapter 8. Quality Assurance and Quality Control (QA/QC) procedures are developed and recorded in survey planning documents, such as a Quality Assurance Project Plan (QAPP) which is described in MARSSIM Chapter 9.

MARSSIM does not provide guidance for translating the release criterion into derived concentration guideline levels (DCGLs). MARSSIM discusses contamination of surface soil and building surfaces in detail. If other media (*e.g.*, ground water, surface water, subsurface soil, equipment, vicinity properties) are potentially contaminated at the time of the final status survey, modifications to the MARSSIM survey design guidance and examples may be required.

The Goal of the Roadmap

The goal of the roadmap is to present a summary of the major steps in the design, implementation, and assessment of a final status survey and to identify where guidance on these steps is located in MARSSIM. A brief description of each step is included in the roadmap along with references to the sections of MARSSIM that provide more detailed guidance.

This roadmap provides the user with basic guidance from MARSSIM combined with “rules of thumb” (indicated by ) for performing compliance demonstration surveys. The roadmap is not designed to be a stand-alone document, but to be used as a quick reference to MARSSIM for

users already familiar with the process of planning and performing surveys. Roadmap users will also find flow charts summarizing the major steps in the Radiation Survey and Site Investigation Process, combined with references to sections in MARSSIM where detailed guidance may be found. In addition, the roadmap serves as an overview and example for applying MARSSIM guidance at sites with radioactive contamination of surface soil and building surfaces. The roadmap assumes a working knowledge of MARSSIM terminology. If such knowledge is lacking, the user may refer to Section 2.2 of MARSSIM for definitions of key terms. In addition, a complete set of definitions is provided in the Glossary.

Data Life Cycle

Compliance demonstration is simply a decision as to whether or not a survey unit meets the release criterion. For most sites, this decision is supported by statistical tests based on the results of one or more surveys. The initial assumption used in MARSSIM is that each survey unit is contaminated above the release criterion until proven otherwise. The surveys are designed to provide the information needed to reject this initial assumption. MARSSIM recommends using the Data Life Cycle as a framework for planning, implementing, and evaluating survey results prior to making a decision. Figure 1 summarizes the major activities associated with each phase of the Data Life Cycle.

Planning Stage

The survey design is developed and documented using the Data Quality Objectives (DQO) Process (Section 2.3.1, Appendix D). The DQOs for the project are established and preliminary surveys (*e.g.*, scoping, characterization) are performed to provide information necessary to design the final status survey for compliance demonstration. The DQOs for the project are re-evaluated for each of the preliminary surveys. The preliminary surveys may provide information for purposes other than compliance demonstration that are not discussed in MARSSIM. For example, a characterization survey may provide information to support evaluation of remedial alternatives. In addition, any of the preliminary surveys may be designed to demonstrate compliance with the release criterion as one of the survey objectives. These alternate survey designs are developed based on site-specific considerations (Section 2.6). The planning phase of the Data Life Cycle produces a final status survey design that is used for demonstrating compliance with the release criterion. This design is recorded in planning documents, such as a Quality Assurance Project Plan (QAPP) described in Section 9.2.

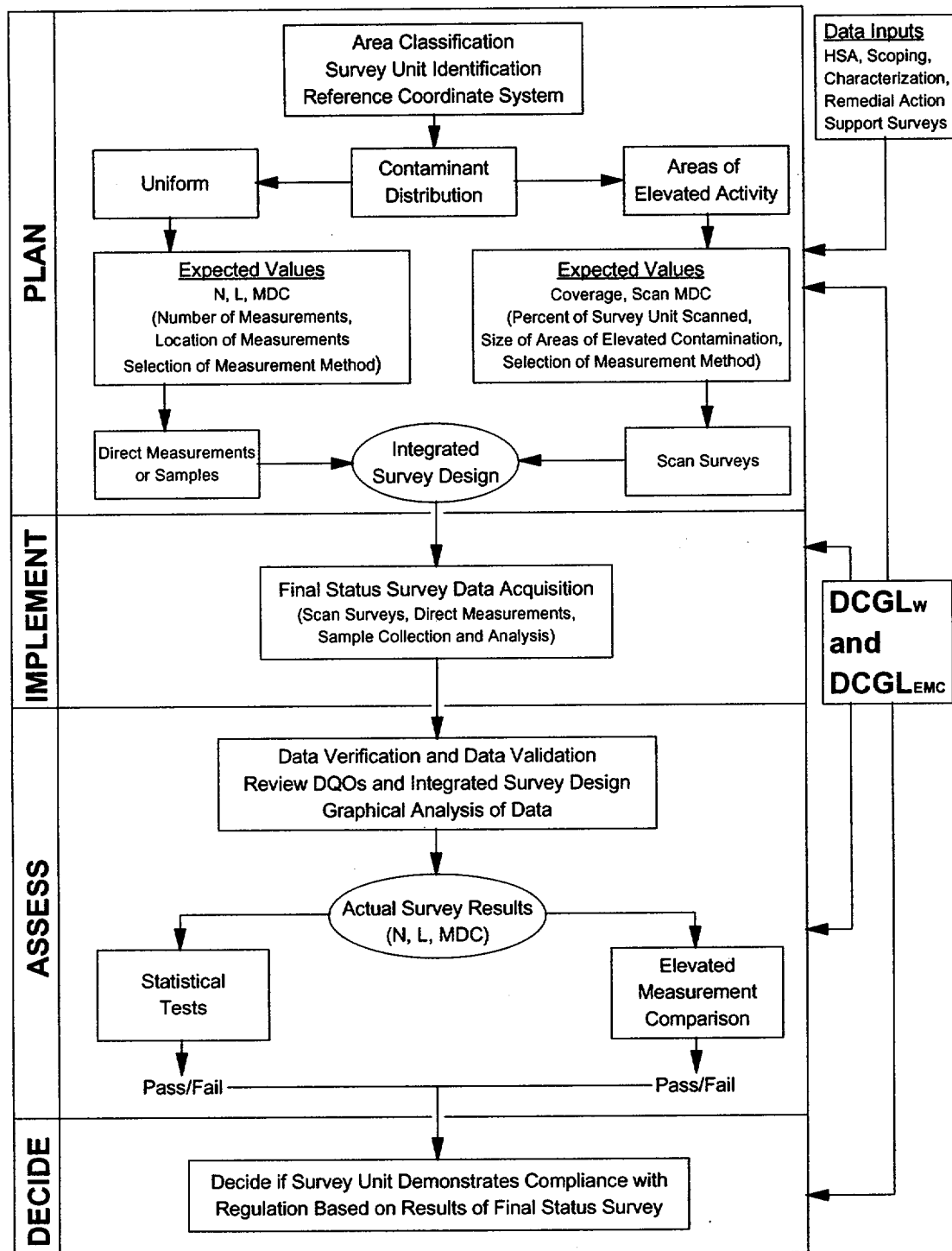


Figure 1 The Data Life Cycle Applied to a Final Status Survey

MARSSIM Roadmap

A minimum amount of information is needed from the preliminary surveys to develop an effective final status survey design. This includes

- Sufficient information to justify classification and specification of boundaries for survey units (the default is Class 1 which results in the highest level of survey effort)
- An estimate of the variability of the contaminant concentration in the survey unit (σ_s) and the reference area (σ_r) if necessary

After the preliminary surveys are completed, the final status survey design can be developed. Figure 2 presents the major steps in the development of a survey design that integrates scanning surveys with direct measurements and sampling. Most of the steps are easy to understand and references to appropriate sections of MARSSIM are included in the flowchart. Several of these steps are important enough to justify additional discussion in this guide. These steps are

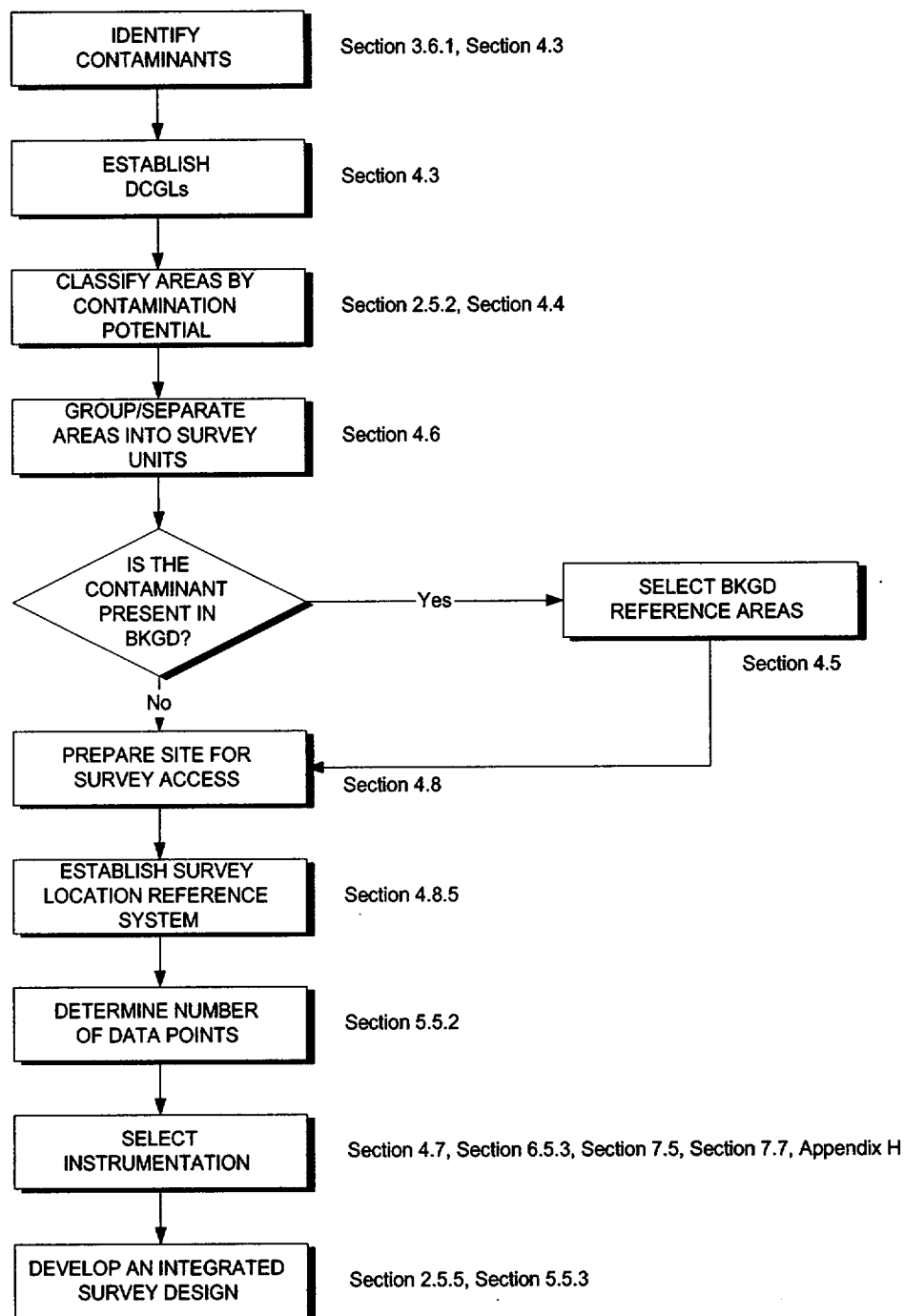
- Classify Areas by Contamination Potential
- Group/Separate Areas into Survey Units
- Determine Number of Data Points
- Select Instrumentation
- Develop an Integrated Survey Design

Classify Areas by Contamination Potential (Section 4.4)

Classification is a critical step in survey design because it determines the level of survey effort based on the potential for contamination. Overestimating the potential for contamination results in an unnecessary increase in the level of survey effort. Underestimating the potential for contamination greatly increases the probability of failing to demonstrate compliance based on the survey results. There are two key decisions made when classifying areas: 1) is the average activity in the area likely to exceed the $DCGL_w$, and 2) is the contamination present in small areas of elevated activity or is the contamination distributed relatively homogeneously across the area. Each of these decisions is considered separately when designing the survey and then combined into an integrated survey design. Class 1 areas, prior to remediation, are impacted areas with concentrations of residual radioactivity that exceed the $DCGL_w$. Class 2 areas are impacted areas where concentrations of residual activity that exceed the $DCGL_w$ are not expected. Class 3 areas are impacted areas that have a low probability of containing areas with residual radioactivity. The information obtained from the preliminary surveys is crucial for classifying areas (see Figure 2.4).



Area classification considers both the level of contamination relative to the $DCGL_w$ and the distribution of the contamination. The contamination may be uniformly distributed or present as small areas of elevated activity.


**Figure 2 Flow Diagram for Designing a Final Status Survey**

Group/Separate Areas into Survey Units (Section 4.6)

Survey units are limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. Table 1 provides suggested survey unit areas based on area classification. The rationale for selecting a larger survey unit area should be developed using the DQO Process and fully documented.

Table 1 Suggested Survey Unit Areas

| Classification | Suggested Area |
|----------------|--------------------------------|
| Class 1 | |
| Structures | up to 100 m ² |
| Land Areas | up to 2,000 m ² |
| Class 2 | |
| Structures | 100 to 1,000 m ² |
| Land Areas | 2,000 to 10,000 m ² |
| Class 3 | |
| Structures | no limit |
| Land Areas | no limit |

 Survey unit areas should be consistent with exposure pathway modeling assumptions used to develop DCGLs.

Determine Number of Data Points (Section 5.5.2)

The number of data points is determined based on the selection of a statistical test, which in turn is based on whether or not the contaminant is present in background. Figure 3 presents a flow chart for determining the number of data points.

The first step in determining the number of data points is to specify the acceptable decision error rates, α and β . Decision error rates are site-specific and selected using the DQO Process. Changes in the values of α and β may result from successive iterations of the DQO Process.

 Values for α and β are site-specific and selected using the DQO Process.

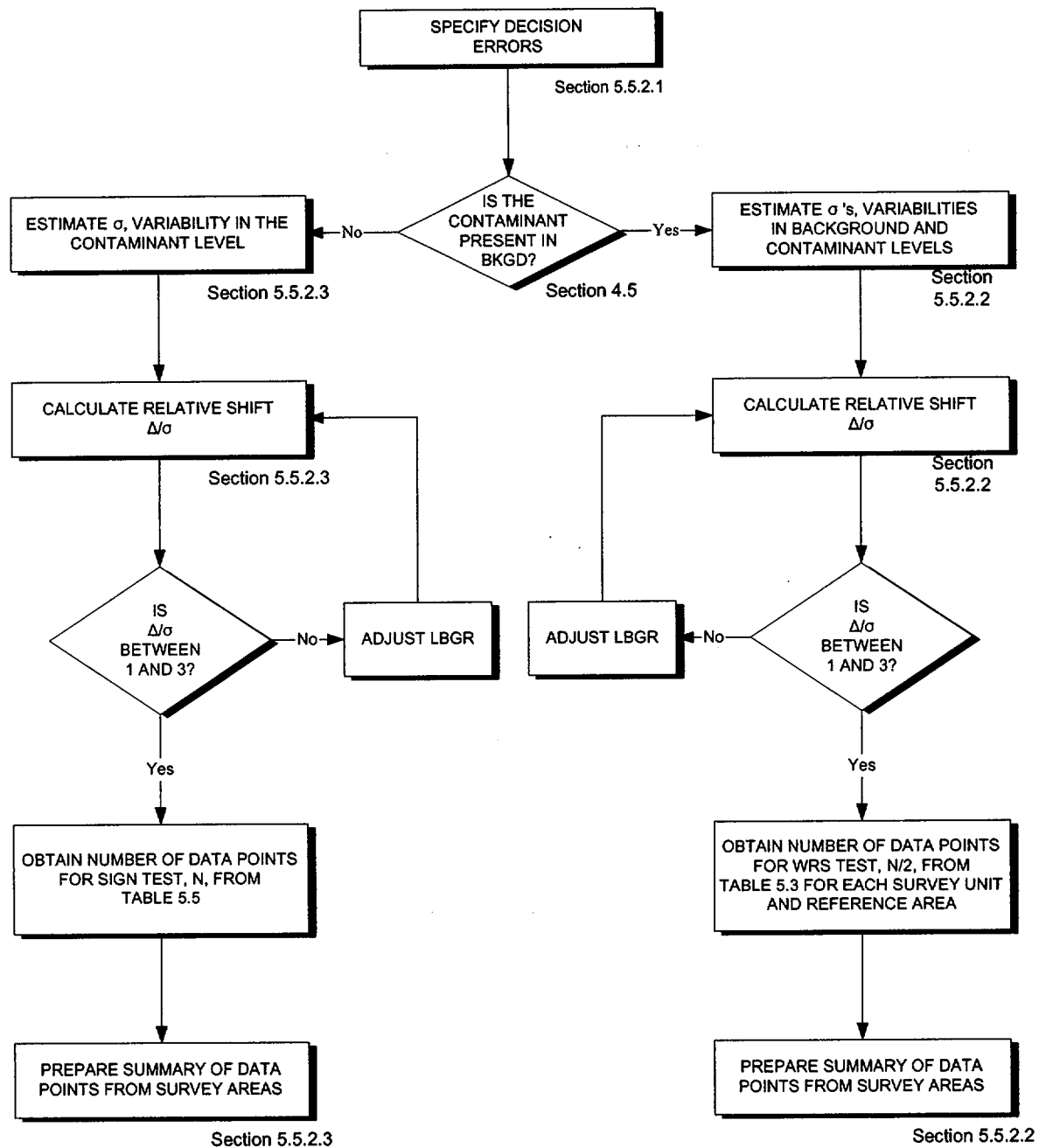



Figure 3 Flow Diagram for Determining the Number of Data Points

The next step, after determining whether or not the contaminant is present in background, is to estimate the variability of the contaminant concentration, σ . The standard deviation of the contaminant concentration determined from the preliminary survey results should provide an appropriate estimate of σ . If the contaminant is present in background, the variability in the survey unit (σ_s) and the variability in the reference area (σ_r) should both be estimated. The larger of the two values should be selected for determining the number of data points. Underestimating σ can underestimate the number of measurements needed to demonstrate compliance with the regulation, which increases the probability the survey unit will fail the statistical test. Overestimating σ can result in collecting more data than is necessary to demonstrate compliance.

 It is better to overestimate values of σ_s and σ_r .

 When σ_s and σ_r are different, select the larger of the two values.


The third step is to calculate the relative shift, Δ/σ . The variability of the contaminant concentration, σ , was determined in the previous step. The shift, Δ , is equal to the width of the gray region. The upper bound of the gray region is defined as the $DCGL_w$. The lower bound of the gray region (LBGR) is a site-specific parameter, adjusted to provide a value for Δ/σ between one and three. Δ/σ can be adjusted using the following steps:

- Initially select LBGR to equal one half the $DCGL_w$. This means Δ ($DCGL_w - LBGR$) also equals one half the $DCGL_w$. Calculate Δ/σ .
- If Δ/σ is between one and three, obtain the appropriate number of data points from Table 5.3 or Table 5.5.
- If Δ/σ is less than one, select a lower value for LBGR. Continue to select lower values for LBGR until Δ/σ is greater than or equal to one, or until LBGR equals zero.
- If Δ/σ is greater than three, select a higher value for LBGR. Continue to select higher values for LBGR until Δ/σ is less than or equal to three.

Alternatively, Δ/σ can be adjusted by solving the following equation and calculating Δ/σ :

$$LBGR = DCGL_w - \sigma$$


If LBGR is less than zero, Δ/σ can be calculated as $DCGL_w/\sigma$.

 Adjust the LBGR to provide a value for Δ/σ between one and three.

The final step in determining the number of data points is to obtain the appropriate value from Table 5.3 or Table 5.5. Table 5.3 provides the number of data points for each survey unit and each reference area when the contaminant is present in background (N/2). Table 5.5 provides the number of data points for each survey unit when the contaminant is not present in background (N).

Select Instrumentation (Section 4.7, Section 6.5.3, Section 7.5, Section 7.7, Appendix H)

Instrumentation or measurement techniques should be selected based on detection sensitivity to provide technically defensible results that meet the objectives of the survey. Because of the uncertainty associated with interpreting scanning results, the detection sensitivity of the selected instruments should be as far below the DCGL as possible. For direct measurements and sample analyses, minimum detectable concentrations (MDCs) less than 10% of the DCGL are preferable while MDCs up to 50% of the DCGL are acceptable.

 Estimates of the MDC that minimize potential decision errors should be used for planning surveys.

Develop an Integrated Survey Design (Section 5.5.3)

The integrated survey design combines scanning surveys with direct measurements and sampling. The level of survey effort is determined by the potential for contamination as indicated by the survey unit classification. This is illustrated in Figure 4. Class 3 survey units receive judgmental scanning and randomly located measurements. Class 2 survey units receive scanning over a portion of the survey unit based on the potential for contamination combined with direct measurements and sampling performed on a systematic grid. Class 1 survey units receive scanning over 100% of the survey unit combined with direct measurements and sampling performed on a systematic grid. The grid spacing is adjusted to account for the scan MDC (Section 5.5.2.4).

Table 2 provides a summary of the recommended survey coverage for structures and land areas. Modifications to the example survey designs may be required to account for other contaminated media (*e.g.*, ground water, subsurface soil).

Implementation Phase

The objectives outlined in the QAPP are incorporated into Standard Operating Procedures (SOPs). The final status survey design is carried out in accordance with the SOPs and the QAPP resulting in the generation of raw data. Chapter 6, Chapter 7, and Appendix H provide information on measurement techniques.

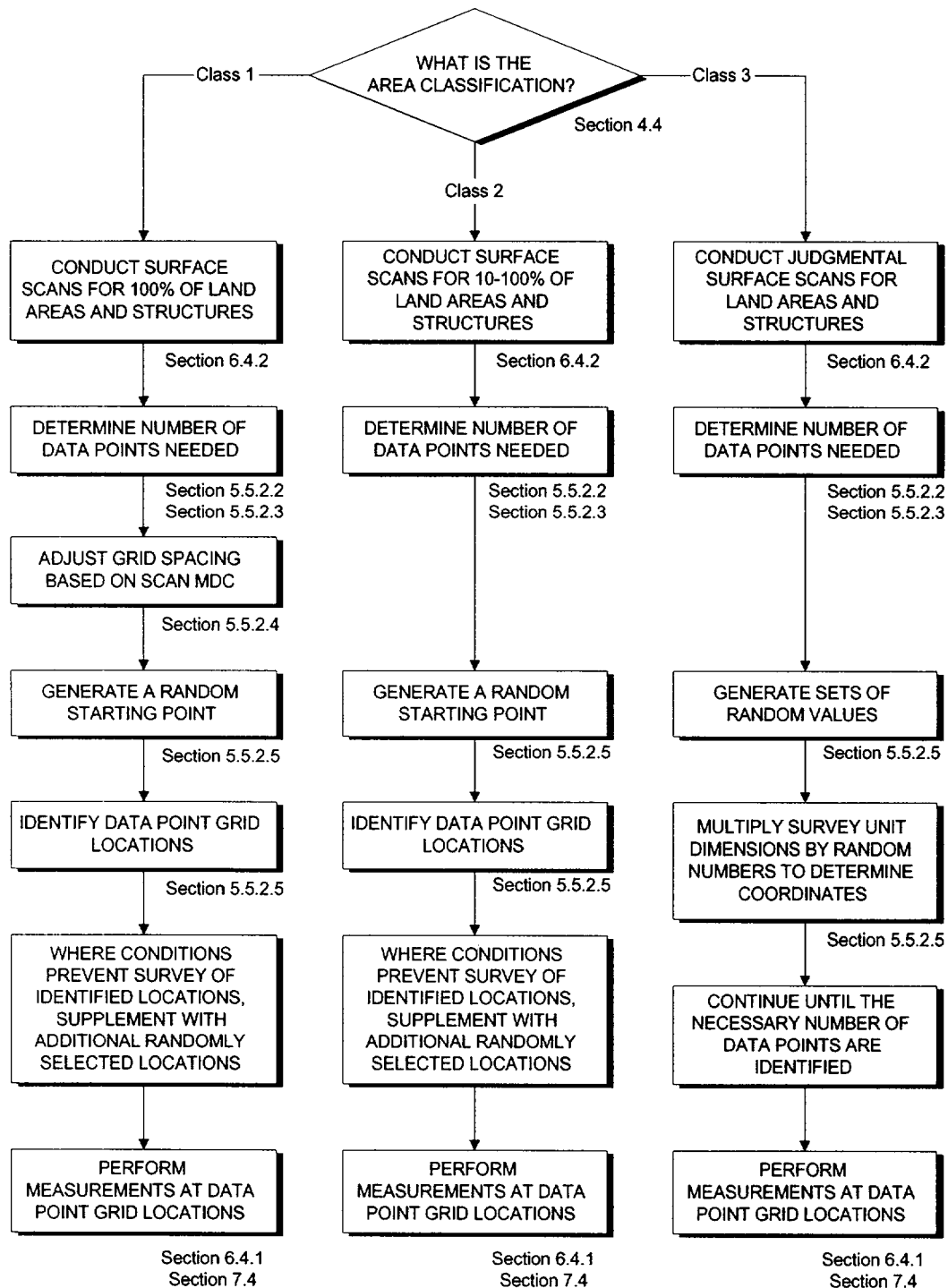


Figure 4 Flow Diagram for Developing an Integrated Survey Design

Table 2 Recommended Survey Coverage for Structures and Land Areas

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

Assessment Phase

The assessment phase of the Data Life Cycle includes verification and validation of the survey results combined with an assessment of the quantity and quality of the data. As previously stated, both the average level of contamination in the survey unit and the distribution of the contamination within the survey unit are considered during area classification. For this reason, the assessment phase includes a graphical review of the data to provide a visual representation of the radionuclide distribution, an appropriate statistical test to demonstrate compliance for the average concentration of a uniformly distributed radionuclide, and the elevated measurement comparison (EMC) to demonstrate compliance for small areas of elevated activity.

The survey data are verified to ensure that SOPs specified in the survey design were followed and that the measurement systems were performed in accordance with the criteria specified in the QAPP (Section 9.3.1). The data are validated to ensure that the results support the objectives of the survey, as documented in the QAPP, or permit a determination that these objectives should be modified (Section 9.3.2). The Data Quality Assessment (DQA) process is then applied using

the verified and validated data to determine if the quality of the data satisfies the data user's needs. DQA is described in Appendix E and is applied in Chapter 8.

The first step in DQA is to review the DQOs and survey design to ensure that they are still applicable. For example, if the data suggest that a survey unit is misclassified, the DQOs and survey design would be modified for the new classification.

The next step is to conduct a preliminary data review to learn about the structure of the data and to identify patterns, relationships, or potential anomalies. This review should include calculating basic statistical quantities (*i.e.*, mean, standard deviation, median) and graphically presenting the data using at least a histogram and a posting plot. The results of the preliminary data review are also used to verify the assumptions of the tests. Some of the assumptions and possible methods for assessing them are summarized in Table 3. Information on diagnostic tests is provided in Section 8.2 and Appendix I.

Table 3 Methods for Checking the Assumptions of Statistical Tests

| Assumption | Diagnostic |
|----------------------|--|
| Spatial Independence | Posting Plot (Figure 8.1) |
| Symmetry | Histogram (Figure 8.2) Quantile Plot (Figure I.2) |
| Data Variance | Sample Standard Deviation (Section 8.2) |
| Power is Adequate | Retrospective Power Chart (Sign Test, Figure I.5) (WRS Test, Figure I.6) |

The final step in interpreting the data is to draw conclusions from the data. Table 4 summarizes the statistical tests recommended in MARSSIM. Section 8.3 provides guidance on performing the Sign test when the contaminant is not present in background. Section 8.4 provides guidance on performing the Wilcoxon Rank Sum (WRS) test when the contaminant is present in background.

Table 4 Summary of Statistical Tests**Radionuclide not in background and radionuclide-specific measurements made:**

| Survey Result | Conclusion |
|--|---|
| All measurements less than $DCGL_w$ | Survey unit meets release criterion |
| Average greater than $DCGL_w$ | Survey unit does not meet release criterion |
| Any measurement greater than $DCGL_w$ and the average less than $DCGL_w$ | Conduct Sign test and elevated measurement comparison |

Radionuclide in background or radionuclide non-specific (gross) measurements made:

| Survey Result | Conclusion |
|--|--|
| Difference between maximum survey unit measurement and minimum reference area measurements is less than $DCGL_w$ | Survey unit meets release criterion |
| Difference of survey unit average and reference area average is greater than $DCGL_w$ | Survey unit does not meet release criterion |
| Difference between any survey unit measurement and any reference area measurement greater than $DCGL_w$ and the difference of survey unit average and reference area average is less than $DCGL_w$ | Conduct WRS test and elevated measurement comparison |

Table 5 provides examples of final status survey investigation levels for each survey unit classification and type of measurement. For a Class 1 survey unit, measurements above the $DCGL_w$ are not necessarily unexpected. However, a measurement above the $DCGL_w$ at one of the discrete measurement locations might be considered unusual if it were much higher than all of the other discrete measurements. Thus, any discrete measurement that is above both the $DCGL_w$ and the statistical-based parameter for the measurements should be investigated further. Any measurement, either at a discrete location or from a scan, that is above the $DCGL_{EMC}$ should be flagged for further investigation.

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

Table 5 Summary of Investigation Levels

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

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


Both the measurements at discrete locations and the scans are subject to the EMC. The result of the EMC does not in itself lead to a conclusion as to whether the survey unit meets or exceeds the release criterion, but is a flag or trigger for further investigation. The investigation may involve taking further measurements in order to determine that the area and level of the elevated residual radioactivity are such that the resulting dose or risk meets the release criterion.¹ The investigation should also provide adequate assurance that there are no other undiscovered areas of elevated residual radioactivity in the survey unit that might result in a dose exceeding the release criterion. This could lead to a re-classification of all or part of a survey unit—that is, unless the results of the investigation indicate that reclassification is not necessary.

Decision Making Phase

A decision is made, in coordination with the responsible regulatory agency, based on the conclusions drawn from the assessment phase. The results of the EMC are used to demonstrate compliance with the dose- or risk-based regulation for small areas of elevated activity, while the nonparametric statistical tests are used to demonstrate that the average radionuclide concentration in the survey unit complies with the release criterion. The objective is to make technically defensible decisions with a specified level of confidence.

¹ Rather than, or in addition to, taking further measurements, the investigation may involve assessing the adequacy of the exposure pathway model used to obtain the DCGLs and area factors, and the consistency of the results obtained with the Historical Site Assessment and the scoping, characterization, and remedial action support surveys.

The EMC consists of comparing each measurement from the survey unit with the investigation levels in Table 5. The EMC is performed for measurements obtained from the systematic or random sample locations as well as locations flagged by scanning surveys. Any measurement from the survey unit that is equal to or greater than the investigation level indicates an area of relatively higher concentration and is investigated, regardless of the outcome of the nonparametric statistical tests.

 Any measurement from the survey unit that is equal to or greater than the investigation level indicates an area of relatively higher concentration and is investigated, regardless of the outcome of the nonparametric statistical tests.

The result of the Sign test or the WRS test is the decision to reject or not to reject the null hypothesis that the survey unit is contaminated above the $DCGL_w$. Provided that the results of any investigations triggered by the EMC have been resolved, a rejection of the null hypothesis leads to the decision that the survey unit meets the release criterion. If necessary, the amount of residual radioactivity in the survey unit can be estimated so that dose or risk calculations can be made. In most cases, the average concentration is the best estimate for the amount of residual radioactivity.

Summary

The roadmap presents a summary of the planning, implementation, assessment, and decision making phases for a final status survey and identifies where guidance on these phases is located in MARSSIM. Each step in the process is described briefly along with references to the sections of MARSSIM to which the user may refer for more detailed guidance. Flow charts are provided to summarize the major steps in the Radiation Survey and Site Investigation Process, again citing appropriate sections of MARSSIM. In addition to providing the user with basic guidance from MARSSIM, the roadmap also includes “rules of thumb” for performing compliance demonstration surveys.

1 INTRODUCTION

1.1 Purpose and Scope of MARSSIM

Radioactive materials have been produced, processed, used, and stored at thousands of sites throughout the United States. Many of these sites—ranging in size from Federal weapons-production facilities covering hundreds of square kilometers to the nuclear medicine departments of small hospitals—were at one time or are now radioactively contaminated.

The owners and managers of a number of sites would like to determine if these sites are contaminated, clean them up if contaminated, and release them for restricted use or for unrestricted public use. The Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Energy (DOE) are responsible for the release of sites following cleanup. These responsibilities apply to facilities under the control of Federal agencies, such as the DOE and Department of Defense (DOD), and to sites licensed by the NRC and its Agreement States. Some States have responsibilities for similar sites under their control.

The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides a nationally consistent consensus approach to conducting radiation surveys and investigations at potentially contaminated sites. This approach should be both scientifically rigorous and flexible enough to be applied to a diversity of site cleanup conditions. MARSSIM's title includes the term "survey" because it provides information on planning and conducting surveys, and includes the term "site investigation" because the process outlined in the manual allows one to begin by investigating any site (*i.e.*, by gathering data or information) that may involve radioactive contamination.

The decommissioning that follows remediation will normally require a demonstration to the responsible Federal or State agency that the cleanup effort was successful and that the release criterion (a specific regulatory limit) was met. In MARSSIM, this demonstration is given the name "final status survey." This manual assists site personnel or others in performing or assessing such a demonstration. (Generally, MARSSIM may serve to guide or monitor remediation efforts whether or not a release criterion is applied.)

As illustrated in Figure 1.1, the demonstration of compliance with respect to conducting surveys is comprised of three interrelated parts:

- I. Translate: Translating the cleanup/release criterion (*e.g.*, mSv/y, mrem/y, specific risk) into a corresponding derived contaminant concentration level (*e.g.*, Bq/kg or pCi/g in soil) through the use of environmental pathway modeling.

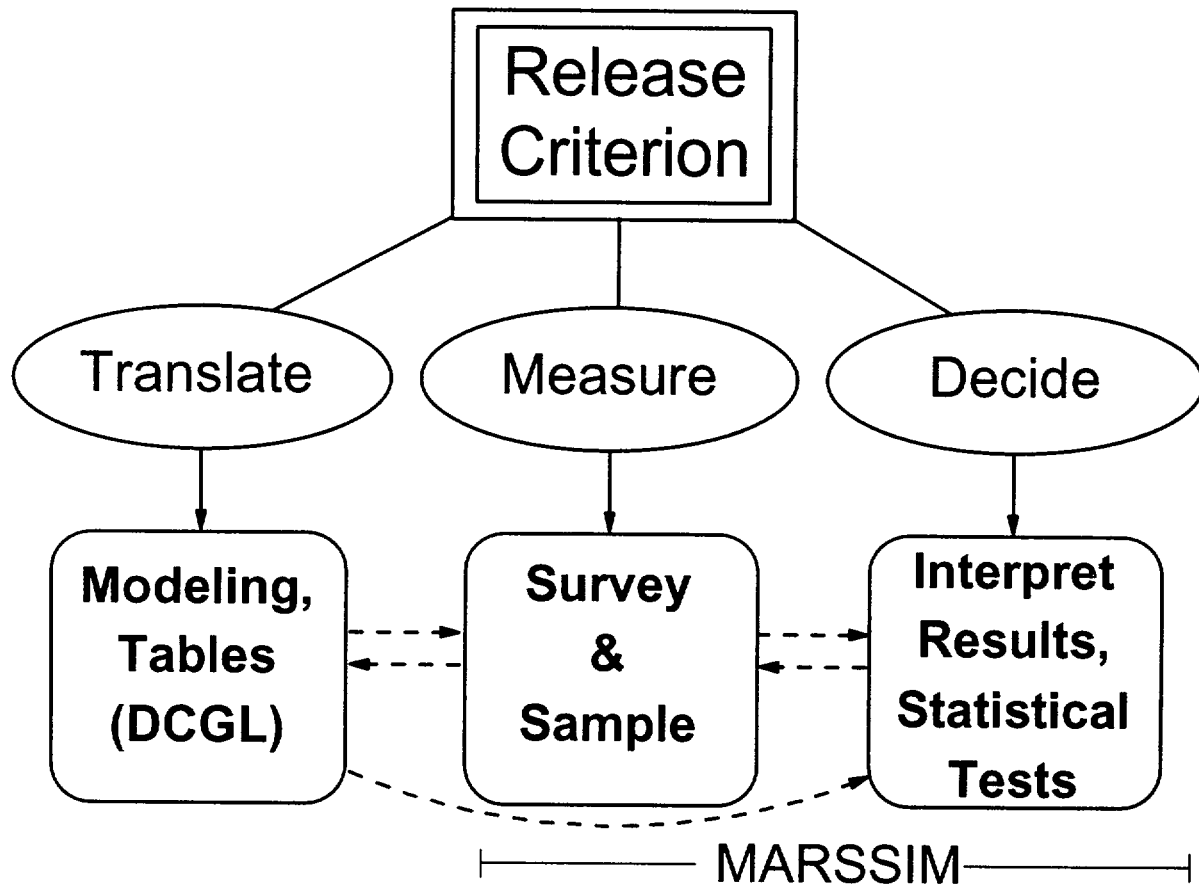


Figure 1.1 Compliance Demonstration

- II. Measure: Acquiring scientifically sound and defensible site-specific data on the levels and distribution of residual contamination, as well as levels and distribution of radionuclides present as background, by employing suitable field and/or laboratory measurement techniques.¹
- III. Decide: Determining that the data obtained from sampling does support the assertion that the site meets the release criterion, within an acceptable degree of uncertainty, through application of a statistically based decision rule.

¹ Measurements include field and laboratory analyses, however, MARSSIM leaves detailed discussions of laboratory sample analyses to another manual (*i.e.*, a companion document, the Multi-Agency Radiation Laboratory Analytical Protocols (MARLAP) manual that is currently under development).

MARSSIM presents comprehensive guidance—specifically for II and III above—for contaminated soil and buildings. This guidance describes a performance-based approach for demonstrating compliance with a dose- or risk-based regulation. This approach includes processes that identify data quality needs and may reveal limitations that enter into conducting a survey. The data quality needs stated as Data Quality Objectives (DQOs) include performance measures and goals in relation to a specific intended use of the data (EPA 1997a).

DQOs must be developed on a site-specific basis. However, because of the large variability in the types of radiation sites, it is impossible to provide criteria that apply to every situation. As an example, MARSSIM presents a method for planning, implementing, assessing, and making decisions about regulatory compliance at sites with radioactive contaminants in surface soil and on building surfaces. In particular, MARSSIM describes generally acceptable approaches for:

- planning and designing scoping, characterization, remediation-support, and final status surveys for sites with surface soil and building surface contamination
- Historical Site Assessment (HSA)
- QA/QC in data acquisition and analysis
- conducting surveys
- field and laboratory methods and instrumentation, and interfacing with radiation laboratories
- statistical hypothesis testing, and the interpretation of statistical data
- documentation

Thus, MARSSIM provides standardized and consistent approaches for planning, conducting, evaluating, and documenting environmental radiological surveys, with a specific focus on the final status surveys that are carried out to demonstrate compliance with cleanup regulations. These approaches may not meet the DQOs at every site, so other methods may be used to meet site-specific DQOs, as long as an equivalent level of performance can be demonstrated.

Table 1.1, at the end of Chapter 1, summarizes the scope of MARSSIM. Several issues related to releasing sites are beyond the scope of MARSSIM. These include translation of dose or risk standards into radionuclide specific concentrations, or demonstrating compliance with ground water or surface water regulations. MARSSIM can be applied to surveys performed at vicinity properties—those not under government or licensee control—but the decision to apply the MARSSIM at vicinity properties is outside the scope of MARSSIM. Other contaminated media (e.g., sub-surface soil, building materials, ground water) and the release of contaminated components and equipment are also not addressed by MARSSIM. With MARSSIM's main focus on final status surveys, this manual continues a process of following remediation activities that are intended to remove below-surface contaminants. Therefore, some of the reasons for limiting the scope of the guidance to contaminated surface soils and building surfaces include:

1) contamination is limited to these media for many sites following remediation, 2) since many

sites have surface soil and building surface contamination as the leading source of contamination, existing computer models used for calculating the concentrations based on dose or risk generally consider only surface soils or building surfaces as a source term, and 3) MARSSIM was written in support of cleanup rulemaking efforts for which supporting data are mostly limited to contaminated surface soil and building surfaces.

MARSSIM also recognizes that there may be other factors, such as cost or stakeholder concerns, that have an impact on designing surveys. Guidance on how to address these specific concerns is outside the scope of MARSSIM. Unique site-specific cases may arise that require a modified approach beyond what is presently described in MARSSIM. This includes examples such as:

1) the release of sites contaminated with naturally occurring radionuclides in which the concentrations corresponding to the release criteria are close to the variability of the background and 2) sites where a reference background cannot be established. However, the process of planning, implementing, assessing, and making decisions about a site described in MARSSIM is applicable to all sites, even if the examples in this manual do not meet a site's specific objectives.

Of MARSSIM's many topics, the Data Quality Objective (DQO) approach to data acquisition and analysis and the Data Quality Assessment (DQA) for determining that data meet stated objectives are two elements that are a consistent theme throughout the manual. The DQO Process and DQA approach, described in Chapter 2, present a method for building common sense and the scientific method into all aspects of designing and conducting surveys, and making best use of the obtainable information. This becomes a formal framework for systematizing the planning of data acquisition surveys so that the data sought yield the kind of information actually needed for making important decisions—such as whether or not to release a particular site following remediation.

1.2 Structure of the Manual

MARSSIM begins with the overview of the Radiation Survey and Site Investigation Process in Chapter 2—Figures 2.4 through 2.8 are flowcharts that summarize the steps and decisions taken in the process. Chapter 3 provides instructions for performing an Historical Site Assessment (HSA)—a detailed investigation to collect existing information on the site or facility and to develop a conceptual site model. The results of the HSA are used to plan surveys, perform measurements, and collect additional information at the site. Chapter 4 covers issues that arise in all types of surveys. Detailed information on performing specific types of surveys is included in Chapter 5. Guidance on selecting the appropriate instruments and measurement techniques for each type of measurement is in Chapters 6 and 7. Chapter 6 discusses direct measurements and scanning surveys, and Chapter 7 discusses sampling and sample preparation for laboratory measurements. The interpretation of survey results is described in Chapter 8. Chapter 9 provides guidance on data management, quality assurance (QA), and quality control (QC). Information on specific subjects related to radiation site investigation can be found in the appendices.

MARSSIM contains several appendices to provide additional guidance on specific topics. Appendix A presents an example of how to apply the MARSSIM guidance to a specific site. Appendix B describes a simplified procedure for compliance demonstration that may be applicable at certain types of sites. Appendix C summarizes the regulations and requirements associated with radiation surveys and site investigations for each of the agencies involved in the development of MARSSIM. Detailed guidance on the DQO Process is in Appendix D, and Appendix E has guidance on DQA. Appendix F describes the relationships among MARSSIM, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA). Sources of information used during site assessment are listed in Appendix G. Appendix H describes field survey and laboratory analysis equipment that may be used for radiation surveys and site investigations. Appendix I offers tables of statistical data and supporting information for interpreting survey results described in Chapter 8. The derivation of the alpha scanning detection limit calculations used in Chapter 6 is described in Appendix J. Comparison tables for QA documents are in Appendix K. Appendix L lists the regional radiation program managers for each of the agencies participating in the development of MARSSIM. Appendix M lists publications that serve as resources describing sampling methods. Information on data validation is provided in Appendix N.

MARSSIM is presented in a modular format, with each module containing guidance on conducting specific aspects of, or activities related to, the survey process. Followed in order, each module leads to the generation and implementation of a complete survey plan. Although this approach may involve some overlap and redundancy in information, it also allows many users to concentrate only on those portions of the manual that apply to their own particular needs or responsibilities. The procedures within each module are listed in order of performance and options are provided to guide a user past portions of the manual that may not be specifically applicable to the user's area of interest. Where appropriate, checklists condense and summarize major points in the process. The checklists may be used to verify that every suggested step is followed or to flag a condition in which specific documentation should explain why a step was not needed.

Also included in the manual is a section titled Roadmap. The roadmap is designed to be used with MARSSIM as a quick reference for users already familiar with the process of planning and performing radiation surveys. The roadmap gives the user basic guidance, rules of thumb, and references to sections in the manual containing detailed guidance.

MARSSIM, which is based on a graded approach, also contains a simplified procedure (see Appendix B) that many users of radioactive materials may—with the approval of the responsible regulatory agency—be able to employ to demonstrate compliance with the release criterion. Sites that may qualify for simplified release procedures are those in which the radioactive materials used were 1) of relatively short half-life (*e.g.*, $t_{1/2} \leq 120$ days) and have since decayed to insignificant quantities, 2) kept only in small enough quantities so as to be exempted or not requiring a specific

license from a regulatory authority, 3) used or stored only in the form of non-leaking sealed sources, or 4) combinations of the above.

1.3 Use of the Manual

Potential users of this manual are Federal, State, and local government agencies having authority for control of radioactive environmental contamination; their contractors; and other parties, such as organizations with licensed authority to possess and use radioactive materials. The manual is intended for a technical audience having knowledge of radiation health physics and an understanding of statistics as well as experience with the practical applications of radiation protection. An understanding of instrumentation and methodologies and expertise in planning, approving, and implementing surveys of environmental levels of radioactive material is assumed. This manual has been written so that individuals responsible for planning, approving, and implementing radiological surveys will be able to understand and apply the guidance provided here. Certain situations and sites may require consultation with more experienced personnel.

MARSSIM provides guidance for conducting radiation surveys and site investigations. MARSSIM uses the word "should" as a recommendation, that ought not be interpreted as a requirement. The reader need not expect that every recommendation in this manual will be taken literally and applied at every site. Rather, it is expected that the survey planning documentation will address how the guidance will be applied on a site-specific basis.

As previously stated, MARSSIM supports implementation of dose- or risk-based regulations. The translation of the regulatory dose limit to a corresponding concentration level is not addressed in MARSSIM, so the guidance in this manual is applicable to a broad range of regulations, including risk- or concentration-based regulations. The terms dose and dose-based regulation are used throughout the manual, but these terms are not intended to limit the use of the manual.

Note that Federal or State agencies that can approve a demonstration of compliance may support requirements that differ from what is presented in this version of MARSSIM. *It is essential, therefore, that the persons carrying out the surveys, whether they are conducting surveys in accordance with the simplified approach of Appendix B or the full MARSSIM process, remain in close communication with the proper Federal or State authorities throughout the compliance demonstration process.*

1.4 Missions of the Federal Agencies Producing MARSSIM

MARSSIM is the product of a multi-agency workgroup with representatives from EPA, NRC, DOE, and DOD. This section briefly describes the missions of the participating agencies. Regulations and requirements governing site investigations for each of the agencies associated with radiation surveys and site investigations are presented in Appendix C.

1.4.1 Environmental Protection Agency

The mission of the U.S. Environmental Protection Agency (EPA) is to improve and preserve the quality of the environment, on both national and global levels. The EPA's scope of responsibility includes implementing and enforcing environmental laws, setting guidelines, monitoring pollution, performing research, and promoting pollution prevention. EPA Headquarters maintains overall planning, coordination, and control of EPA programs, and EPA's ten regional offices are responsible for executing EPA's programs within the boundaries of each region. EPA also coordinates with, and supports research and development of, pollution control activities carried out by State and local governments.

1.4.2 Nuclear Regulatory Commission

The mission of the U.S. Nuclear Regulatory Commission (NRC) is to ensure adequate protection of public health and safety, the common defense and security, and the environment in the use of certain radioactive materials in the United States. The NRC's scope of responsibility includes regulation of commercial nuclear power reactors; non-power research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the transport, storage, and disposal of nuclear materials and waste. The Energy Reorganization Act of 1974 and the Atomic Energy Act of 1954, as amended, provide the foundation for regulation of the Nation's commercial use of radioactive materials.

1.4.3 Department of Energy

The mission of the Department of Energy (DOE) is to develop and implement a coordinated national energy policy to ensure the availability of adequate energy supplies and to develop new energy sources for domestic and commercial use. In addition, DOE is responsible for the development, construction and testing of nuclear weapons for the U.S. Military. DOE is also responsible for managing the low- and high-level radioactive wastes generated by past nuclear weapons and research programs and for constructing and maintaining a repository for civilian radioactive wastes generated by the commercial nuclear reactors. DOE has the lead in decontaminating facilities and sites previously used in atomic energy programs.

1.4.4 Department of Defense

The global mission of the Department of Defense (DOD) is to provide for the defense of the United States. In doing this, DOD is committed to protecting the environment. Each military service has specific regulations addressing the use of radioactive sources and the development of occupational health programs and radiation protection programs. The documents describing these regulations are used as guidance in developing environmental radiological surveys within DOD and are discussed in Appendix C.

Table 1.1 Scope of MARSSIM

| Within Scope of MARSSIM | | Beyond Scope of MARSSIM | |
|--------------------------------|--|--------------------------------|--|
| <i>Guidance</i> | MARSSIM provides technical guidance on conducting radiation surveys and site investigations. | <i>Regulation</i> | MARSSIM does not set new regulations or non-technical issues (e.g., legal or policy) for site cleanup. Release criterion will be provided rather than calculated using MARSSIM. |
| <i>Tool Box</i> | MARSSIM can be thought of as an extensive tool box with many components—some within the text of MARSSIM, others by reference. | <i>Tool Box</i> | Many topics are beyond the scope of MARSSIM, for example: -a public participation program -packaging and transportation of wastes for disposal -decontamination and stabilization techniques -training |
| <i>Measurement</i> | The guidance given in MARSSIM is performance-based and directed towards acquiring site-specific data. | <i>Procedure</i> | The approaches suggested in MARSSIM vary depending on the various site data needs—there are no set procedures for sample collection, measurement techniques, storage and disposal established in MARSSIM. |
| <i>Modeling</i> | The interface between environmental pathway modeling and MARSSIM is an important survey design consideration addressed in MARSSIM. | <i>Modeling</i> | Environmental pathway modeling and ecological endpoints in modeling are beyond the scope of MARSSIM. |

Table 1.1 Scope of MARSSIM (continued)

| Within Scope of MARSSIM | | Beyond Scope of MARSSIM | |
|--------------------------------|--|--------------------------------|---|
| <i>Soil and Buildings</i> | The two main media of interest in MARSSIM are contaminated surface soil and building surfaces. | <i>Other Media</i> | MARSSIM does not cover other media, including construction materials, equipment, subsurface soil, surface or subsurface water, biota, air, sewers, sediments or volumetric contamination. |
| <i>Final Status Survey</i> | The focus of MARSSIM is on the final status survey as this is the deciding factor in judging if the site meets the release criterion. | <i>Materials or Equipment</i> | MARSSIM does not recommend the use of any specific materials or equipment—there is too much variability in the types of radiation sites—this information will be in other documents. |
| <i>Radiation</i> | MARSSIM only considers radiation-derived hazards. | <i>Chemicals</i> | MARSSIM does not deal with any hazards posed by chemical contamination. |
| <i>Remediation Method</i> | MARSSIM assists users in determining when sites are ready for a final status survey and provides guidance on how to determine if remediation was successful. | <i>Remediation Method</i> | MARSSIM does not discuss selection and evaluation of remedial alternatives, public involvement, legal considerations, policy decisions related to planning |
| <i>DQO Process</i> | MARSSIM presents a systemized approach for designing surveys to collect data needed for making decisions such as whether or not to release a site. | <i>DQO Process</i> | MARSSIM does not provide prescriptive or default values of DQOs. |
| <i>DQA</i> | MARSSIM provides a set of statistical tests for evaluating data and lists alternate tests that may be applicable at specific sites. | <i>DQA</i> | MARSSIM does not prescribe a statistical test for use at all sites. |

2 OVERVIEW OF THE RADIATION SURVEY AND SITE INVESTIGATION PROCESS

2.1 Introduction

This chapter provides a brief overview of the Radiation Survey and Site Investigation (RSSI) Process, several important aspects of this Process, and its underlying principles. The concepts introduced here are discussed in detail throughout the manual.

The purpose of MARSSIM is to provide a standardized approach to demonstrating compliance with a dose- or risk-based regulation. Since most of the manual is based on general technical and statistical concepts, much of the guidance can still be applied to other types of regulations or standards. The purpose of this chapter is to provide the overview information required to understand the rest of this manual.

Section 2.2 introduces and defines key terms used throughout the manual. Some of these terms may be familiar to the MARSSIM user, while others are new terms developed specifically for this manual.

Section 2.3 describes the flow of information used to decide whether or not a site or facility complies with a regulation. The section describes the framework that is used to demonstrate compliance with a regulation, and is the basis for all guidance presented in this manual. The decision-making process is broken down into four phases: 1) planning, 2) implementation, 3) assessment, and 4) decision making.

Section 2.4 introduces the Radiation Survey and Site Investigation Process, which can be used for compliance demonstration at many sites. The section describes a series of surveys that combine to form the core of this process. Each survey has specified goals and objectives to support a final decision on whether or not a site or facility complies with the appropriate regulations. Flow diagrams showing how the different surveys support the overall process are provided, along with descriptions of the information provided by each type of survey.

Section 2.5 presents major considerations that relate to the decision-making and survey-design processes. This section, as well as the examples discussed in detail throughout the manual, focuses on residual radioactive contamination in surface soils and on building surfaces. Recommended survey designs for demonstrating compliance are presented along with the rationale for selecting these designs.

Section 2.6 recognizes that the methods presented in MARSSIM may not represent the optimal survey design at all sites. Some alternate methods for applying the Radiation Survey and Site Investigation process are discussed. Different methods for demonstrating compliance that are technically defensible may be developed with the approval of the responsible regulatory agency.

MARSSIM provides an approach that is technically defensible and flexible enough to be applied to a variety of site-specific conditions. Applying this guidance to a dose- or risk-based regulation provides a consistent approach to protecting human health and the environment. The manual's performance-based approach to decision making provides the flexibility needed to address compliance demonstration at individual sites.

2.2 Understanding Key MARSSIM Terminology

The first step in understanding the Radiation Survey and Site Investigation (RSSI) Process is accomplished by understanding the scope of this manual, the terminology, and the concepts set forth. Some of the terms used in MARSSIM were developed for the purposes of this manual, while other commonly used terms are also adopted for use in MARSSIM. This section explains some of the terms roughly in the order of their presentation in the manual.

The process described in MARSSIM begins with the premise that a release criterion has already been provided in terms of a measurement quantity. The methods presented in MARSSIM are generally applicable and are not dependent on the value of the release criterion.

A *release criterion* is a regulatory limit expressed in terms of dose (mSv/y or mrem/y) or risk (cancer incidence or cancer mortality). The terms release limit or cleanup standard are also used to describe this term. A release criterion is typically based on the total effective dose equivalent (TEDE), the committed effective dose equivalent (CEDE), risk of cancer incidence (morbidity), or risk of cancer death (mortality) and generally cannot be measured directly. *Exposure pathway modeling* is used to calculate a radionuclide-specific predicted concentration or surface area concentration of specific nuclides that could result in a dose (TEDE or CEDE) or specific risk equal to the release criterion. In this manual, such a concentration is termed the *derived concentration guideline level (DCGL)*. Exposure pathway modeling is an analysis of various exposure pathways and scenarios used to convert dose or risk into concentration. In many cases DCGLs can be obtained from responsible regulatory agency guidance based on default modeling input parameters, while other users may elect to take into account site-specific parameters to determine DCGLs. In general, the units for the DCGL are the same as the units for measurements performed to demonstrate compliance (e.g., Bq/kg or pCi/g, Bq/m² or dpm/100 cm²). This allows direct comparisons between the survey results and the DCGL. A discussion of the uncertainty associated with using DCGLs to demonstrate compliance is included in Appendix D, Section D.6.

An *investigation level* is a radionuclide-specific level based on the release criterion that, if exceeded, triggers some response such as further investigation or remediation. An investigation level may be used early in decommissioning to identify areas requiring further investigation, and may also be used as a screening tool during compliance demonstration to identify potential problem areas. A DCGL is an example of a specific investigation level.

While the derivation of DCGLs is outside the scope of MARSSIM, it is important to understand the assumptions that underlie this derivation. The derivation assumptions must be consistent with those used for planning a compliance demonstration survey. One of the most important assumptions used for converting a dose or risk limit into a media-specific concentration is the modeled area of contamination. Other considerations include sample depth, composition, modeling parameters, and exposure scenarios. MARSSIM defines two potential DCGLs based on the area of contamination.

- If the residual radioactivity is evenly distributed over a large area, MARSSIM looks at the average activity over the entire area. The $DCGL_w^1$ (the DCGL used for the statistical tests, see Section 2.5.1.2) is derived based on an average concentration over a large area.
- If the residual radioactivity appears as small areas of elevated activity² within a larger area, typically smaller than the area between measurement locations, MARSSIM considers the results of individual measurements. The $DCGL_{EMC}$ (the DCGL used for the elevated measurement comparison (EMC), see Section 2.5.3 and Section 2.5.4) is derived separately for these small areas and generally from different exposure assumptions than those used for larger areas.

A *site* is any installation, facility, or discrete, physically separate parcel of land, or any building or structure or portion thereof, that is being considered for survey and investigation.

Area is a very general term that refers to any portion of a site, up to and including the entire site.

Decommissioning is the process of safely removing a site from service, reducing residual radioactivity through remediation to a level that permits release of the property, and termination of the license or other authorization for site operation. Although only part of the process, the term decommissioning is used in this sense for the Radiation Survey and Site Investigation (RSSI) Process, and is used this way throughout MARSSIM.

¹ The "W" in $DCGL_w$ stands for Wilcoxon Rank Sum test, which is the statistical test recommended in MARSSIM for demonstrating compliance when the contaminant is present in background. The Sign test recommended for demonstrating compliance when the contaminant is not present in background also uses the $DCGL_w$.

² A small area of elevated activity, or maximum point estimate of contamination, might also be referred to as a "hot spot." This term has been purposefully omitted from MARSSIM because the term often has different meanings based on operational or local program concerns. As a result, there may be problems associated with defining the term and reeducating MARSSIM users in the proper use of the term. Because these implications are inconsistent with MARSSIM concepts, the term is not used.

A *survey unit* is a physical area consisting of structure or land areas of specified size and shape for which a separate decision will be made as to whether or not that area exceeds the release criterion. This decision is made as a result of the *final status survey*—the survey in the RSSI Process used to demonstrate compliance with the regulation or standard. The size and shape of the survey unit are based on factors, such as the potential for contamination, the expected distribution of contamination, and any physical boundaries (*e.g.*, buildings, fences, soil type, surface water body) at the site.

For MARSSIM, *measurement* is used interchangeably to mean: 1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring. *Direct measurements* are obtained by placing a detector near the media being surveyed and inferring the radioactivity level directly from the detector response. *Scanning* is a measurement technique performed by moving a portable radiation detector at a constant speed above a surface to semi-quantitatively detect areas of elevated activity. *Sampling* is the process of collecting a portion of an environmental medium as being representative of the locally remaining medium. The collected portion, or aliquot, of the medium is then analyzed to identify the contaminant and determine the concentration. The word sample may also refer to a set of individual measurements drawn from a population whose properties are studied to gain information about the entire population. This second definition of sample is primarily used for statistical discussions.

To make the best use of resources for decommissioning, MARSSIM places greater survey efforts on areas that have, or had, the highest potential for contamination. This is referred to as a *graded approach*. The final status survey uses statistical tests to support decision making. These statistical tests are performed using survey data from areas with common characteristics, such as contamination potential, which are distinguishable from other areas with different characteristics. *Classification* is the process by which an area or survey unit is described according to radiological characteristics. The significance of survey unit classification is that this process determines the final status survey design and the procedures used to develop this design. Preliminary area classifications, made earlier in the MARSSIM Process, are useful for planning subsequent surveys.

Areas that have no reasonable potential for residual contamination are classified as *non-impacted areas*. These areas have no radiological impact from site operations and are typically identified early in decommissioning. Areas with some potential for residual contamination are classified as *impacted areas*.

Impacted areas are further divided into one of three classifications:

- *Class 1 Areas:* Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiation surveys) above the DCGL_w. Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions³, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material and high specific activity.
- *Class 2 Areas:* Areas that have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL_w. To justify changing the classification from Class 1 to Class 2, there should be measurement data that provides a high degree of confidence that no individual measurement would exceed the DCGL_w. Other justifications for reclassifying an area as Class 2 may be appropriate, based on site-specific considerations. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form, 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of buildings or rooms subjected to airborne radioactivity, 5) areas handling low concentrations of radioactive materials, and 6) areas on the perimeter of former contamination control areas.
- *Class 3 Areas:* Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the DCGL_w, based on site operating history and previous radiation surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and therefore receive the highest degree of survey effort for the final status survey using a graded approach, followed by Class 2, and then by Class 3. Non-impacted areas do not receive any level of survey coverage because they have no potential for residual contamination. Non-impacted areas are determined on a site-specific basis. Examples of areas that would be non-impacted rather than impacted usually include residential or other buildings that have or had nothing more than smoke detectors or exit signs with sealed radioactive sources.

³ Remediated areas are identified as Class 1 areas because the remediation process often results in less than 100% removal of the contamination, even though the goal of remediation is to comply with regulatory standards and protect human health and the environment. The contamination that remains on the site after remediation is often associated with relatively small areas with elevated levels of residual radioactivity. This results in a non-uniform distribution of the radionuclide and a Class 1 classification. If an area is expected to have no potential to exceed the DCGL_w and was remediated to demonstrate the residual radioactivity is as low as reasonably achievable (ALARA), the remediated area might be classified as Class 2 for the final status survey.

If the radionuclide of potential concern is present in background, or if the measurement system used to determine concentration in the survey unit is not radionuclide-specific, background measurements are compared to the survey unit measurements to determine the level of residual radioactivity. The *background reference area* is a geographical area from which representative reference measurements are performed for comparison with measurements performed in specific survey units. The background reference area is defined as an area that has similar physical, chemical, radiological, and biological characteristics as the survey unit(s) being investigated but has not been contaminated by site activities (*i.e.*, non-impacted).

The process of planning the survey, implementing the survey plan, and assessing the survey results prior to making a decision is called the *Data Life Cycle*. Survey planning uses the *Data Quality Objectives (DQO) Process* to ensure that the survey results are of sufficient quality and quantity to support the final decision. *Quality Assurance and Quality Control (QA/QC)* procedures are performed during implementation of the survey plan to collect information necessary to evaluate the survey results. *Data Quality Assessment (DQA)* is the process of assessing the survey results, determining that the quality of the data satisfies the objectives of the survey, and interpreting the survey results as they apply to the decision being made.

A systematic process and structure for quality should be established to provide confidence in the quality and quantity of data collected to support decision making. The data used in decision making should be supported by a planning document that records how quality assurance and quality control are applied to obtain type and quality of results that are needed and expected. There are several terms used to describe a variety of planning documents, some of which document only a small part of the survey design process. MARSSIM uses the term *Quality Assurance Project Plan (QAPP)* to describe a single document that incorporates all of the elements of the survey design. This term is consistent with consensus guidance ANSI/ASQC E4-1994 (ASQC 1995) and EPA guidance (EPA 1994c; EPA 1997a), and is recommended to promote consistency. The use of the term QAPP in MARSSIM does not exclude the use of other terms (*e.g.*, Decommissioning Plan, Sampling and Analysis Plan, Field Sampling Plan) to describe survey documentation provided the information included in the documentation supports the objectives of the survey.

2.3 Making Decisions Based on Survey Results

Compliance demonstration is simply a decision as to whether or not a survey unit meets the release criterion. For most sites this decision is based on the results of one or more surveys. When survey results are used to support a decision, the decision maker⁴ needs to ensure that the

⁴ The term decision maker is used throughout this section to describe the person, team, board, or committee responsible for the final decision regarding disposition of the survey unit.

data will support that decision with satisfactory confidence. Usually a decision maker will make a correct decision after evaluating the data. However, since uncertainty in the survey results is unavoidable, the possibility of errors in decisions supported by survey results is unavoidable. For this reason, positive actions must be taken to manage the uncertainty in the survey results so that sound, defensible decisions may be made. These actions include proper survey planning to control known causes of uncertainty, proper application of quality control (QC) procedures during implementation of the survey plan to detect and control significant sources of error, and careful analysis of uncertainty before the data are used to support decision making. These actions describe the flow of data throughout each type of survey, and are combined in the Data Life Cycle as shown in Figure 2.1.

There are four phases of the Data Life Cycle:

- Planning Phase.** The survey design is developed and documented using the Data Quality Objectives (DQO) Process. Quality assurance and quality control (QA/QC) procedures are developed and documented in the Quality Assurance Project Plan (QAPP). The QAPP is the principal product of the planning process which incorporates the DQOs as it integrates all technical and quality aspects for the life cycle of the project, including planning, implementation, and assessment. The QAPP documents planning results for survey operations and provides a specific format for obtaining the type and quality of data needed for decision making. The QAPP elements are presented in an order corresponding to the Data Life Cycle by grouping them into two types of elements: 1) project management; and 2) collection and evaluation of environmental data (ASQC 1995). The DQO process is described in Appendix D, and applied in Chapters 3, 4, and 5 of this manual. Development of the QAPP is described in Section 9.2 and applied throughout decommissioning.

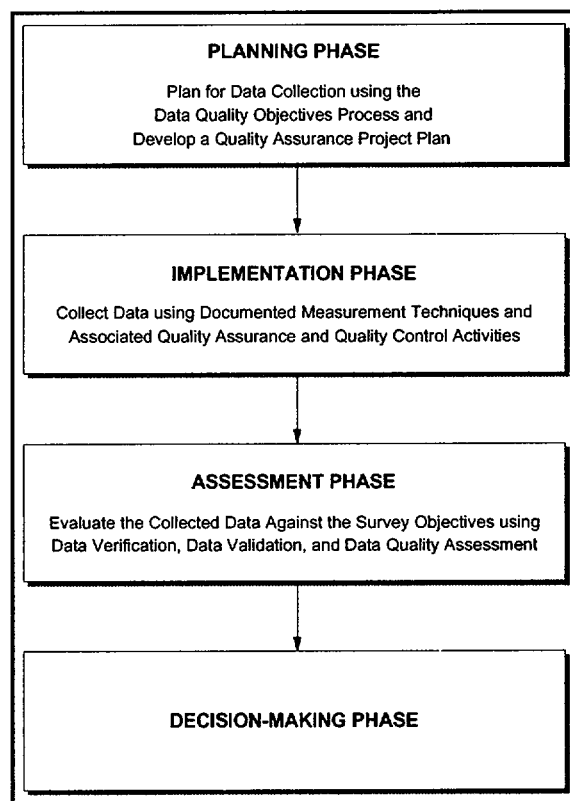


Figure 2.1 The Data Life Cycle

- *Implementation Phase.* The survey design is carried out in accordance with the SOPs and QAPP, resulting in the generation of raw data. Chapter 6, Chapter 7, and Appendix H provide information on the selection of data collection techniques. The QA and QC measurements, discussed in Chapter 6 and Chapter 7, also generate data and other important information that will be used during the Assessment Phase.
- *Assessment Phase.* The data generated during the Implementation Phase are first verified to ensure that the SOPs specified in the QAPP were actually followed and that the measurement systems performed in accordance with the criteria specified in the QAPP. Then the data are validated to ensure that the results of data collection activities support the objectives of the survey as documented in the QAPP, or permit a determination that these objectives should be modified. The data quality assessment (DQA) process is then applied using the validated data to determine if the quality of the data satisfies the data user's needs. Data verification and validation are described in Section 9.3. The DQA process is described in Appendix E and is applied in Chapter 8.
- *Decision-Making Phase.* A decision is made, in coordination with the responsible regulatory agency, based on the conclusions drawn from the assessment process. The ultimate objective is to make technically defensible decisions with a specified level of confidence (Chapter 8).

2.3.1 Planning Effective Surveys—Planning Phase

The first step in designing effective surveys is planning. The DQO Process is a series of planning steps based on the scientific method for establishing criteria for data quality and developing survey designs (ASQC 1995, EPA 1994a, EPA 1987b, EPA 1987c). Planning radiation surveys using the DQO Process improves the survey effectiveness and efficiency, and thereby the defensibility of decisions. This minimizes expenditures related to data collection by eliminating unnecessary, duplicative, or overly precise data. Using the DQO Process ensures that the type, quantity, and quality of environmental data used in decision making will be appropriate for the intended application. MARSSIM supports the use of the DQO Process to design surveys for input to both evaluation techniques (elevated measurement comparison and the statistical test). The DQO Process provides systematic procedures for defining the criteria that the survey design should satisfy, including what type of measurements to perform, when and where to perform measurements, the level of decision errors for the survey, and how many measurements to perform.

The level of effort associated with planning a survey is based on the complexity of the survey. Large, complicated sites generally receive a significant amount of effort during the planning phase, while smaller sites may not require as much planning. This graded approach defines data quality requirements according to the type of survey being designed, the risk of making a decision

error based on the data collected, and the consequences of making such an error. This approach provides a more effective survey design combined with a basis for judging the usability of the data collected.

DQOs are qualitative and quantitative statements derived from the outputs of the DQO Process that:

- clarify the study objective
- define the most appropriate type of data to collect
- determine the most appropriate conditions for collecting the data
- specify limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision

The DQO Process consists of seven steps, as shown in Figure 2.2. Each step is discussed in detail in Appendix D. While all of the outputs of the DQO Process are important for designing efficient surveys, there are some that are referred to throughout the manual. These DQOs are mentioned briefly here, and are discussed in detail throughout MARSSIM and in Appendix D.

The minimum information (outputs) required from the DQO Process to proceed with the methods described in MARSSIM are:

- classify and specify boundaries of survey units: this can be accomplished at any time, but must be finalized during final status survey planning (Section 4.4, Section 4.6)
- state the null hypothesis (H_0): the residual radioactivity in the survey unit exceeds the release criterion (Section 2.5, Appendix D, Section D.6)
- specify a gray region where the consequences of decision errors are relatively minor: the upper bound of the gray region is defined as the $DCGL_w$, and the lower bound of the gray region (LBGR) is a site-specific variable generally initially selected to equal one half the $DCGL_w$ and adjusted to provide an acceptable value for the relative shift (Section 5.5.2.2, Section 5.5.2.3, Appendix D, Section D.6)
- define Type I and Type II decision errors and assign probability limits for the occurrence of these errors: the probability of making a Type I decision error (α) or a Type II decision error (β) are site-specific variables (Section 5.5.2.2, Section 5.5.2.3, Appendix D, Section D.6)
- estimate the standard deviation of the measurements in the survey unit: the standard deviation (σ) is a site-specific variable, typically estimated from preliminary survey data (Section 5.5.2.2, Section 5.5.2.3)
- specify the relative shift: the shift (Δ) is equal to the width of the gray region ($DCGL_w - LBGR$), and the relative shift is defined as Δ/σ , which is generally designed to have a value between one and three (Section 5.5.2.2, Section 5.5.2.3)

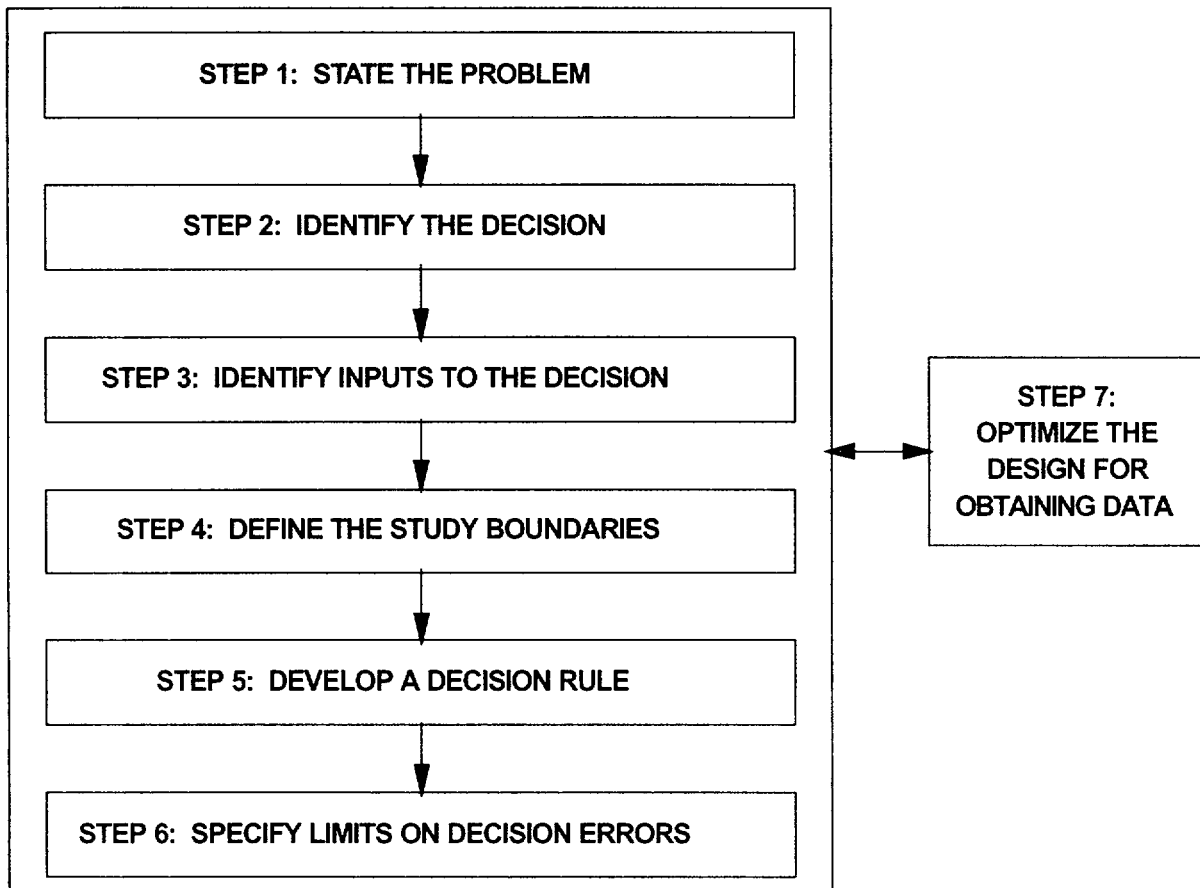


Figure 2.2 The Data Quality Objectives Process

- specify the detection limit for all measurement techniques (scanning, direct measurement, and sample analysis) specified in the QAPP: the minimum detectable concentration (MDC) is unique for each measurement system (Section 6.7)
- calculate the estimated number of measurements (N) and specify the measurement locations required to demonstrate compliance: the number of measurements depends on the relative shift (Δ/σ), Type I and Type II decision error rates (α and β), the potential for small areas of elevated activity, and the selection and classification of survey units (Section 5.5.2.2, Section 5.5.2.3)
- specify the documentation requirements for the survey, including survey planning documentation: documentation supporting the decision on whether or not the site complies with the release criterion is determined on a site-specific basis (Appendix N, Section N.2)

In addition to DQOs, values for the Data Quality Indicators (DQIs) should also be established and recorded during the planning stage. Where DQOs include performance measures and goals in relation to a specific intended use of the data, DQIs quantify the amount of error in the data collection process and the analytical measurement system regardless of how the data may be used (EPA 1997a). Precision, bias, accuracy, representativeness, comparability, and completeness are the DQIs recommended for quantifying the amount of error for survey data. These DQIs are discussed in detail in Appendix N, Section N.6.

2.3.2 Estimating the Uncertainty in Survey Results—Implementation Phase

To encourage flexibility and the use of optimal measurement techniques for a specific site, MARSSIM does not provide detailed guidance on specific techniques. Instead, MARSSIM encourages the decision maker to evaluate available techniques based on the survey objectives. Guidance on evaluating these objectives, such as detection limit, is provided.

QC programs can both lower the chances of making an incorrect decision and help the data user understand the level of uncertainty that surrounds the decision (EPA 1997a). As discussed previously, QC data are collected and analyzed during implementation to provide an estimate of the uncertainty associated with the survey results. QC measurements (scans, direct measurements, and samples) are technical activities performed to measure the attributes and performance of the survey. During any survey, a certain number of measurements should be taken for QC purposes.

2.3.3 Interpreting Survey Results—Assessment Phase

Assessment of environmental data is used to evaluate whether the data meet the objectives of the survey and whether the data are sufficient to determine compliance with the DCGL (EPA 1992a, EPA 1992b, EPA 1996a). The assessment phase of the Data Life Cycle consists of three phases: data verification, data validation, and Data Quality Assessment (DQA).

Data verification is used to ensure that the requirements stated in the planning documents are implemented as prescribed (see Section 9.3). Data validation is used to ensure that the results of the data collection activities support the objectives of the survey as documented in the QAPP, or permit a determination that these objectives should be modified (see Section 9.3 and Appendix N). Data quality assessment (DQA) is the scientific and statistical evaluation of data to determine if the data are of the right type, quality, and quantity to support their intended use (EPA 1996a). DQA helps complete the Data Life Cycle by providing the assessment needed to determine that the planning objectives are achieved (see Section 8.2). Figure 2.3 illustrates where data verification, data validation, and DQA fit into the Assessment Phase of the Data Life Cycle.

There are five steps in the DQA Process:

- Review the DQOs and Survey Design
- Conduct a Preliminary Data Review
- Select the Statistical Test
- Verify the Assumptions of the Statistical Test
- Draw Conclusions from the Data

The strength of DQA is its design that progresses in a logical and efficient manner to promote an understanding of how well the data meet the intended use. The Assessment Phase is described in more detail in Appendix E. Section 2.6 discusses the flexibility of the Data Life Cycle and describes the use of survey designs other than those described later in MARSSIM.

2.3.4 Uncertainty in Survey Results

Uncertainty in survey results arises primarily from two sources: survey design errors and measurement errors. Survey design errors occur when the survey design is unable to capture the complete extent of variability that exists for the radionuclide distribution in a survey unit. Since it is impossible in every situation to measure the residual radioactivity at every point in space and time, the survey results will be incomplete to some degree. It is also impossible to know with complete certainty the residual radioactivity at locations that were not measured, so the incomplete survey results give rise to uncertainty. The greater the natural or inherent variation in residual radioactivity, the greater the uncertainty associated with a decision based on the survey results. The unanswered question is: "How well do the survey results represent the true level of residual radioactivity in the survey unit?"

Measurement errors create uncertainty by masking the true level of residual radioactivity and may be classified as random or systematic errors. Random errors affect the precision of the measurement system, and show up as variations among repeated measurements. Systematic errors show up as measurements that are biased to give results that are consistently higher or lower than the true value. Measurement uncertainty is discussed in Section 6.8.

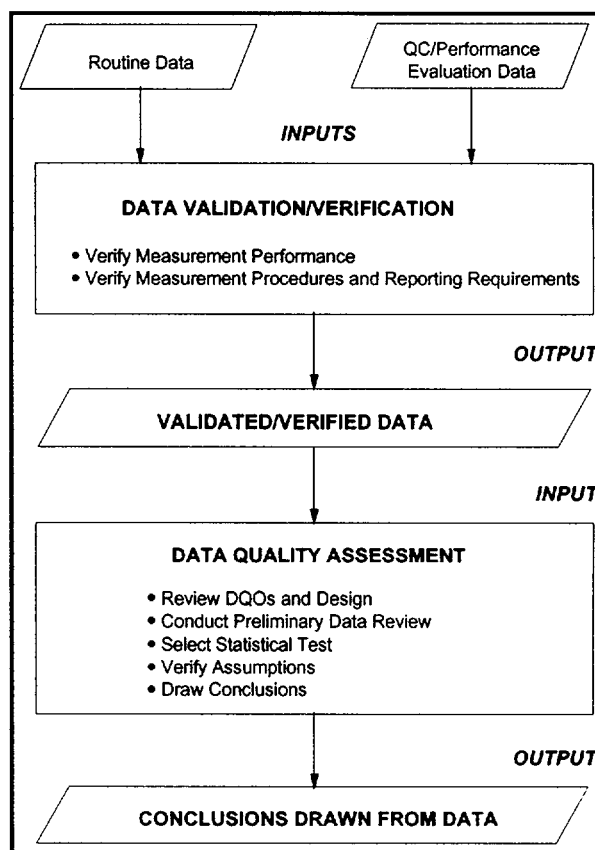


Figure 2.3 The Assessment Phase of the Data Life Cycle (EPA 1996a)

MARSSIM uses the Data Life Cycle to control and estimate the uncertainty in the survey results on which decisions are made. Adequate planning should minimize known sources of uncertainty. QC data collected during implementation of the survey plan provide an estimate of the uncertainty. Statistical hypothesis testing during the assessment phase provides a level of confidence for the final decision. There are several levels of decisions included within each survey type. Some decisions are quantitative, based on the numerical results of measurements performed during the survey. Other decisions are qualitative based on the available evidence and best professional judgment. The Data Life Cycle can and should be applied consistently to both types of decisions.

2.3.5 Reporting Survey Results

The process of reporting survey results is an important consideration in planning the survey. Again, the level of effort for reporting should be based on the complexity of the survey. A simple survey with relatively few results may specify a single report, while a more complicated survey may specify several reports to meet the objectives of the survey. Reporting requirements for individual surveys should be developed during planning and clearly documented in the QAPP. These requirements should be developed with cooperation from the people performing the analyses (*e.g.*, the analytical laboratory should be consulted on reporting results for samples). The Health Physics Society has developed several suggestions for reporting survey results (EPA 1980c). These suggestions include:

- Report the actual result of the analysis. Do not report data as “less than the detection limit.” Even negative results and results with large uncertainties can be used in the statistical tests to demonstrate compliance. Results reported only as “<MDC” cannot be fully used and, for example, complicate even such simple analyses as calculating an average. While the nonparametric tests described in Section 8.3 and Section 8.4 can accommodate as much as 40% of the results as non-detects, it is better to report the actual results and avoid the possibility of exceeding this limit.
- Report results using the correct units and the correct number of significant digits. The choice of reporting results using SI units (*e.g.*, Bq/kg, Bq/m²) or conventional units (*e.g.*, pCi/g, dpm/100 cm²) is made on a site-specific basis. Generally, MARSSIM recommends that all results be reported in the same units as the DCGLs. Sometimes the results may be more convenient to work with as counts directly from the detector. In these cases the user should decide what the appropriate units are for a specific survey based on the survey objectives. The user should also report the correct number of significant digits as described in EPA 1980c.

- Report the measurement uncertainty for every analytical result or series of results, such as for a measurement system. This uncertainty, while not directly used for demonstrating compliance with the release criterion, is used for survey planning and data assessment throughout the Radiation Survey and Site Investigation Process. In addition, the uncertainty is used for evaluating the performance of measurement systems using QC measurement results (as described in Section 6.2 for scans and direct measurements, and in Section 7.2 for laboratory analysis of samples). The uncertainty is also used for comparing individual measurements to the action level, which is especially important in the early stages of decommissioning (scoping, characterization, and remedial action support surveys described in Section 2.4) when decisions are made based on a limited number of measurements. Section 6.8 discusses methods for calculating the measurement uncertainty.
- Report the minimum detectable concentration (MDC) for the measurement system as well as the method used to calculate the MDC. The MDC is an *a priori* estimate of the capability for detecting an activity concentration with a specific measurement system (EPA 1980c). As such, this estimate is valuable for planning and designing radiation surveys. Optimistic estimates of the MDC (calculated using ideal conditions that may not apply to actual measurements) overestimate the ability of a technique to detect residual radioactivity, especially when scanning for alpha or low-energy beta radiations. This can invalidate survey results, especially for scanning surveys. Using a more realistic MDC, as described in Section 6.7, during scoping and characterization surveys helps in the proper classification of survey units for final status surveys and minimizes the possibility of designing and performing subsequent surveys because of errors in classification. Estimates of the MDC that minimize potential decision errors should be used for planning surveys.

Reporting requirements for individual surveys should be developed during planning and clearly documented in the QAPP.

2.4 Radiation Survey and Site Investigation Process

The Data Life Cycle discussed in Section 2.3 is the basis for the performance-based guidance in MARSSIM. As a framework for collecting the information required for demonstrating compliance identified using the DQO Process, MARSSIM recommends using a series of surveys. The Radiation Survey and Site Investigation (RSSI) Process is an example of a series of surveys designed to demonstrate compliance with a dose- or risk-based regulation for sites with radioactive contamination.

There are six principal steps in the RSSI Process:

- Site Identification
- Historical Site Assessment
- Scoping Survey
- Characterization Survey
- Remedial Action Support Survey
- Final Status Survey

Table 2.1 provides a simplified overview of the principal steps in the RSSI process and how the Data Life Cycle can be used in an iterative fashion within the process. Each of these steps is briefly described in the Sections 2.4.1 through 2.4.6, and described in more detail in Chapter 3 and Chapter 5. In addition, there is a brief description of regulatory agency confirmation and verification (see Section 2.4.7). Because MARSSIM focuses on demonstrating compliance with a release criterion, specifically through the use of a final status survey, these surveys have additional objectives that are not fully discussed in MARSSIM (*e.g.*, health and safety of workers, supporting selection of values for exposure pathway model parameters).

Figure 2.4 illustrates the Radiation Survey and Site Investigation Process in terms of area classification, and lists the major decision to be made for each type of survey. The flowchart demonstrates one method for quickly estimating the survey unit classification early in the MARSSIM Process based on limited information. While this figure shows the relationship between area classification and survey unit classification along with the major decision points that determine classification, this illustration is not designed to comprehensively consider every possibility that may occur at individual survey units. As such, it is a useful tool for visualizing the classification process, but there are site-specific characteristics that may cause variation from this scheme.

The flowchart, illustrated in Figures 2.5 through 2.8, presents the principal steps and decisions in the site investigation process and shows the relationship of the survey types to the overall assessment process. As shown in these figures, there are several sequential steps in the site investigation process and each step builds on information provided by its predecessor. Properly applying each sequential step in the RSSI Process should provide a high degree of assurance that the release criterion has not been exceeded.

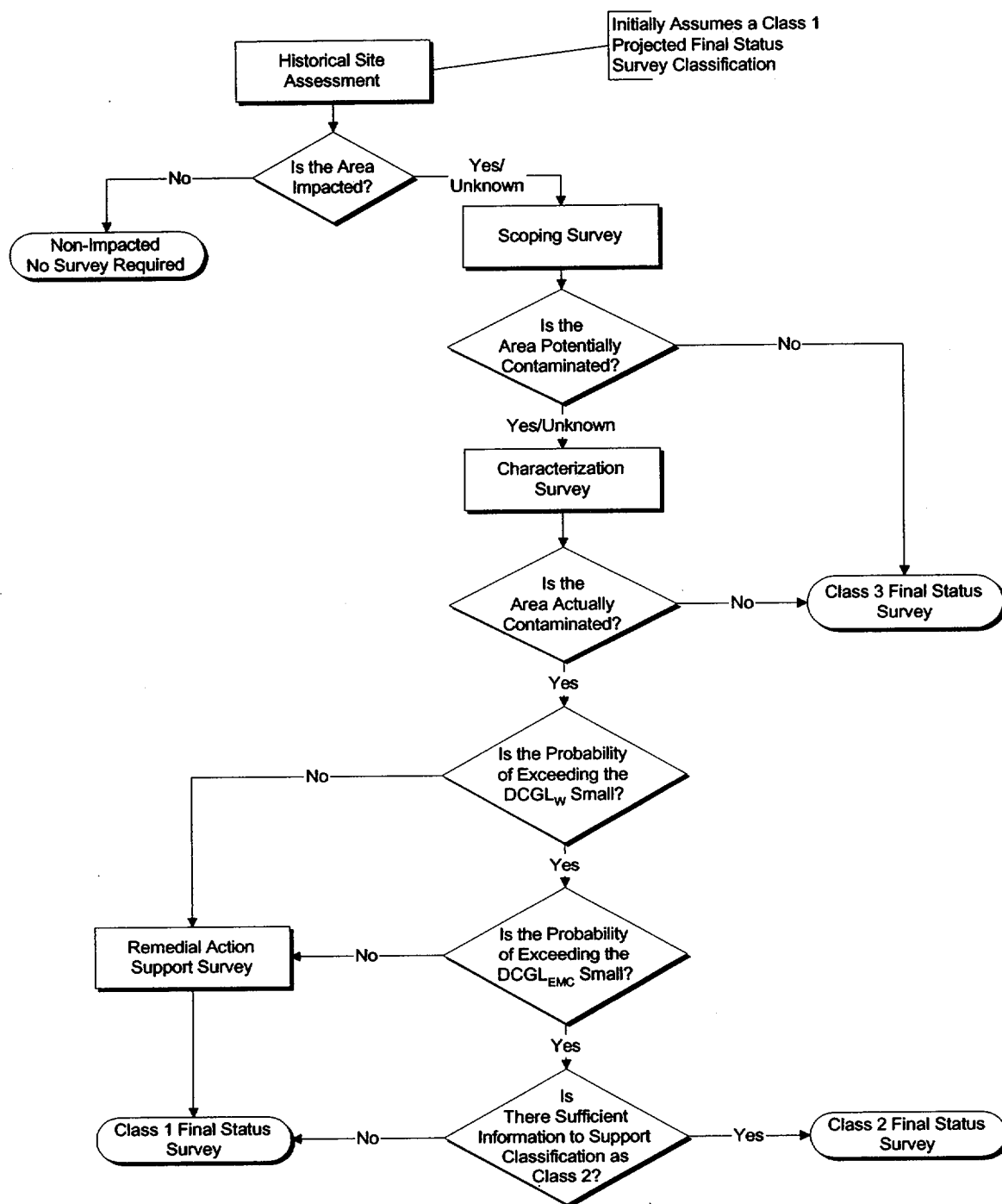
Table 2.1 The Data Life Cycle used to Support the Radiation Survey and Site Investigation Process

| RSSI Process | Data Life Cycle | | MARSSIM Guidance |
|--------------------------------|--|---------------------------------------|---|
| Site Identification | | | Provides information on identifying potential radiation sites (Section 3.3) |
| Historical Site Assessment | Historical Site Assessment Data Life Cycle | Plan Implement Assess Decide | Provides information on collecting and assessing existing site data (Sections 3.4 through 3.9) and potential sources of information (Appendix G) |
| Scoping Survey | Scoping Data Life Cycle | Plan Implement Assess Decide | Discusses the purpose and general approach for performing scoping surveys, especially as sources of information when planning final status surveys (Section 5.2) |
| Characterization Survey | Characterization Data Life Cycle | Plan Implement Assess Decide | Discusses the purpose and general approach for performing characterization surveys, especially as sources of information when planning final status surveys (Section 5.3) |
| Remedial Action Support Survey | Remedial Action Data Life Cycle | Plan Implement Assess Decide | Discusses the purpose and general approach for performing remedial action support surveys, especially as sources of information when planning final status surveys (Section 5.4) |
| Final Status Survey | Final Status Data Life Cycle | Plan Implement Assess Decide | Provides detailed guidance for planning final status surveys (Chapter 4 and Section 5.5), selecting measurement techniques (Chapter 6, Chapter 7, and Appendix H), and assessing the data collected during final status surveys (Chapter 8 and Chapter 9) |

2.4.1 Site Identification

The identification of known, likely, or potential sites is generally easily accomplished, and is typically performed before beginning decommissioning. Any facility preparing to terminate an NRC or agreement state license would be identified as a site. Formerly terminated NRC licenses may also become sites for the EPA Superfund Program. Portions of military bases or DOE facilities may be identified as sites based on records of authorization to possess or handle radioactive materials. In addition, information obtained during the performance of survey activities may identify additional potential radiation sites related to the site being investigated. Information on site identification is provided in Section 3.3.

Overview of the Radiation Survey and Site Investigation Process



**Figure 2.4 The Radiation Survey and Site Investigation Process
in Terms of Area Classification**

Overview of the Radiation Survey and Site Investigation Process

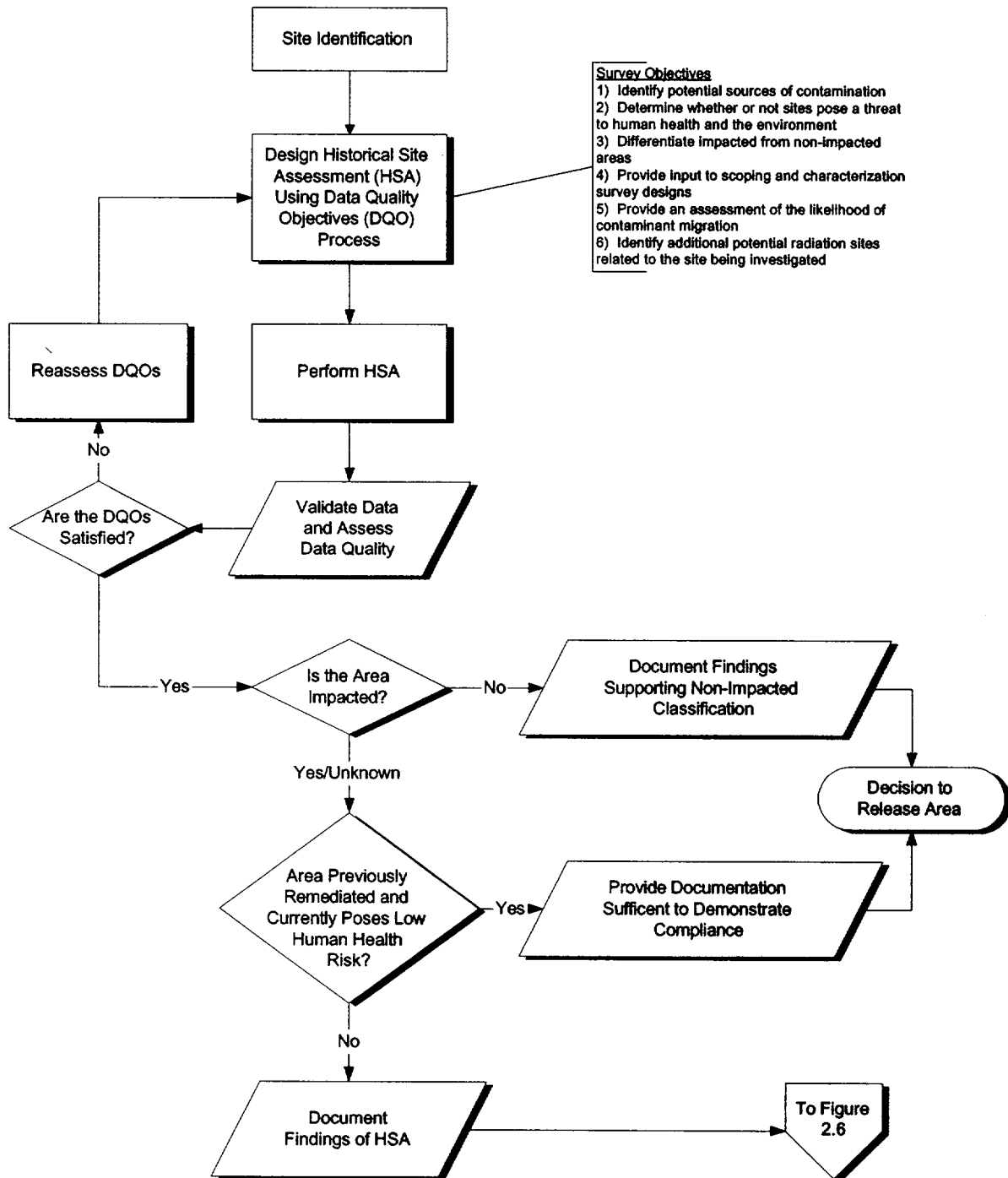


Figure 2.5 The Historical Site Assessment Portion of the Radiation Survey and Site Investigation Process

Overview of the Radiation Survey and Site Investigation Process

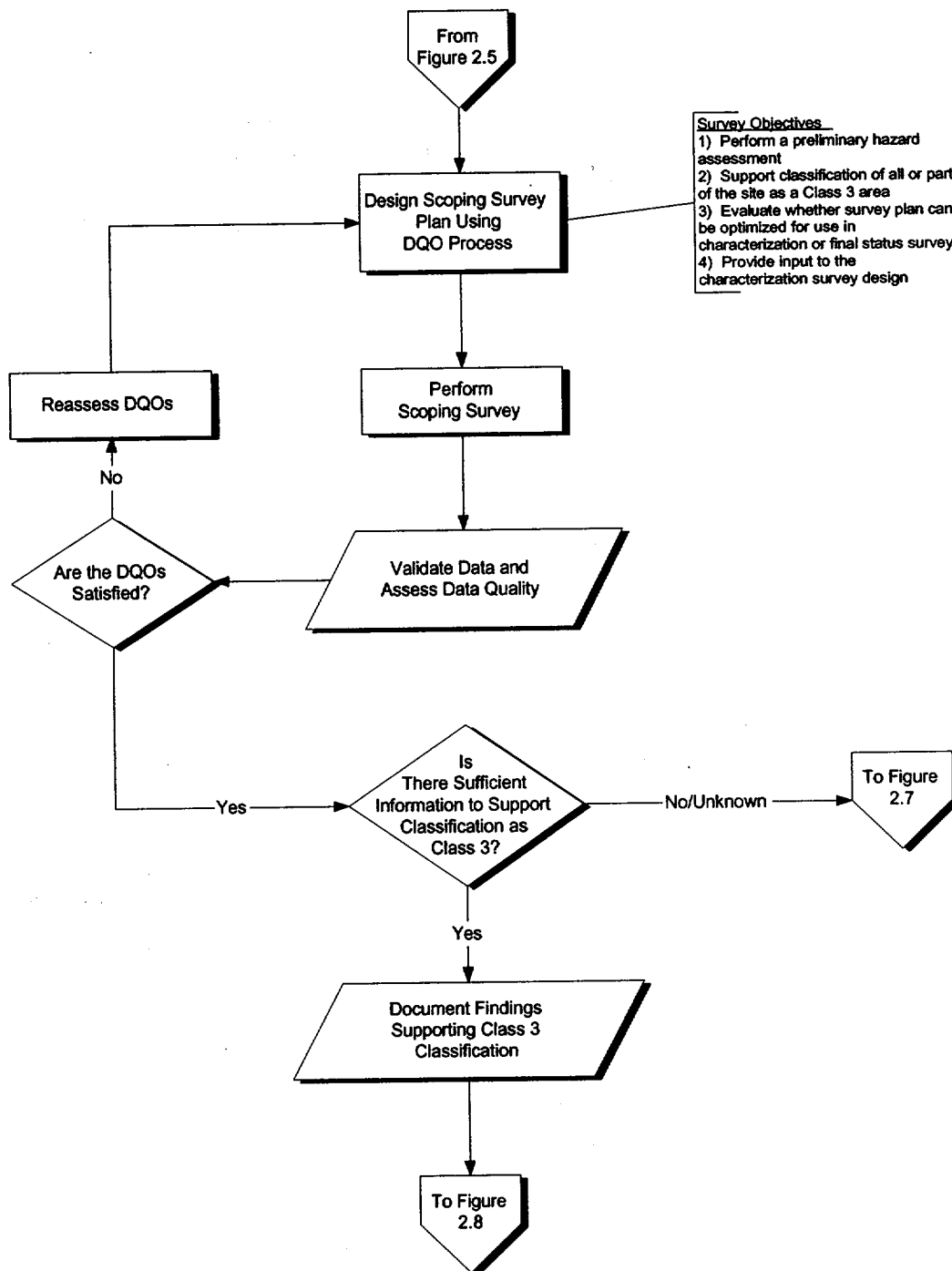
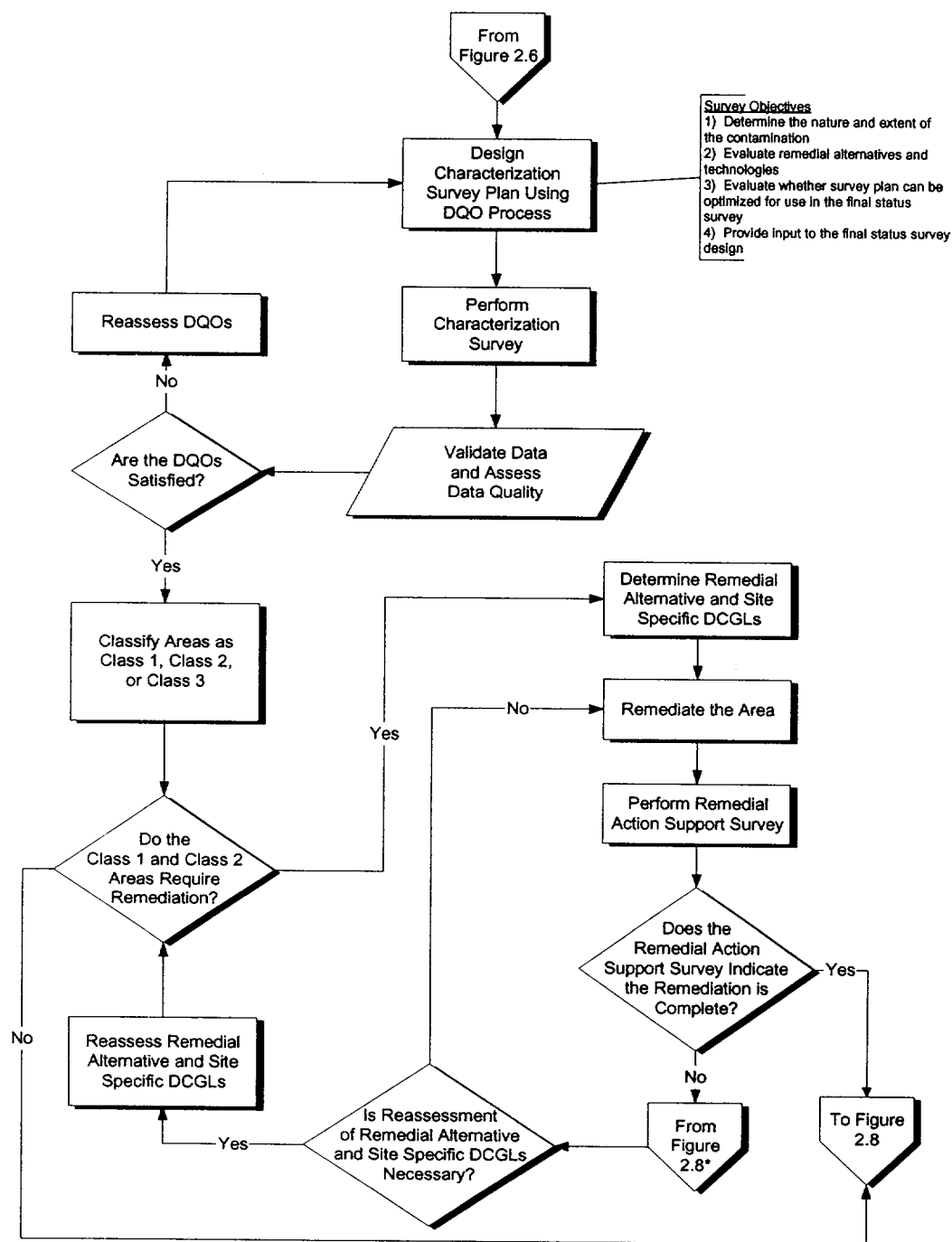


Figure 2.6 The Scoping Survey Portion of the Radiation Survey and Site Investigation Process

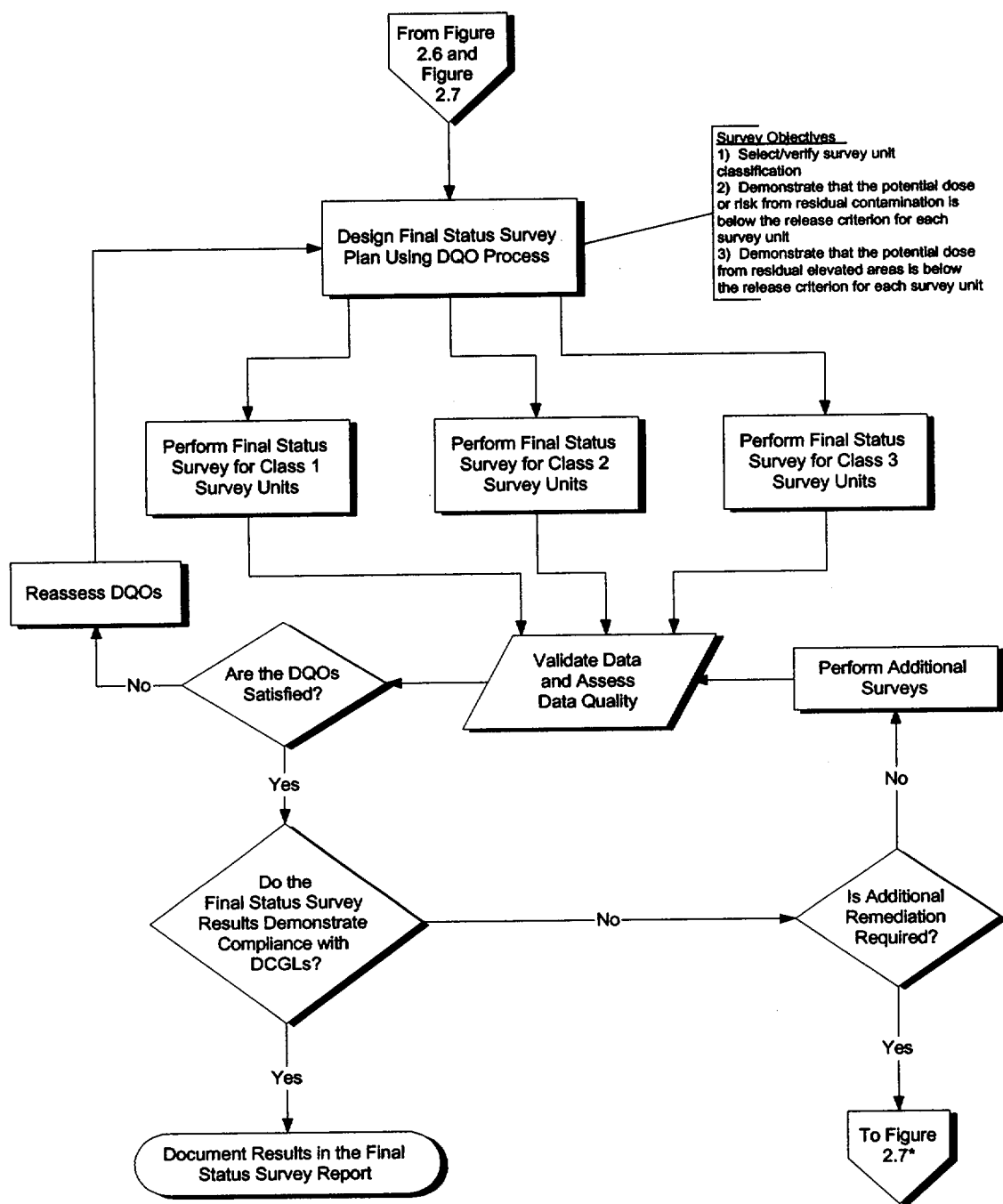
Overview of the Radiation Survey and Site Investigation Process



* The point where survey units that fail to demonstrate compliance in the final status survey in Figure 2.8 re-enter the process

Figure 2.7 The Characterization and Remedial Action Support Survey Portion of the Radiation Survey and Site Investigation Process

Overview of the Radiation Survey and Site Investigation Process



* Connects with the Remedial Action Support Survey portion of the process in Figure 2.7

Figure 2.8 The Final Status Survey Portion of the Radiation Survey and Site Investigation Process

2.4.2 Historical Site Assessment

The primary purpose of the Historical Site Assessment (HSA) is to collect existing information concerning the site and its surroundings.

The primary objectives of the HSA are to:

- identify potential sources of contamination
- determine whether or not sites pose a threat to human health and the environment
- differentiate impacted from non-impacted areas
- provide input to scoping and characterization survey designs
- provide an assessment of the likelihood of contaminant migration
- identify additional potential radiation sites related to the site being investigated

The HSA typically consists of three phases: identification of a candidate site, preliminary investigation of the facility or site, and site visits or inspections. The HSA is followed by an evaluation of the site based on information collected during the HSA.

2.4.3 Scoping Survey

If the data collected during the HSA indicate an area is impacted, a scoping survey could be performed. Scoping surveys provide site-specific information based on limited measurements.

The primary objectives of a scoping survey are to:

- perform a preliminary hazard assessment
- support classification of all or part of the site as a Class 3 area
- evaluate whether the survey plan can be optimized for use in the characterization or final status surveys
- provide data to complete the site prioritization scoring process (CERCLA and RCRA sites only)
- provide input to the characterization survey design if necessary

Scoping surveys are conducted after the HSA is completed and consist of judgment measurements based on the HSA data. If the results of the HSA indicate that an area is Class 3 and no contamination is found, the area may be classified as Class 3 and a Class 3 final status survey is performed. If the scoping survey locates contamination, the area may be considered as Class 1 (or Class 2) for the final status survey and a characterization survey is typically performed. Sufficient information should be collected to identify situations that require immediate radiological attention. For sites where the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements are applicable, the scoping survey should collect sufficient

data to complete the Hazard Ranking System (HRS) scoring process. For sites where the Resource Conservation and Recovery Act (RCRA) requirements are applicable, the scoping survey should collect sufficient data to complete the National Corrective Action Prioritization System (NCAPS) scoring process. Sites that meet the National Contingency Plan (NCP) criteria for a removal should be referred to the Superfund removal program (EPA 1988c). A comparison of MARSSIM guidance to CERCLA and RCRA requirements is provided in Appendix F.

2.4.4 Characterization Survey

If an area could be classified as Class 1 or Class 2 for the final status survey, based on the HSA and scoping survey results, a characterization survey is warranted. The characterization survey is planned based on the HSA and scoping survey results. This type of survey is a detailed radiological environmental characterization of the area.

The primary objectives of a characterization survey are to:

- determine the nature and extent of the contamination
- collect data to support evaluation of remedial alternatives and technologies
- evaluate whether the survey plan can be optimized for use in the final status survey
- support Remedial Investigation/Feasibility Study requirements (CERCLA sites only) or Facility Investigation/Corrective Measures Study requirements (RCRA sites only)
- provide input to the final status survey design

The characterization survey is the most comprehensive of all the survey types and generates the most data. This includes preparing a reference grid, systematic as well as judgment measurements, and surveys of different media (*e.g.*, surface soils, interior and exterior surfaces of buildings). The decision as to which media will be surveyed is a site-specific decision addressed throughout the Radiation Survey and Site Investigation Process.

2.4.5 Remedial Action Support Survey

If an area is adequately characterized and is contaminated above the derived concentration guideline levels (DCGLs), a decontamination plan should be prepared. A remedial action support survey is performed while remediation is being conducted, and guides the cleanup in a real-time mode.

Remedial action support surveys are conducted to:

- support remediation activities
- determine when a site or survey unit is ready for the final status survey

- provide updated estimates of site-specific parameters used for planning the final status survey

This manual does not provide guidance on the routine operational surveys used to support remediation activities. The determination that a survey unit is ready for a final status survey following remediation is an important step in the RSSI Process. In addition, remedial activities result in changes to the distribution of contamination within the survey unit. For most survey units, the site-specific parameters used during final status survey planning (*e.g.*, variability in the radionuclide concentration, probability of small areas of elevated activity) will need to be re-established following remediation. Obtaining updated values for these critical parameters should be considered when planning a remedial action support survey.

2.4.6 Final Status Survey

The final status survey is used to demonstrate compliance with regulations. This type of survey is the major focus of this manual.

The primary objectives of the final status survey are to:

- select/verify survey unit classification
- demonstrate that the potential dose or risk from residual contamination is below the release criterion for each survey unit
- demonstrate that the potential dose or risk from small areas of elevated activity is below the release criterion for each survey unit

The final status survey provides data to demonstrate that all radiological parameters satisfy the established guideline values and conditions.

Although the final status survey is discussed as if it were an activity performed at a single stage of the site investigation process, this does not have to be the case. Data from other surveys conducted during the Radiation Survey and Site Investigation Process—such as scoping, characterization, and remedial action support surveys—can provide valuable information for planning a final status survey provided they are of sufficient quality.

Professional judgment and biased sampling are important for locating contamination and characterizing the extent of contamination at a site. However, the MARSSIM focus is on planning the final status survey which utilizes a more systematic approach to sampling. Systematic sampling is based on rules that endeavor to achieve the representativeness in sampling consistent with the application of statistical tests.

2.4.7 Regulatory Agency Confirmation and Verification

The regulatory agency responsible for the site often confirms whether the site is acceptable for release. This confirmation may be accomplished by the agency or an impartial party. Although some actual measurements may be performed, much of the work required for confirmation and verification will involve evaluation and review of documentation and data from survey activities. The evaluation may include site visits to observe survey and measurement procedures or split-sample analyses by the regulatory agency's laboratory. Therefore, accounting for confirmation and verification activities during the planning stages is important to each type of survey. In some cases, post-remedial sampling and analysis may be performed by an impartial party. The review of survey results should include verifying that the data quality objectives are met, reviewing the analytical data used to demonstrate compliance, and verifying that the statistical test results support the decision to release the site. Confirmation and verification are generally ongoing processes throughout the Radiation Survey and Site Investigation (RSSI) Process.

2.5 Demonstrating Compliance With a Dose- or Risk-Based Regulation

MARSSIM presents a process for demonstrating compliance with a dose- or risk-based regulation. The RSSI Process provides flexibility in planning and performing surveys based on site-specific considerations. A dose- or risk-based regulation usually allows one to take into account radionuclide and site-specific differences.

The final status survey is designed to demonstrate compliance with the release criterion. The earlier surveys in the RSSI Process are performed to support decisions and assumptions used in the design of the final status survey. These preliminary surveys (*e.g.*, scoping, characterization) may have other objectives in addition to compliance demonstration that need to be considered during survey planning that are not fully discussed in this manual. For this reason MARSSIM focuses on final status survey design. To allow maximum flexibility in the survey design, MARSSIM provides guidance on designing a survey using the RSSI Process. This allows users with few resources available for planning to develop an acceptable survey design. The rationale for the development of the guidance in MARSSIM is presented in the following sections. Users with available planning resources are encouraged to investigate alternate survey designs for site-specific applications using the information provided in Section 2.6.

2.5.1 The Decision to Use Statistical Tests

The objective of compliance demonstration is to provide some level of confidence that the release criterion is not exceeded. As previously stated, 100% confidence in a decision cannot be proven because the data always contain some uncertainty. The use of statistical methods is necessary to provide a quantitative estimate of the probability that the release criterion is not exceeded at a

particular site. Statistical methods provide for specifying (controlling) the probability of making decision errors and for extrapolating from a set of measurements to the entire site in a scientifically valid fashion (EPA 1994b).

Clearly stating the null hypothesis is necessary before a statistical test can be performed. The null hypothesis recommended for use in MARSSIM is: "The residual radioactivity in the survey unit exceeds the release criterion." This statement directly addresses the issue of compliance demonstration for the regulator and places the burden of proof for demonstrating compliance on the site owner or responsible party. The statistical tests are only applied at sites that were subjected to an Historical Site Assessment (HSA). At this point, the results of the HSA have been reviewed and the site is determined to be impacted based on existing data and professional judgment as described in Chapter 3. An impacted site, by definition, is expected to contain areas of contamination, so this statement of the null hypothesis is reasonable for these sites.

The information needed to perform a statistical test is determined by the assumptions used to develop the test. MARSSIM recommends the use of nonparametric statistical tests because these tests use fewer assumptions, and consequently require less information to verify these assumptions. The tests described in MARSSIM (see Chapter 8) are relatively easy to understand and implement compared to other statistical tests.

Site conditions can also affect the selection of statistical tests. The distribution of contamination is of particular concern at sites with residual radioactivity. Is the contamination distributed uniformly, or is it located in small areas of elevated activity? Is the residual radioactivity present as surface, volumetric, or subsurface contamination? To demonstrate the use of the RSSI Process at radiation sites, MARSSIM addresses only surface soil and building surfaces for the final status survey to demonstrate compliance. This represents a situation that is expected to commonly occur at sites with radioactive contamination, and allows the survey design to take into account the ability to directly measure surface radioactivity using scanning techniques. Other contaminated media may be identified during the HSA or preliminary surveys (*i.e.*, scoping, characterization, remedial action support). If other contaminated media (*e.g.*, subsurface contamination, volumetric contamination of building materials) are identified, methodologies for demonstrating compliance other than those described in this manual may need to be developed or evaluated. Situations where scanning techniques may not be effective (*e.g.*, volumetric or subsurface contamination) are discussed in existing guidance (EPA 1989a, EPA 1994b, EPA 1994d).

2.5.1.1 Small Areas of Elevated Activity

While the development of DCGLs is outside the scope of MARSSIM, this manual assumes that DCGLs will be developed using exposure pathway models which in turn assume a relatively uniform distribution of contamination. While this represents an ideal situation, small areas of elevated activity are a concern at many sites.

MARSSIM addresses the concern for small areas of elevated activity by using a simple comparison to an investigation level as an alternative to statistical methods. Using the elevated measurement comparison (EMC) represents a conservative approach, in that every measurement needs to be below the action level. The investigation level for this comparison is called the $DCGL_{EMC}$, which is the $DCGL_w$ modified to account for the smaller area. This area factor correction (discussed in Section 5.5.2.4) is considered to be a defensible modification because the exposure assumptions (*e.g.*, exposure time and duration) are the same as those used to develop the $DCGL_w$. In the case of multiple areas of elevated activity in a survey unit, a posting plot (discussed in Section 8.2.2.2) or similar representation of the distribution of activity in the survey unit can be used to determine any pattern in the location of these areas.

If elevated levels of residual radioactivity are found in an isolated area, in addition to residual radioactivity distributed relatively uniformly across the survey unit, the unity rule (Section 4.3.3) can be used to ensure that the total dose or risk meets the release criterion. If there is more than one of these areas, a separate term should be included in the calculation for each area of elevated activity. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally only apply to Class 1 survey units, since areas of elevated activity should not be present in Class 2 or Class 3 survey units.

2.5.1.2 Relatively Uniform Distribution of Contamination

As discussed previously, the development of a DCGL starts with the assumption of a relatively uniform distribution of contamination. Some variability in the measurements is expected. This is primarily due to a random spatial distribution of contamination and uncertainties in the measurement process. The arithmetic mean of the measurements taken from such a distribution would represent the parameter of interest for demonstrating compliance.

Whether or not the radionuclide of concern is present in background determines the form of the statistical test. The Wilcoxon Rank Sum (WRS) test is recommended for comparisons of survey unit radionuclide concentrations with background. When the radionuclide of concern is not present in background, the Sign test is recommended. Instructions on performing these tests are provided in Section 8.3 and Section 8.4.

The WRS and Sign tests are designed to determine whether or not the level of residual activity uniformly distributed throughout the survey unit exceeds the $DCGL_w$. Since these methods are based on ranks, the results are generally expressed in terms of the median. When the underlying measurement distribution is symmetric, the mean is equal to the median. When the underlying distribution is not symmetric, these tests are still true tests of the median but only approximate tests of the mean. However, numerous studies show that this is a fairly good approximation (Hardin and Gilbert, 1993). The assumption of symmetry is less restrictive than that of normality because the normal distribution is itself symmetric. If, however, the measurement distribution is skewed to the right, the average will generally be greater than the median. In severe cases, the average may exceed the $DCGL_w$ while the median does not. For this reason, MARSSIM recommends comparing the arithmetic mean of the survey unit data to the $DCGL_w$ as a first step in the interpretation of the data (see Section 8.2.2.1).

The WRS test is a two-sample test that compares the distribution of a set of measurements in a survey unit to that of a set of measurements in a reference area. The test is performed by first adding the value of the $DCGL_w$ to each measurement in the reference area. The combined set of survey unit data and adjusted reference area data are listed, or ranked, in increasing numerical order. If the ranks of the adjusted reference site measurements are significantly higher than the ranks of the survey unit measurements, the survey unit demonstrates compliance with the release criterion.

The Sign test is a one-sample test that compares the distribution of a set of measurements in a survey unit to a fixed value, namely the $DCGL_w$. First, the value for each measurement in the survey unit is subtracted from the $DCGL_w$. The resulting distribution is tested to determine if the center of the distribution is greater than zero. If the adjusted distribution is significantly greater than zero, the survey unit demonstrates compliance with the release criterion.

Guidance on performing the statistical tests and presenting graphical representations of the data is provided in Chapter 8 and Appendix I.

2.5.2 Classification

Classifying a survey unit is crucial to the survey design because this step determines the level of survey effort based on the potential for contamination. Areas are initially classified as impacted or non-impacted based on the results of the HSA. Non-impacted areas have no reasonable potential for residual contamination and require no further evidence to demonstrate compliance with the release criterion. When planning the final status survey, impacted areas may be further divided into survey units. If a survey unit is classified incorrectly, the potential for making decision errors increases. For this reason, all impacted areas are initially assumed to be Class 1. Class 1 areas require the highest level of survey effort because they are known to have contaminant concentrations above the $DCGL_w$, or the contaminant concentrations are unknown. Information

indicating the potential or known contaminant concentration is less than the $DCGL_w$ can be used to support re-classification of an area or survey unit as Class 2 or Class 3.

There is a certain amount of information necessary to demonstrate compliance with the release criterion. The amount of this information that is available and the level of confidence in this information is reflected in the area classification. The initial assumption for affected areas is that none of the necessary information is available. This results in a default Class 1 classification. This corresponds with the statement of the null hypothesis that the survey unit is contaminated, and represents the most efficient case for the regulator. For this reason, the recommendations for a Class 1 final status survey represent the minimal amount of information necessary to demonstrate compliance.

Not all of the information available for an area will have been collected for purposes of compliance demonstration. For example, data are collected during characterization surveys to determine the extent, and not necessarily the amount, of contamination. This does not mean that the data do not meet the objectives of compliance demonstration, but may mean that statistical tests would be of little or no value because the data have not been collected using appropriate protocols or design. Rather than discard potentially valuable information, MARSSIM allows for a qualitative assessment of existing data (Chapter 3). Non-impacted areas represent areas where all of the information necessary to demonstrate compliance is available from existing sources. For these areas, no statistical tests are considered necessary. A classification as Class 2 or Class 3 indicates that some information on describing the potential for contamination is available for that survey unit. The data collection recommendations are modified to account for the information already available, and the statistical tests are performed on the data collected during the final status survey.

As previously stated, the conservative assumption that an area receive a classification of Class 1 is only applied to impacted sites. The HSA (described in Chapter 3) is used to provide an initial classification for the site of impacted or non-impacted based on existing data and professional judgment.

2.5.3 Design Considerations for Small Areas of Elevated Activity

Scanning surveys are typically used to identify small areas of elevated activity. The size of the area of elevated activity that the survey is designed to detect affects the $DCGL_{EMC}$, which in turn determines the ability of a scanning technique to detect these areas. Larger areas have a lower $DCGL_{EMC}$ and are more difficult to detect than smaller areas.

The percentage of the survey unit to be covered by scans is also an important consideration. 100% coverage means that the entire surface area of the survey unit has been covered by the field of view of the scanning instrument. 100% scanning coverage provides a high level of confidence

that all areas of elevated activity have been identified. If the available information concerning the survey unit provides information demonstrating that areas of elevated activity may not be present, the survey unit may be classified as Class 2 or Class 3. Because there is already some level of confidence that areas of elevated activity are not present, 100% coverage may not be necessary to demonstrate compliance. The scanning survey coverage may be adjusted based on the level of confidence supplied by the existing data. If there is evidence providing a high level of confidence that areas of elevated activity are not present, 10% scanning coverage may meet the objectives of the survey. If the existing information provides a lower level of confidence, the scanning coverage may be adjusted between 10 and 100% based on the level of confidence and the objectives of the survey. A general recommendation is to always err to minimize the decision error. In general, scanning the entire survey unit is less expensive than finding areas of elevated activity later in the survey process. Finding such areas will lead to performing additional surveys due to survey unit misclassification.

Another consideration for scanning surveys is the selection of scanning locations. This is not an issue when 100% of the survey unit is scanned. Whenever less than 100% of the survey unit is scanned, a decision must be made on what areas are scanned. The general recommendation is that when large amounts of the survey unit are scanned (*e.g.*, >50%), the scans should be systematically performed along transects of the survey unit. When smaller amounts of the survey unit are scanned, selecting areas based on professional judgment may be more appropriate and efficient for locating areas of elevated activity (*e.g.*, drains, ducts, piping, ditches). A combination of 100% scanning in portions of the survey unit selected based on professional judgement and less coverage (*e.g.*, 20-50%) for all remaining areas may result in an efficient scanning survey design for some survey units.

2.5.4 Design Considerations for Relatively Uniform Distributions of Contamination

The survey design for areas with relatively uniform distributions of contamination is primarily controlled by classification and the requirements of the statistical test. Again, the recommendations provided for Class 1 survey units are designed to minimize the decision error. Recommendations for Class 2 or Class 3 surveys may be appropriate based on the existing information and the level of confidence associated with this information.

The first consideration is the identification of survey units. The identification of survey units may be accomplished early (*e.g.*, scoping) or late (*e.g.*, final status) in the survey process, but must be accomplished prior to performing a final status survey. Early identification of survey units can help in planning and performing surveys throughout the RSSI Process. Late identification of survey units can prevent misconceptions and problems associated with reclassification of areas based on results of subsequent surveys. The area of an individual survey unit is determined based on the area classification and modeling assumptions used to develop the DCGL_w. Identification of survey units is discussed in Section 4.6.

Another consideration is the estimated number of measurements to demonstrate compliance using the statistical tests. Section 5.5.2 describes the calculations used to estimate the number of measurements. These calculations use information that is usually available from planning or from preliminary surveys (*i.e.*, scoping, characterization, remedial action support).

The information needed to perform these calculations is: 1) acceptable values for the probabilities of making Type I (α) or Type II (β) decision errors, 2) the estimates of the measurement variability in the survey unit (σ_s) and the reference area (σ_r) if necessary, and 3) the shift (Δ).

MARSSIM recommends that site-specific values be determined for each of these parameters. To assist the user in selecting site-specific values for decision error rates and Δ , MARSSIM recommends that an initial value be selected and adjusted to develop a survey design that is appropriate for a specific site. An arbitrary initial value of one half the $DCGL_w$ is selected for the lower bound of the gray region. This value is adjusted to provide a relative shift (Δ/σ) value between one and three as described in Section 5.5.2. For decision error rates a value that minimizes the risk of making a decision error is recommended for the initial calculations. The number of measurements can be recalculated using different decision error rates until an optimum survey design is obtained. A prospective power curve (see Appendix D, Section D.6 and Appendix I, Section I.9) that considers the effects of these parameters can be very helpful in designing a survey and considering alternative values for these parameters, and is highly recommended.

To ensure that the desired power is achieved with the statistical test and to account for uncertainties in the estimated values of the measurement variabilities, MARSSIM recommends that the estimated number of measurements calculated using the formulas in Section 5.5.2.2 and 5.5.2.3 be increased by 20%. Insufficient numbers of measurements may result in failure to achieve the DQO for power and result in increased Type II decision errors, where survey units below the release criterion fail to demonstrate compliance.

Once survey units are identified and the number of measurements is determined, measurement locations should be selected. The statistical tests assume that the measurements are taken from random locations within the survey unit. A random survey design is used for Class 3 survey units, and a random starting point for the systematic grid is used for Class 2 and Class 1 survey units.

2.5.5 Developing an Integrated Survey Design

To account for assumptions used to develop the $DCGL_w$ and the realistic possibility of small areas of elevated activity, an integrated survey design should be developed to include all of the design considerations. An integrated survey design combines a scanning survey for areas of elevated

activity with random measurements for relatively uniform distributions of contamination. Table 2.2 presents the recommended conditions for demonstrating compliance for a final status survey based on classification.

Table 2.2 Recommended Conditions for Demonstrating Compliance Based on Survey Unit Classification for a Final Status Survey

| Survey Unit Classification | | Statistical Test | Elevated Measurement Comparison | Sampling and/or Direct Measurements | Scanning |
|----------------------------|---------|------------------|---------------------------------|-------------------------------------|--------------------|
| Impacted | Class 1 | Yes | Yes | Systematic | 100% Coverage |
| | Class 2 | Yes | Yes | Systematic | 10-100% Systematic |
| | Class 3 | Yes | Yes | Random | Judgmental |
| Non-Impacted | | No | No | No | None |

Random measurement patterns are used for Class 3 survey units to ensure that the measurements are independent and meet the requirements of the statistical tests. Systematic grids are used for Class 2 survey units because there is an increased probability of small areas of elevated activity. The use of a systematic grid allows the decision maker to draw conclusions about the size of any potential areas of elevated activity based on the area between measurement locations, while the random starting point of the grid provides an unbiased method for determining measurement locations for the statistical tests. Class 1 survey units have the highest potential for small areas of elevated activity, so the areas between measurement locations are adjusted to ensure that these areas can be identified by the scanning survey if the area of elevated activity is not detected by the direct measurements or samples.

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

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

Scanning surveys in Class 2 areas are also performed primarily to find areas of elevated activity not detected by the measurements using the systematic pattern. However, the measurement

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

Class 3 areas have the lowest potential for areas of elevated activity. For this reason, MARSSIM recommends that scanning surveys be performed in areas of highest potential (*e.g.*, corners, ditches, drains) based on professional judgment. This provides a qualitative level of confidence that no areas of elevated activity were missed by the random measurements or that there were no errors made in the classification of the area.

Note that the DCGL itself is not free of error. The assumptions made in any model used to develop DCGLs for a site should be examined carefully. The results of this examination should determine if the use of site-specific parameters result in large changes in the DCGLs, or whether a site-specific model should be developed to obtain DCGLs more relevant to the exposure conditions at the site. Appendix D, Section D.6 provides additional information about the uncertainty associated with the DCGL and other considerations for developing an integrated survey design using the DQO Process.

2.6 Flexibility in Applying MARSSIM Guidance

Section 2.5 describes an example that applies the performance-based guidance presented in Section 2.3 and Section 2.4 to design a survey for a site with specific characteristics (*i.e.*, surface soil and building surface contamination). Obviously this design cannot be uniformly applied at every site with radioactive contamination, so flexibility has been provided in the form of performance-based guidance. This guidance encourages the user to develop a site-specific survey design to account for site-specific characteristics. It is expected that most users will adopt the portions of the MARSSIM guidance that apply to their site. In addition, changes to the overall survey design that account for site-specific differences would be presented as part of the survey plan. The plan should also demonstrate that the extrapolation from measurements performed at specific locations to the entire site or survey unit is performed in a technically defensible manner.

Where Section 2.5 describes the development of a generic survey design that will be applicable at most radiation sites, this section describes the flexibility available within the MARSSIM for designing a site-specific survey design. Alternate methods for accomplishing the demonstration of compliance are briefly described and references for obtaining additional information on these alternate methods are provided.

2.6.1 Alternate Statistical Methods

MARSSIM encourages the use of statistics to provide a quantitative estimate of the probability that the release criterion is not exceeded at a site. While it is unlikely that any site will be able to demonstrate compliance with a dose- or risk-based regulation without at least considering the use of statistics, MARSSIM recognizes that the use of statistical tests may not always provide the most effective method for demonstrating compliance. For example, MARSSIM recommends a simple comparison to an investigation level to evaluate the presence of small areas of elevated activity in place of complicated statistical tests. At some sites a simple comparison of each measurement result to the $DCGL_w$, to demonstrate that all the measurement results are below the release criterion, may be more effective than statistical tests for the overall demonstration of compliance with the regulation provided an adequate number of measurements are performed.

MARSSIM recommends the use of nonparametric statistical tests for evaluating environmental data. There are two reasons for this recommendation: 1) environmental data is usually not normally distributed, and 2) there are often a significant number of qualitative survey results (*e.g.*, less than MDC). Either one of these conditions means that parametric statistical tests may not be appropriate. If one can demonstrate that the data are normally distributed and that there are a sufficient number of results to support a decision concerning the survey unit, parametric tests will generally provide higher power (or require fewer measurements to support a decision concerning the survey unit). The tests to demonstrate that the data are normally distributed generally require more measurements than the nonparametric tests. EPA provides guidance on selecting and performing statistical tests to demonstrate that data are normally distributed (EPA 1996a). Guidance is also available for performing parametric statistical tests (NRC 1992, EPA 1989a, EPA 1994b, EPA 1996a).

There are a wide variety of statistical tests designed for use in specific situations. These tests may be preferable to the generic statistical tests recommended in MARSSIM when the underlying assumptions for these tests can be verified. Table 2.3 lists several examples of statistical tests that may be considered for use at individual sites or survey units. A brief description of the tests and references for obtaining additional information on these tests are also listed in the table. Applying these tests may require consultation with a statistician.

Table 2.3 Examples of Alternate Statistical Tests

| Alternate Tests | Probability Model Assumed | Type of Test | Reference | Advantages | Disadvantages |
|---|--------------------------------------|--|--|--|---|
| Alternate 1-Sample Tests (no reference area measurements) | | | | | |
| Student's t Test | Normal | Parametric test for H_0 : Mean $< L$ | <i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.2-2. | Appropriate if data appears to be normally distributed and symmetric. | Relies on a non-robust estimator for μ and σ . Sensitive to outliers and departures from normality. |
| t Test Applied To Logarithms | Lognormal | Parametric test for H_0 : Median $< L$ | <i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.2-2 | This is a well-known and easy-to-apply test. Useful for a quick summary of the situation if the data is skewed to right. | Relies on a non-robust estimator for σ . Sensitive to outliers and departures from lognormality. |
| Minimum Variance Unbiased Estimator For Lognormal Mean | Lognormal | Parametric estimates for mean and variance of lognormal distribution | Gilbert, <i>Statistical Methods for Environmental Pollution Monitoring</i> , p. 164, 1987. | A good parametric test to use if the data is lognormal. | Inappropriate if the data is not lognormal. |
| Chen Test | Skewed to right, including Lognormal | Parametric test for H_0 : Mean > 0 | <i>Journal of the American Statistical Association</i> (90), p.767, 1995. | A good parametric test to use if the data is lognormal. | Applicable only for testing H_0 : "survey unit is clean." Survey unit must be significantly greater than 0 to fail. Inappropriate if the data is not skewed to the right. |

Table 2.3 (continued)

| Alternative Tests | Probability Model Assumed | Type of Test | Reference | Advantages | Disadvantages |
|--|---|---|---|--|---|
| Alternate 1-Samples Tests (no reference area measurements) | | | | | |
| Bayesian Approaches | Varies, but a family of probability distributions must be selected. | Parametric test for H_0 : Mean $< L$ | DeGroot, <i>Optimal Statistical Decisions</i> , p. 157, 1970. | Permits use of subjective "expert judgment" in interpretation of data. | Decisions based on expert judgment may be difficult to explain and defend. |
| Bootstrap | No restriction | Nonparametric. Uses resampling methods to estimate sampling variance. | Hall, <i>Annals of Statistics</i> (22), p. 2011-2030, 1994. | Avoids assumptions concerning the type of distribution. | Computer intensive analysis required. Accuracy of the results can be difficult to assess. |
| Lognormal Confidence Intervals Using Bootstrap | Lognormal | Uses resampling methods to estimate one-sided confidence interval for lognormal mean. | Angus, <i>The Statistician</i> (43), p. 395, 1994. | Nonparametric method applied within a parametric lognormal model. | Computer intensive analysis required. Accuracy of the results can be difficult to assess. |

Table 2.3 (continued)

| Alternative Tests | Probability Model Assumed | Type of Test | Reference | Advantages | Disadvantages |
|---|--|---|--|---|---|
| Alternate 2-Sample Tests (reference area measurements are required) | | | | | |
| Student's t Test | Symmetric, normal | Parametric test for difference in means $H_0: \mu_x < \mu_y$ | <i>Guidance for Data Quality Assessment</i> , EPA QA/G-9, p. 3.3-2 | Easy to apply. Performance for non-normal data is acceptable. | Relies on a non-robust estimator for σ , therefore test results are sensitive to outliers. |
| Mann-Whitney Test | No restrictions | Nonparametric test difference in location $H_0: \mu_x < \mu_y$ | Hollander and Wolfe, <i>Nonparametric Statistical Methods</i> , p. 71, 1973. | Equivalent to the WRS test, but used less often. Similar to resampling, because test is based on set of all possible differences between the two data sets. | Assumes that the only difference between the test and reference areas is a shift in location. |
| Kolmogorov-Smirnov | No restrictions | Nonparametric test for any difference between the 2 distributions | Hollander and Wolfe, <i>Nonparametric Statistical Methods</i> , p. 219, 1973. | A robust test for equality of two sample distributions against all alternatives. | May reject because variance is high, although mean is in compliance. |
| Bayesian Approaches | Varies, but a family of probability distributions must be selected | Parametric tests for difference in means or difference in variance. | Box and Tiao, <i>Bayesian Inference in Statistical Analysis</i> , Chapter 2, 1973. | Permits use of "expert judgment" in the interpretation of data. | Decisions based on expert judgement may be difficult to explain and defend. |

Table 2.3 (continued)

| Alternative Tests | Probability Model Assumed | Type of Test | Reference | Advantages | Disadvantages |
|---|---------------------------|---|---|--|--|
| Alternate 2-Sample Tests (reference area measurements are required) | | | | | |
| 2-Sample Quantile Test | No restrictions | Nonparametric test for difference in shape and location. | EPA, <i>Methods for Evaluating the Attainment of Cleanup Standards</i> , Vol. 3, p. 7.1, 1992. | Will detect if survey unit distribution exceeds reference distribution in the upper quantiles. | Applicable only for testing H_0 : "survey unit is clean." Survey unit must be significantly greater than 0 to fail. |
| Simultaneous WRS and Quantile Test | No restrictions | Nonparametric test for difference in shape and location. | EPA, <i>Methods for Evaluating the Attainment of Cleanup Standards</i> , Vol. 3, p. 7.17, 1992. | Additional level of protection provided by using two tests. Has advantages of both tests. | Cannot be combined with the WRS test that uses H_0 : "survey unit is not clean." Should only be combined with WRS test for H_0 : "survey unit is clean." |
| Bootstrap and Other Resampling Methods | No restrictions | Nonparametric. Uses resampling methods to estimate sampling variance. | Hall, <i>Annals of Statistics</i> (22), p. 2011, 1994. | Avoids assumptions concerning the type of distribution. Generates informative resampling distributions for graphing. | Computer intensive analysis required. |
| Alternate to Statistical Tests | | | | | |
| Decision Theory | No restrictions | Incorporates loss function in the decision theory approach. | DOE, <i>Statistical and Cost-Benefit Enhancements to the DQO Process for Characterization Decisions</i> , 1996. | Combines elements of cost-benefit analysis and risk assessment into the planning process. | Limited experience in applying the method to compliance demonstration and decommissioning. Computer intensive analysis required. |

2.6.2 Alternate Null Hypothesis

The selection of the null hypothesis in MARSSIM is designed to be protective of human health and the environment as well as consistent with current methods used for demonstrating compliance with regulations. MARSSIM also acknowledges that site-specific conditions (*e.g.*, high variability in background, lack of measurement techniques with appropriate detection sensitivity) may preclude the use of the null hypothesis that the survey unit is assumed to be contaminated. Similarly, a different null hypothesis and methodology could be used for different survey units (*e.g.*, Class 3 survey units). NUREG 1505 (NRC 1997b) provides guidance on determining when background variability might be an issue, designing surveys based on the null hypothesis that the survey unit concentration is indistinguishable from the concentration in the reference area, and performing statistical tests to demonstrate that the survey unit is indistinguishable from background.

2.6.3 Integrating MARSSIM with Other Survey Designs

2.6.3.1 Accelerated Cleanup Models

There are a number of approaches designed to expedite site cleanups. These approaches can save time and resources by reducing sampling, preventing duplication of effort, and reducing inactive time periods between steps in a cleanup process. Although Section 2.4 describes the RSSI Process recommended in MARSSIM as one with six principal steps, MARSSIM is not intended to be a serial process that would slow site cleanups. Rather, MARSSIM supports existing programs and encourages approaches to expedite site cleanups. Part of the significant emphasis on planning in MARSSIM is meant to promote saving time and resources.

There are many examples of accelerated cleanup approaches. The Superfund Accelerated Cleanup Model (SACM), which includes a module called integrated site assessment, has as its objectives increased efficiency and shorter response times (EPA 1992f, EPA 1993c, EPA 1997b).

Sandia National Laboratories (SNL) uses the Observational Approach. This approach uses an iterative process of sample collection and real-time data evaluation to characterize a site. This process allows early field results to guide later data collection in the field. Data collection is limited to only that required for selecting a unique remedy for a site.⁵

At DOE's Hanford Site, the parties to the Tri-Party Agreement negotiated a method to implement the CERCLA process in order to 1) accelerate the assessment phase, and 2) coordinate RCRA

⁵ Information on the Observational Approach recommended by Sandia National Laboratories is available on the internet at <http://www.em.doe.gov/tie/strechar.html>.

and CERCLA requirements whenever possible, thereby resulting in cost savings. The Hanford Past Practice Strategy (HPPS) was developed in 1991 to accelerate decisionmaking and initiation of remediation through activities that include maximizing the use of existing data consistent with data quality objectives.⁶

The adaptive sampling programs at the Environmental Assessment Division (EAD) of Argonne National Laboratory quantitatively fuse soft data (for example, historical records, aerial photos, nonintrusive geophysical data) with hard sampling results to estimate contaminant extent, measure the uncertainty associated with these estimates, determine the benefits from collecting additional samples, and assist in siting new sample locations to maximize the information gained.⁷

2.6.3.2 Superfund Soil Screening Guidance

The goal of the Soil Screening Guidance (EPA 1996b, EPA 1996c) is to help standardize and accelerate the evaluation and cleanup of contaminated soils at sites on the National Priorities List (NPL) designated for future residential land use. The guidance provides a methodology for calculating risk-based, site-specific, soil screening levels for chemical contaminants in soil that may be used to identify areas needing further investigation at NPL sites. While the Soil Screening Guidance was not developed for use with radionuclides, the methodology used is comparable to the MARSSIM guidance for demonstrating compliance using DCGLs. The Soil Screening Guidance assumes that there is a low probability of contamination, and does not account for small areas of elevated activity. These assumptions correlate to a Class 3 area in MARSSIM. Because the Soil Screening Guidance is designed as a screening tool instead of a final demonstration of compliance, the specific values for decision error levels, the bounds of the gray region, and the number and location of measurements are developed to support these objectives. However, MARSSIM guidance can be integrated with the survey design in the Soil Screening Guidance using this guidance as an alternate MARSSIM survey design.

The Soil Screening Guidance survey design is based on collecting samples, so scan surveys and direct measurements are not considered. To reduce analytical costs the survey design recommends compositing samples and provides a statistical test for demonstrating compliance. Compositing samples provides an additional source of uncertainty and prevents the detection of small areas of elevated activity.

⁶ Information on the Hanford Past Practice Strategy is available on the internet at <http://www.bhi-erc.com/map/sec5.html>.

⁷ Information on the Argonne National Laboratory adaptive sampling programs can be obtained on the internet at <http://www.ead.anl.gov/~web/newead/prgprj/proj/adaptive/adaptive.html>.

3 HISTORICAL SITE ASSESSMENT

3.1 Introduction

The Radiation Survey and Site Investigation (RSSI) Process uses a graded approach that starts with the Historical Site Assessment (HSA) and is later followed by other surveys that lead to the final status survey. The HSA is an investigation to collect existing information describing a site's complete history from the start of site activities to the present time. The necessity for detailed information and amount of effort to conduct an HSA depend on the type of site, associated historical events, regulatory framework, and availability of documented information. For example, some facilities—such as Nuclear Regulatory Commission (NRC) licensees that routinely maintain records throughout their operations—already have HSA information in place. Other facilities, such as Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) sites, may initiate a comprehensive search to gather HSA information (also see Appendix F for comparison of Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), CERCLA, and RCRA). In the former case, the HSA is essentially complete and a review of the following sections ensures that all information sources are incorporated into the overall investigation. In still other cases, where sealed sources or small amounts of radionuclides are described by the HSA, the site may qualify for a simplified decommissioning procedure (see Appendix B).

The HSA

- identifies potential, likely, or known sources of radioactive material and radioactive contamination based on existing or derived information
- identifies sites that need further action as opposed to those posing no threat to human health
- provides an assessment for the likelihood of contaminant migration
- provides information useful to scoping and characterization surveys
- provides initial classification of the site or survey unit¹ as impacted or non-impacted

The HSA may provide information needed to calculate derived concentration guideline levels (DCGLs, initially described in Section 2.2) and furthermore provide information that reveals the magnitude of a site's DCGLs. This information is used for comparing historical data to potential DCGLs and determining the suitability of the existing data as part of the assessment of the site. The HSA also supports emergency response and removal activities within the context of the

¹ Refer to Section 4.6 for a discussion of survey units.

EPA's Superfund program, fulfills public information needs, and furnishes appropriate information about the site early in the Site Investigation process. For a large number of sites (*e.g.* currently licensed facilities), site identification and reconnaissance may not be needed. For certain response activities, such as reports concerning the possible presence of radioactivity, preliminary investigations may consist more of a reconnaissance and a scoping survey in conjunction with efforts to gather historical information.

The HSA is typically described in three sections: identification of a candidate site (Section 3.3), preliminary investigation of the facility or site (Section 3.4), and site reconnaissance (Section 3.5). The reconnaissance however is not a scoping survey. The HSA is followed by an evaluation of the site based on information collected during the HSA.

3.2 Data Quality Objectives

The Data Quality Objectives (DQO) Process assists in directing the planning of data collection activities performed during the HSA. Information gathered during the HSA supports other DQOs when this process is applied to subsequent surveys.

Three HSA-DQO results are expected:

- identifying an individual or a list of planning team members—including the decision maker (DQO Step 1, Appendix D, Section D.1)
- concisely describing the problem (DQO Step 1, Appendix D, Section D.1)
- initially classifying site and survey unit as impacted or non-impacted (DQO Step 4, Appendix D, Section D.4)

Other results may accompany these three, and this added information may be useful in supporting subsequent applications of the DQO process.

The planning team clarifies and defines the DQOs for a site-specific survey. This multidisciplinary team of technical experts offers the greatest potential for solving problems when identifying every important aspect of a survey. Including a stakeholder group representative is an important consideration when assembling this team. Once formed, the team can also consider the role of public participation for this assessment and the possible surveys to follow. The number of team members is directly related to the scope and complexity of the problem. For a small site or simplified situations, planning may be performed by the site owner. For other specific sites (*e.g.*, CERCLA), a regulatory agency representative may be included.

The representative's role facilitates survey planning—without direct participation in survey plan development—by offering comments and information based on past precedent, current guidance, and potential pitfalls. For a large, complex facility, the team may include technical project managers, site managers, scientists, engineers, community and local government representatives, health physicists, statisticians, and regulatory agency representatives. A reasonable effort should be made to include other individuals—that is, specific decision makers or data users—who may use the study findings sometime in the future.

The planning team is generally led by a member who is referred to as the decision maker. This individual is often the person with the most authority over the study and may be responsible for assigning the roles and responsibilities to planning team members. Overall, the decision-making process arrives at final decisions based on the planning team's recommendations.

The problem or situation description provides background information on the fundamental issue to be addressed by the assessment (see EPA 1994a). The following steps may be helpful during DQO development:

- describe the conditions or circumstances regarding the problem or situation and the reason for undertaking the survey
- describe the problem or situation as it is currently understood by briefly summarizing existing information
- conduct literature searches and interviews, and examine past or ongoing studies to ensure that the problem is correctly defined
- if the problem is complex, consider breaking it into more manageable pieces

Section 3.4 provides guidance on gathering existing site data and determining the usability of this data.

The initial classification of the site involves developing a conceptual model based on the existing information collected during the preliminary investigation. Conceptual models describe a site or facility and its environs and present hypotheses regarding the radionuclides for known and potential residual contamination (EPA 1987b, 1987c). The classification of the site is discussed in Section 3.6, Evaluation of Historical Site Assessment Data.

Several results of the DQO Process may be addressed initially during the HSA. This information or decision may be based on limited or incomplete data. As the site assessment progresses and as decisions become more difficult, the iterative nature of the DQO Process allows for re-evaluation of preliminary decisions. This is especially important for classification of sites and survey units where the final classification is not made until the final status survey is planned.

3.3 Site Identification

A site may already be known for its prior use and presence of radioactive materials. Elsewhere, potential radiation sites may be identified through the following:

- records of authorization to possess or handle radioactive materials (*e.g.*, NRC or NRC Agreement State License, DOE facility records, Naval Radioactive Materials Permit, USAF Master Materials License, Army Radiation Authorization, State Authorization for Naturally Occurring and Accelerator Produced Radioactive Material (NARM))
- notification to government Agencies of possible releases of radioactive substances
- citizens filing a petition under section 105(d) of the Superfund Amendments and Reauthorization Act of 1986 (SARA; EPA 1986)
- ground and aerial radiological surveys
- contacts with knowledge of the site
- review of EPA's Environmental Radiation Ambient Monitoring System (ERAMS) database (Appendix G)

Once identified, the name, location, and current legal owner or custodian (where available) of the site should be recorded.

3.4 Preliminary HSA Investigation

This limited-scope investigation serves to collect readily available information concerning the facility or site and its surroundings. The investigation is designed to obtain sufficient information to provide initial classification of the site or survey unit as impacted or non-impacted. Information on the potential distribution of radioactive contamination may be used for classifying each site or survey unit as Class 2 or Class 1 and is useful for planning scoping and characterization surveys.

Table 3.1 provides a set of questions that can be used to assist in the preliminary HSA investigation. Apart from obvious cases (*e.g.*, NRC licensees), this table focuses on characteristics that identify a previously unrecognized or known but undeclared source of potential contamination. Furthermore, these questions may identify confounding factors for selecting reference sites.

Table 3.1 Questions Useful for the Preliminary HSA Investigation

| | | |
|-----|---|---|
| 1. | Was the site ever licensed for the manufacture, use, or distribution of radioactive materials under Agreement State Regulations, NRC licenses, or Armed Services permits, or for the use of 91B material? | Indicates a higher probability that the area is impacted. |
| 2. | Did the site ever have permits to dispose of, or incinerate, radioactive material onsite? Is there evidence of such activities? | Evidence of radioactive material disposal indicates a higher probability that the area is impacted. |
| 3. | Has the site ever had deep wells for injection or permits for such? | Indicates a higher probability that the area is impacted. |
| 4. | Did the site ever have permits to perform research with radiation generating devices or radioactive materials except medical or dental x-ray machines? | Research that may have resulted in the release of radioactive materials indicates a higher probability that the area is impacted. |
| 5. | As a part of the site's radioactive materials license were there ever any Soil Moisture Density Gauges (Americium-Beryllium or Plutonium-Beryllium sources), or Radioactive Thickness Monitoring Gauges stored or disposed of onsite? | Leak test records of sealed sources may indicate whether or not a storage area is impacted. Evidence of radioactive material disposal indicates a higher probability that the area is impacted. |
| 6. | Was the site used to create radioactive material(s) by activation? | Indicates a higher probability that the area is impacted. |
| 7. | Were radioactive sources stored at the site? | Leak test records of sealed sources may indicate whether or not a storage area is impacted. |
| 8. | Is there evidence that the site was involved in the Manhattan Project or any Manhattan Engineering District (MED) activities (1942-1946)? | Indicates a higher probability that the area is impacted. |
| 9. | Was the site ever involved in the support of nuclear weapons testing (1945-1962)? | Indicates a higher probability that the area is impacted. |
| 10. | Were any facilities on the site used as a weapons storage area? Was weapons maintenance ever performed at the site? | Indicates a higher probability that the area is impacted. |
| 11. | Was there ever any decontamination, maintenance, or storage of radioactively contaminated ships, vehicles, or planes performed onsite? | Indicates a higher probability that the area is impacted. |

Table 3.1 Questions Useful for the Preliminary HSA Investigation (continued)

| | | |
|-----|---|---|
| 12. | Is there a record of any aircraft accident at or near the site (e.g., depleted uranium counterbalances, thorium alloys, radium dials)? | May include other considerations such as evidence of radioactive materials that were not recovered. |
| 13. | Was there ever any radiopharmaceutical manufacturing, storage, transfer, or disposal onsite? | Indicates a higher probability that the area is impacted. |
| 14. | Was animal research ever performed at the site? | Evidence that radioactive materials were used for animal research indicates a higher probability that the area is impacted. |
| 15. | Were uranium, thorium, or radium compounds (NORM) used in manufacturing, research, or testing at the site, or were these compounds stored at the site? | Indicates a higher probability that the area is impacted or results in a potential increase in background variability. |
| 16. | Has the site ever been involved in the processing or production of Naturally Occurring Radioactive Material (e.g., radium, fertilizers, phosphorus compounds, vanadium compounds, refractory materials, or precious metals) or mining, milling, processing, or production of uranium? | Indicates a higher probability that the area is impacted or results in a potential increase in background variability. |
| 17. | Were coal or coal products used onsite? If yes, did combustion of these substances leave ash or ash residues onsite? If yes, are runoff or production ponds onsite? | May indicate other considerations such as a potential increase in background variability. |
| 18. | Was there ever any onsite disposal of material known to be high in naturally occurring radioactive materials (e.g., monazite sands used in sandblasting)? | May indicate other considerations such as a potential increase in background variability. |
| 19. | Did the site process pipe from the oil and gas industries? | Indicates a higher probability that the area is impacted or results in a potential increase in background variability. |
| 20. | Is there any reason to expect that the site may be contaminated with radioactive material (other than previously listed)? | See Section 3.6.3. |

Appendix G of this document provides a general listing and cross-reference of information sources—each with a brief description of the information contained in each source. The *Site Assessment Information Directory* (EPA 1991e) contains a detailed compilation of data sources, including names, addresses, and telephone numbers of agencies that can provide HSA information.

3.4.1 Existing Radiation Data

Site files, monitoring data, former site evaluation data, Federal, State, or local investigations, or emergency actions may be sources of useful site information. Existing site data may provide specific details about the identity, concentration, and areal distribution of contamination. However, these data should be examined carefully because:

- Previous survey and sampling efforts may not be compatible with HSA objectives or may not be extensive enough to characterize the facility or site fully.
- Measurement protocols and standards may not be known or compatible with HSA objectives (*e.g.*, Quality Assurance/Quality Control (QA/QC) procedures, limited analysis rather than full-spectrum analysis) or may not be extensive enough to characterize the facility or site fully.
- Conditions may have changed since the site was last sampled (*i.e.*, substances may have been released, migration may have spread the contamination, additional waste disposal may have occurred, or decontamination may have been performed).

Existing data can be evaluated using the Data Quality Assessment (DQA) process described in Appendix E. (Also see DOE 1987 and EPA 1980c, 1992a, 1992b, 1996a for additional guidance on evaluating data.)

3.4.1.1 Licenses, Site Permits, and Authorizations

The facility or site radioactive materials license and supporting or associated documents are potential sources of information for licensed facilities. If a license does not exist, there may be a permit or other document that authorized site operations involving radioactivity. These documents may specify the quantities of radioactive material authorized for use at the site, the chemical and physical form of the materials, operations for which the materials are (or were) used, locations of these operations at the facility or site, and total quantities of material used at the site during its operating lifetime.

EPA and State agencies maintain files on a variety of environmental programs. These files may contain permit applications and monitoring results with information on specific waste types and quantities, sources, type of site operations, and operating status of the facility or site. Some of these information sources are listed in Appendix G (*e.g.*, Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), Resource Conservation and Recovery Information System (RCRIS), Ocean Data Evaluation System (ODES)).

3.4.1.2 Operating Records

Records and other information sources useful for site evaluations include those describing onsite activities; current and past contamination control procedures; and past operations involving demolition, effluent releases, discharge to sewers or onsite septic systems, production of residues, land filling, waste and material storage, pipe and tank leaks, spills and accidental releases, release of facilities or equipment from radiological controls, and onsite or offsite radioactive and hazardous waste disposal. Some records may be or may have been classified for National Security purposes and means should be established to review all pertinent records. Past operations should be summarized in chronological order along with information indicating the type of permits and approvals that authorized these operations. Estimates of the total activity disposed of or released at the site and the physical and chemical form of the radioactive material should also be included. Records on waste disposal, environmental monitoring, site inspection reports, license applications, operational permits, waste disposal material balance and inventory sheets, and purchase orders for radioactive materials are useful—for estimating total activity. Information on accidents, such as fires, flooding, spills, unintentional releases, or leakage, should be collected as potential sources of contamination. Possible areas of localized contamination should be identified.

Site plats or plots, blueprints, drawings, and sketches of structures are especially useful to illustrate the location and layout of buildings on the site. Site photographs, aerial surveys, and maps can help verify the accuracy of these drawings or indicate changes following the time when the drawings were prepared. Processing locations—plus waste streams to and from the site as well as the presence of stockpiles of raw materials and finished product—should be noted on these photographs and maps. Buildings or outdoor processing areas may have been modified or reconfigured such that former processing areas were converted to other uses or configurations. The locations of sewers, pipelines, electric lines, water lines, *etc.*, should also be identified. This information facilitates planning the Site Reconnaissance and subsequent surveys, developing a site conceptual model, and increasing the efficiency of the survey program.

Corporate contract files may also provide useful information during subsequent stages of the Radiation Survey and Site Investigation Process. Older facilities may not have complete operational records, especially for obsolete or discontinued processes. Financial records may also provide information on purchasing and shipping that in turn help to reconstruct a site's operational history.

While operating records can be useful tools during the HSA, the investigator should be careful not to place too much emphasis on this type of data. These records are often incomplete and lack information on substances previously not considered hazardous. Out-of-date blueprints and drawings may not show modifications made during the lifetime of a facility.

3.4.2 Contacts and Interviews

Interviews with current or previous employees are performed to collect first-hand information about the site or facility and to verify or clarify information gathered from existing records. Interviews to collect first-hand information concerning the site or facility are generally conducted early in the data-gathering process. Interviews cover general topics, such as radioactive waste handling procedures. Results of early interviews are used to guide subsequent data collection activities.

Interviews scheduled late in the data gathering process may be especially useful. This activity allows questions to be directed to specific areas of the investigation that need additional information or clarification. Photographs and sketches can be used to assist the interviewer and allow the interviewees to recall information of interest. Conducting interviews onsite where the employees performed their tasks often stimulates memories and facilitates information gathering. In addition to interviewing managers, engineers, and facility workers, interviews may be conducted with laborers and truck drivers to obtain information from their perspective. The investigator should be cautious in the use of interview information. Whenever possible, anecdotal evidence should be assessed for accuracy and results of interviews should be backed up with supporting data. Steps that ensure specific information is properly recorded may include hiring trained investigators and taking affidavits.

3.5 Site Reconnaissance

The objective of the Site Reconnaissance or Site Visit is to gather sufficient information to support a decision regarding further action. Reconnaissance activity is not a risk assessment, a scoping survey, or a study of the full extent of contamination at a facility or site. The reconnaissance offers an opportunity to record information concerning hazardous site conditions as they apply to conducting future survey work. In this regard, information describing physical hazards, structural integrity of buildings, or other conditions, defines potential problems that may impede future work. This section is most applicable to sites with less available information and may not be necessary at other sites having greater amounts of data, such as Nuclear Regulatory Commission (NRC) licensed facilities.

To prepare for the Site Reconnaissance, begin by reviewing what is known about the facility or site and identify data gaps. Given the site-specific conditions, consider whether or not a Site Reconnaissance is necessary and practical. This type of effort may be deemed necessary if a site is abandoned, not easily observed from areas of public access, or discloses little information during file searches. These same circumstances may also make a Site Reconnaissance risky for health and safety reasons—in view of the many unknowns—and may make entry difficult. This investigative step may be practical, but less critical, for active facilities whose operators grant

access and provide requested information. Remember to arrange for proper site access and prepare an appropriate health and safety plan, if required, before initiating the Site Reconnaissance.

Investigators should acquire signed consent forms from the site or equipment owner to gain access to the property to conduct the reconnaissance. Investigators are to determine if State and Federal officials, and local individuals, should be notified of the reconnaissance schedule. If needed, local officials should arrange for public notification. Guidance on obtaining access to sites can be found in *Entry and Continued Access Under CERCLA* (EPA 1987d).

A study plan should be prepared before the Site Reconnaissance to anticipate every reconnaissance activity and identify specific information to be gathered. This plan should incorporate a survey of the site's surroundings and provide details for activities that verify or identify the location of: nearby residents, worker populations, drinking water or irrigation wells, foods, and other site environs information.

Preparing for the Site Reconnaissance includes initially gathering necessary materials and equipment. This includes a camera to document site conditions, health and safety monitoring instruments including a radiation detection meter for use during the site visit, and extra copies of topographic maps to mark target locations, water distribution areas, and other important site features. A logbook is critical to keeping a record of field activities and observations as they occur. For documentation purposes MARSSIM recommends that the logbook be completed in waterproof ink, preferably by one individual. Furthermore, each page of the logbook should be signed and dated, including the time of day, after the last entry on the page. Corrections should be documented and approved.

3.6 Evaluation of Historical Site Assessment Data

The main purpose of the Historical Site Assessment (HSA) is to determine the current status of the site or facility, but the data collected may also be used to differentiate sites that need further action from those that pose little or no threat to human health and the environment. This screening process can serve to provide a site disposition recommendation or to recommend additional surveys. Because much of the data collected during HSA activities is qualitative or is analytical data of unknown quality, many decisions regarding a site are the result of professional judgment.

There are three possible recommendations that follow the HSA:

- An emergency action to reduce the risk to human health and the environment—this alternative is applicable to Superfund removal actions, which are discussed in detail by EPA (EPA 1988c).

- The site or area is impacted and further investigation is needed before a decision regarding final disposition can be made. The area may be Class 1, Class 2, or Class 3, and a scoping survey or a characterization survey should be performed. Information collected during the HSA can be very useful in planning these subsequent survey activities.
- The site or area is non-impacted. There is no possibility or an extremely low probability of residual radioactive materials being present at the site. The site or area can be released.

Historical analytical data indicating the presence of contamination in environmental media (surface soil, subsurface soil, surface water, ground water, air, or buildings) can be used to support the hypothesis that radioactive material was released at the facility or site. A decision that the site is contaminated can be made regardless of the quality of the data, its attribution to site operations, or its relationship to background levels. In such cases, analytical indications are sufficient to support the hypothesis—it is not necessary to definitively demonstrate that a problem exists. Conversely, historical analytical data can also be used to support the hypothesis that no release has occurred. However, these data should not be the sole basis for this hypothesis. Using historical analytical data as the principal reason for ruling out the occurrence of contamination forces the data to demonstrate that a problem does not exist.

In most cases it is assumed there will be some level of process knowledge available in addition to historical analytical data. If process knowledge suggests that no residual contamination should be present and the historical analytical data also suggests that no residual contamination is present, the process knowledge provides an additional level of confidence and supports classifying the area as non-impacted. However, if process knowledge suggests no residual contamination should be present but the historical analytical data indicate the presence of residual contamination, the area will probably be considered impacted.

The following sections describe the information recommended for assessing the status of a site. This information is needed to accurately and completely support a site disposition recommendation. If some of the information is not available, it should be identified as a data need for future surveys. Data needs are collected during Step 3 of the Data Quality Objective (DQO) process (Identify Inputs to the Decision) as described in Appendix D, Section D.3. Section 3.6.5 provides information on professional judgment and how it may be applied to the decision making process.

3.6.1 Identify Potential Contaminants

An efficient HSA gathers information sufficient to identify the radionuclides used at the site—including their chemical and physical form. The first step in evaluating HSA data is to estimate the potential for residual contamination by these radionuclides.

Site operations greatly influence the potential for residual contamination (NRC 1992a). An operation that only handled encapsulated sources is expected to have a low potential for contamination—assuming that the integrity of the sources was not compromised. A review of leak-test records for such sources may be adequate to demonstrate the low probability of residual contamination. A chemical manufacturing process facility would likely have contaminated piping, ductwork, and process areas, with a potential for soil contamination where spills, discharges, or leaks occurred. Sites using large quantities of radioactive ores—especially those with outside waste collection and treatment systems—are likely to have contaminated grounds. If loose dispersible materials were stored outside or process ventilation systems were poorly controlled, then windblown surface contamination may be possible.

Consider how long the site was operational. If enough time elapsed since the site discontinued operations, radionuclides with short half-lives may no longer be present in significant quantities. In this case, calculations demonstrating that residual activity could not exceed the DCGL may be sufficient to evaluate the potential residual contaminants at the site. A similar consideration can be made based on knowledge of a contaminant's chemical and physical form. Such a determination relies on records of radionuclide inventories, chemical and physical forms, total amounts of activity in waste shipments, and purchasing records to document and support this decision. However, a number of radionuclides experience significant decay product ingrowth, which should be included when evaluating existing site information.

3.6.2 Identify Potentially Contaminated Areas

Information gathered during the HSA should be used to provide an initial classification of the site areas as impacted or non-impacted.

Impacted areas have a potential for radioactive contamination (based on historical data) or contain known radioactive contamination (based on past or preliminary radiological surveillance). This includes areas where 1) radioactive materials were used and stored; 2) records indicate spills, discharges, or other unusual occurrences that could result in the spread of contamination; and 3) radioactive materials were buried or disposed. Areas immediately surrounding or adjacent to these locations are included in this classification because of the potential for inadvertent spread of contamination.

Non-impacted areas—identified through knowledge of site history or previous survey information—are those areas where there is no reasonable possibility for residual radioactive contamination. The criteria used for this segregation need not be as strict as those used to demonstrate final compliance with the regulations. However, the reasoning for classifying an area as non-impacted should be maintained as a written record. Note that—based on accumulated survey data—an impacted area's classification may change as the RSSI Process progresses.

All potential sources of radioactivity in impacted areas should be identified and their dimensions recorded (in 2 or 3 dimensions—to the extent they can be measured or estimated). Sources can be delineated and characterized through visual inspection during the site reconnaissance, interviews with knowledgeable personnel, and historical information concerning disposal records, waste manifests, and waste sampling data. The HSA should address potential contamination from the site whether it is physically within or outside of site boundaries. This approach describes the site in a larger context, but as noted in Chapter 1, MARSSIM's scope concerns releasing a site and not areas outside a site's boundaries.

3.6.3 Identify Potentially Contaminated Media

The next step in evaluating the data gathered during the HSA is to identify potentially contaminated media at the site. To identify media that may and media that do not contain residual contamination supports both preliminary area classification (Section 4.4) and planning subsequent survey activities.

This section provides guidance on evaluating the likelihood for release of radioactivity into the following environmental media: surface soil, subsurface soil, sediment, surface water, ground water, air, and buildings. While MARSSIM's scope is focused on surface soils and building surfaces, this section makes note of still other media to provide a starting place to identify and address all possible media. The evaluation will result in either a finding of "Suspected Contamination" or "No Suspected Contamination," which may be based on analytical data, professional judgment, or a combination of the two.

Subsequent sections describe the environmental media and pose questions pertinent to each type. Each question is accompanied by a commentary. Carefully consider the questions within the context of the site and the available data. Avoid spending excessive amounts of time answering each question because answers to every question are unlikely to be available at each site. Questions that cannot be answered based on existing data can be used to direct future surveys of the site. Also, keep in mind the numerous differences in site-specific circumstances and that the questions do not identify every characteristic that might apply to a specific site. Additional questions or characteristics identified during a specific site assessment should be included in the HSA report (Section 3.8; EPA 1991f).

3.6.3.1 Surface Soil

Surface soil is the top layer of soil on a site that is available for direct exposure, growing plants, resuspension of particles for inhalation, and mixing from human disturbances. Surface soil may also be defined as the thickness of soil that can be measured using direct measurement or scanning techniques. Typically, this layer is represented as the top 15 cm (6 in.) of soil (40 CFR 192). Surface sources may include gravel fill, waste piles, concrete, or asphalt paving. For many sites

where radioactive materials were used, one first assumes that surface contamination exists and the evaluation is used to identify areas of high and low probability of contamination (Class 1, Class 2 or Class 3 areas).

- Were all radiation sources used at the site encapsulated sources?

A site where only encapsulated sources were used would be expected to have a low potential for contamination. A review of the leak-test records and documentation of encapsulated source location may be adequate for a finding of "No Suspected Contamination."

- Were radiation sources used only in specific areas of the site?

Evidence that radioactive materials were confined to certain areas of the site may be helpful in determining which areas are impacted and which are non-impacted.

- Was surface soil regraded or moved elsewhere for fill or construction purposes?

This helps to identify additional potential radiation sites.

3.6.3.2 Subsurface Soil and Media

Subsurface soil and media are defined as any solid materials not considered to be surface soil. The purpose of these investigations is to locate and define the vertical extent of the potential contamination. Subsurface measurements can be expensive, especially for beta- or alpha-emitting radionuclides. Removing areas from consideration for subsurface measurements or defining areas as non-impacted for subsurface sampling conserves limited resources and focuses the site assessment on areas of concern.

- Are there areas of known or suspected surface soil contamination?

Surface soil contamination can migrate deeper into the soil. Surface soil sources should be evaluated based on radionuclide mobility, soil permeability, and infiltration rate to determine the potential for subsurface contamination. Computer modeling may be helpful for evaluating these types of situations.

- Is there a ground-water plume without an identifiable source?

Contaminated ground water indicates that a source of contamination is present. If no source is identified during the HSA, subsurface contamination is a probable source.

- Is there potential for enhanced mobility of radionuclides in soils?

Radionuclide mobility can be enhanced by the presence of solvents or other volatile chemicals that affect the ion-exchange capacity of soil.

- Is there evidence that the surface has been disturbed?

Recent or previous excavation activities are obvious sources of surface disturbance. Areas with developed plant life (forested or old growth areas) may indicate that the area remained undisturbed during the operating life of the facility. Areas where vegetation is removed during previous excavation activity may be distinct from mature plant growth in adjacent areas. If a site is not purposely replanted, vegetation may appear in a sequence starting with grasses that are later replaced by shrubs and trees. Typically, grasslands recover within a few years, sagebrush or low ground cover appears over decades, while mature forests may take centuries to develop.

- Is there evidence of subsurface disturbance?

Non-intrusive, non-radiological measurement techniques may provide evidence of subsurface disturbance. Magnetometer surveys can identify buried metallic objects, and ground-penetrating radar can identify subsurface anomalies such as trenches or dump sites. Techniques involving special equipment are discussed in Section 6.10.

- Are surface structures present?

Structures constructed at a site—during the operational history of that site—may cover below-ground contamination. Some consideration for contaminants that may exist beneath parking lots, buildings, or other onsite structures may be warranted as part of the investigation. There may be underground piping, drains, sewers, or tanks that caused contamination.

3.6.3.3. Surface Water

Surface waters include streams and rivers, lakes, coastal tidal waters, and oceans. Note that certain ditches and intermittently flowing streams qualify as surface water. The evaluation determines whether radionuclides are likely to migrate to surface waters or their sediments. Where a previous release is not suspected, the potential for future release depends on the distance to surface water and the flood potential at the site. With regard to the two preceding sections, one can also consider an interaction between soil and water in relation to seasonal factors including soil cracking due to freezing, thawing, and dessication that influence the dispersal or infiltration of radionuclides.

- Is surface water nearby?

The proximity of a contaminant to local surface water is essentially determined by runoff and radionuclide migration through the soil. The definition for *nearby* depends on site-specific conditions. If the terrain is flat, precipitation is low, and soils are sandy, nearby may be within several meters. If annual precipitation is high or occasional rainfall events are high, within 1,200 meters (3/4 mile) might be considered nearby. In general, sites need not include the surface water pathway where the overland flow distance to the nearest surface water is more than 3,200 meters (2 miles).

- Is the waste quantity particularly large?

Depending on the physical and chemical form of the waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of more importance—*i.e.*, a greater risk or hazard—than a *large* quantity of solid waste stored in water tight containers.

- Is the drainage area large?

The drainage area includes the area of the site itself plus the upgradient area that produces runoff flowing over the site. Larger drainage areas generally produce more runoff and increase the potential for surface water contamination.

- Is rainfall heavy?

If the site and surrounding area are flat, a combination of heavy precipitation and low infiltration rate may cause rainwater to pool on the site. Otherwise, these characteristics may contribute to high runoff rates that carry radionuclides overland to surface water. Total annual rainfall exceeding one meter (40 inches), or a once in two-year-24-hour precipitation exceeding five cm (two inches) might be considered "heavy."

Rainfall varies for locations across the continental United States from high (*e.g.*, 89 in./y, Mt. Washington, NH) to low values (*e.g.*, 4.2 in./y, Las Vegas, NV). Precipitation rates will vary during the year at each location due to seasonal and geographic factors. A median value for rainfall within the United States, as found in van der Leeden *et al.* 1990, is about 26 in./y as is observed for Minneapolis, MN.

- Is the infiltration rate low?

Infiltration rates range from very high in gravelly and sandy soils to very low in fine silt and clay soils. Paved sites prevent infiltration and generate runoff.

- Are sources of contamination poorly contained or prone to runoff?

Proper containment which prevents radioactive material from migrating to surface water generally uses engineered structures such as dikes, berms, run-on and runoff control systems, and spill collection and removal systems. Sources prone to releases via runoff include leaks, spills, exposed storage piles, or intentional disposal on the ground surface. Sources not prone to runoff include underground tanks, above-ground tanks, and containers stored in a building.

- Is a runoff route well defined?

A well defined runoff route—along a gully, trench, berm, wall, *etc.*—will more likely contribute to migration to surface water than a poorly defined route. However, a poorly defined route may contribute to dispersion of contamination to a larger area of surface soil.

- Has deposition of waste into surface water been observed?

Indications of this type of activity will appear in records from past practice at a site or from information gathered during personal interviews.

- Is ground water discharge to surface water probable?

The hydrogeology and geographical information of the area around and inside the site may be sufficiently documented to indicate discharge locations.

- Does analytical or circumstantial evidence suggest surface water contamination?

Any condition considered suspicious—and that indicates a potential contamination problem—can be considered circumstantial evidence.

- Is the site prone to flooding?

The Federal Emergency Management Agency (FEMA) publishes flood insurance rate maps that delineate 100-year and 500-year flood plains. Ten-year floodplain maps may also be available. Generally, a site on a 500-year floodplain is not considered prone to flooding.

3.6.3.4 Ground Water

Proper evaluation of ground water includes a general understanding of the local geology and subsurface conditions. Of particular interest is descriptive information relating to subsurface stratigraphy, aquifers, and ground water use.

- Are sources poorly contained?

Proper containment which prevents radioactive material from migrating to ground water generally uses engineered structures such as liners, layers of low permeability soil (*e.g.*, clay), and leachate collection systems.

- Is the source likely to contaminate ground water?

Underground tanks, landfills,² surface impoundments and lagoons are examples of sources that are likely to release contaminants that migrate to ground water. Above ground tanks, drummed solid wastes, or sources inside buildings are less likely to contribute to ground-water contamination.

- Is waste quantity particularly large?

Depending on the physical and chemical form of the waste and its location, *large* is a relative term. A *small* quantity of liquid waste may be of more importance—*i.e.*, greater risk or hazard—than a *large* quantity of solid waste stored in water tight containers.

- Is precipitation heavy?

If the site and surrounding area are flat, a combination of heavy precipitation and low infiltration rate may cause rainwater to pool on the site. Otherwise, these characteristics may contribute to high runoff rates that carry radionuclides overland to surface water. Total annual rainfall exceeding one meter (40 in.), or a once in two-year-24-hour precipitation exceeding five cm (two in.) might be considered "heavy."

Rainfall varies for locations across the continental United States from high (*e.g.*, 89 in./y, Mt. Washington, NH) to low values (*e.g.*, 4.2 in./y, Las Vegas, NV). Precipitation rates will vary during the year at each location due to seasonal and geographic factors. A median value for rainfall within the United States, as found in van der Leeden *et al.* 1990, is about 26 in./y as is observed for Minneapolis, MN.

- Is the infiltration rate high?

Infiltration rates range from very high in gravelly and sandy soils to very low in fine silt and clay soils. Unobstructed surface areas are potential candidates for further examination to determine infiltration rates.

² Landfills can affect the geology and hydrogeology of a site and produce heterogeneous conditions. It may be necessary to consult an expert on landfills and the conditions they generate.

- Is the site located in an area of karst terrain?

In karst terrain, ground water moves rapidly through channels caused by dissolution of the rock material (usually limestone) that facilitates migration of contaminants.

- Is the subsurface highly permeable?

Highly permeable soils favor downward movement of water that may transport radioactive materials. Well logs, local geologic literature, or interviews with knowledgeable individuals may help answer this question.

- What is the distance from the surface to an aquifer?

The shallower the source of ground water, the higher the threat of contamination. It is difficult to determine whether an aquifer may be a potential source of drinking water in the future (*e.g.*, next 1,000 years). This generally applies to the shallowest aquifer below the site.

- Are suspected contaminants highly mobile in ground water?

Mobility in ground water can be estimated based on the distribution coefficient (K_d) of the radionuclide. Elements with a high K_d , like thorium (*e.g.*, $K_d = 3,200 \text{ cm}^3/\text{g}$), are not mobile while elements with a low K_d , like hydrogen (*e.g.*, $K_d = 0 \text{ cm}^3/\text{g}$), are very mobile. The NRC (NRC 1992b) and Department of Energy (DOE) (Yu, *et al.*, 1993) provide a compilation of K_d values. These values can be influenced by site-specific considerations such that site-specific K_d values need to be evaluated or determined. Also, the mobility of a radionuclide can be enhanced by the presence of a solvent or volatile chemical.

- Does analytical or circumstantial evidence suggest ground water contamination?

Evidence for contamination may appear in current site data; historical, hydrogeological, and geographical information systems records; or as a result of personal interviews.

3.6.3.5 Air

Evaluation of air is different than evaluation of other potentially contaminated media. Air is rarely the source of contamination. Air is evaluated as a pathway for resuspending and dispersing radioactive contamination as well as a contaminated media.

- Were there observations of contaminant releases into the air?

Direct observation of a release to the air might occur where radioactive materials are suspected to be present in particulate form (*e.g.*, mine tailings, waste pile) or adsorbed to particulates (*e.g.*, contaminated soil), and where site conditions favor air transport (*e.g.*, dry, dusty, windy).

- Does analytical or circumstantial evidence suggest a release to the air?

Other evidence for releases to the air might include areas of surface soil contamination that do not appear to be caused by direct deposition or overland migration of radioactive material.

- For radon exposure only, are there elevated amounts of radium (^{226}Ra) in the soil or water that could act as a source of radon in the air?

The source, ^{226}Ra , decays to ^{222}Rn , which is radon gas. Once radon is produced, the gas needs a pathway to escape from its point of origin into the air. Radon is not particularly soluble in water, so this gas is readily released from water sources which are open to air. Soil, however, can retain radon gas until it has decayed (see Section 6.9). The rate that radon is emitted by a solid, *i.e.* radon flux, can be measured directly to evaluate potential sources of radon.

- Is there a prevailing wind and a propensity for windblown transport of contamination?

Information pertaining to geography, ground cover (*e.g.*, amount and types of local vegetation), meteorology (*e.g.*, windspeed at 7 meters above ground level) for and around the site, plus site-specific parameters related to surface soil characteristics enter into calculations used to describe particulate transport. Mean annual windspeed can be obtained from the National Weather Service surface station nearest to the site.

3.6.3.6 Structures

Structures used for storage, maintenance, or processing of radioactive materials are potentially contaminated by these materials. The questions presented in Table 3.1 help to determine if a building might be potentially contaminated. The questions listed in this section are for identifying potentially contaminated structures, or portions of structures, that might not be identified using Table 3.1. Section 4.8.3.1 also presents useful information on identifying structural contamination.

- Were adjacent structures used for storage, maintenance, or processing of radioactive materials?

Adjacent is a relative term for this question. A processing facility with a potential for venting radioactive material to the air could contaminate buildings downwind. A facility with little potential for release outside of the structures handling the material would be less likely to contaminate nearby structures.

- Is a building or its addition or a new structure located on a former radioactive waste burial site or contaminated land?

Comparing past and present photographs or site maps and retrieving building permits or other structural drawings and records in relation to historical operations information will reveal site locations where structures may have been built over buried waste or contaminated land.

- Was the building constructed using contaminated material?

Building materials such as concrete, brick, or cinder block may have been formed using contaminated material.

- Does the potentially non-impacted portion of the building share a drainage system or ventilation system with a potentially contaminated area?

Technical and architectural drawings for site structures along with visual inspections are required to determine if this is a concern in terms of current or past operations.

- Is there evidence that previously identified areas of contamination were remediated by painting or similar methods of immobilizing contaminants?

Removable sources of contamination immobilized by painting may be more difficult to locate, and may need special consideration when planning subsequent surveys.

3.6.4 Develop a Conceptual Model of the Site

Starting with project planning activities, one gathers and analyzes available information to develop a conceptual site model. The model is essentially a site diagram showing locations of known contamination, areas of suspected contamination, types and concentrations of radionuclides in impacted areas, potentially contaminated media, and locations of potential reference (background) areas. The diagram should include the general layout of the site including buildings and property boundaries. When possible, produce three dimensional diagrams. The conceptual site model will be upgraded and modified as information becomes available throughout the RSSI Process. The process of developing this model is also briefly described in Attachment A of EPA 1996b.

The model is used to assess the nature and the extent of contamination, to identify potential contaminant sources, release mechanisms, exposure pathways, human and/or environmental receptors, and to develop exposure scenarios. Further, this model helps to identify data gaps, determine media to be sampled, and assists staff in developing strategies for data collection. Site history and preliminary survey data generally are extremely useful sources of information for developing this model. The conceptual site model should include known and suspected sources of contamination and the types of contaminants and affected media. Such a model can also illustrate known and potential routes of migration and known or potential human and environmental receptors.

The site should be classified or initially divided into similar areas. Classification may be based on the operational history of the site or observations made during the Site Reconnaissance (see Section 3.5.2). After the site is classified using current and past site characteristics, further divide the site or facility based on anticipated future use. This classification can help to a) assign limited resources to areas that are anticipated to be released without restrictions, and b) identify areas with little or no possibility of unrestricted release. Figure 3.1 shows an example of how a site might be classified in this manner. Further classification of a site may be possible based on site disposition recommendations (unrestricted vs. release with passive controls).

3.6.5 Professional Judgment

In some cases, traditional sources of information, data, models, or scientific principles are unavailable, unreliable, conflicting, or too costly or time consuming to obtain. In these instances professional judgment may be the only practical tool available to the investigator. Professional judgment is the expression of opinion, that is documented in written form and based on technical knowledge and professional experience, assumptions, algorithms, and definitions, as stated by an expert in response to technical problems (NRC 1990). For general applications, this type of judgment is a routine part of scientific investigation where knowledge is incomplete. Professional judgment can be used as an independent review of historical data to support decision making during the HSA. Professional judgment should only be used in situations where data are not reasonably obtainable by collection or experimentation.

The process of recruiting professionals should be documented and as unbiased as possible. The credentials of the selected individual or individuals enhance the credibility of the elicitation, and the ability to communicate their reasoning is a primary determinant of the quality of the results. Qualified professionals can be identified by different sources, including the planning team, professional organizations, government agencies, universities, consulting firms, and public interest groups. The selection criteria for the professionals should include potential conflict of interest (economic or personal), evidence of expertise in a required topic, objectiveness, and availability.

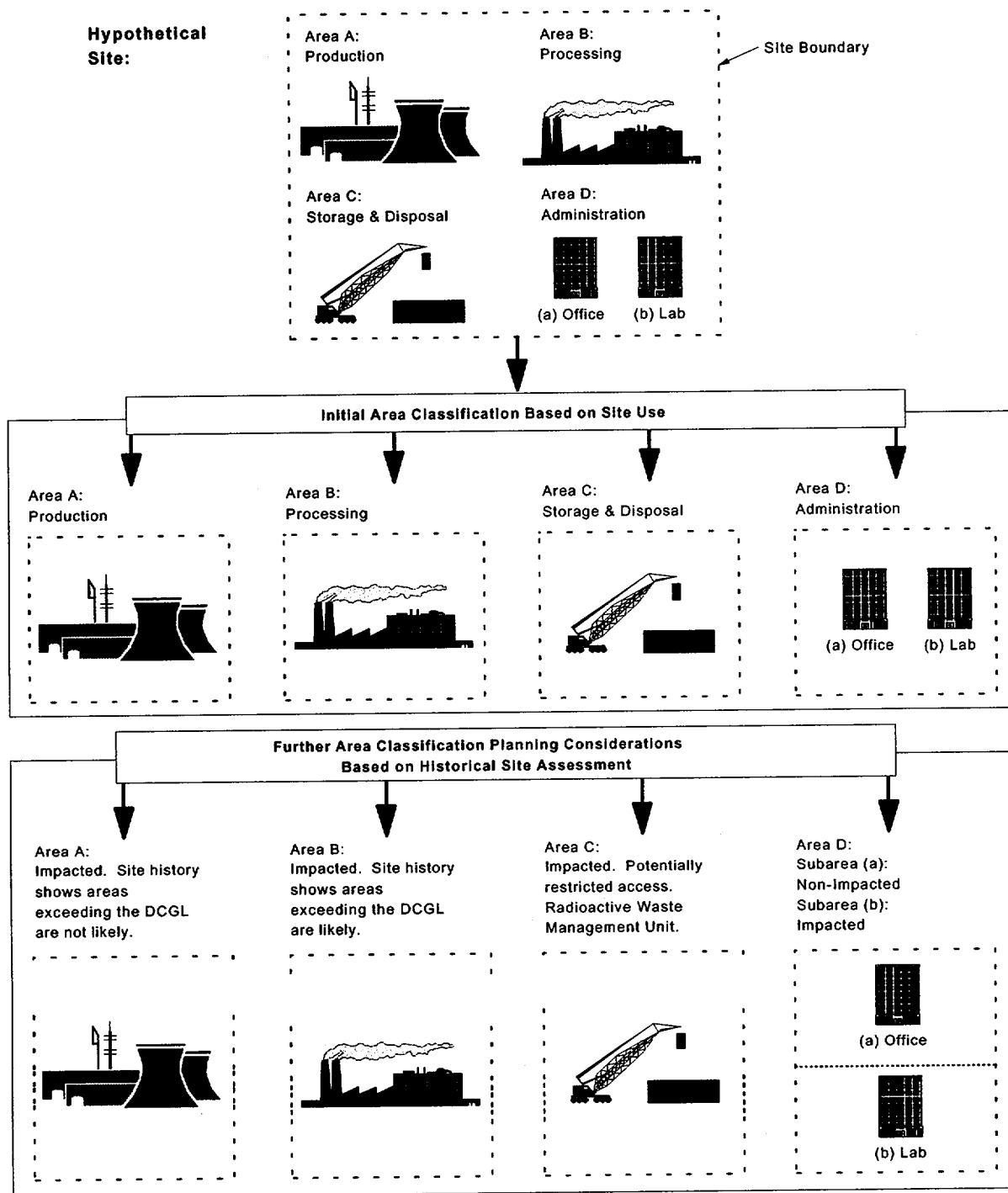


Figure 3.1 Example Showing how a Site Might be Classified Prior to Cleanup Based on the Historical Site Assessment

3.7 Determining the Next Step in the Site Investigation Process

As stated in Section 1.1, the purpose of this manual is to describe a process-oriented approach for demonstrating compliance with the release criterion for residual radioactivity. The highest probability of demonstrating compliance can be obtained by sequentially following each step in the RSSI Process. In some cases, however, performing each step in the process is not practical or necessary. This section provides guidance on how the results of the HSA can be used to determine the next step in the process.

The best method for determining the next step is to review the purpose for each type of survey described in Chapter 5. For example, a scoping survey is performed to provide sufficient information for determining 1) whether present contamination warrants further evaluation and 2) initial estimates of the level of effort for decontamination and preparing a plan for a more detailed survey. If the HSA demonstrates that this information is already available, do not perform a scoping survey. On the other hand, if the information obtained during the HSA is limited, a scoping survey may be necessary to narrow the scope of the characterization survey.

The exception to conducting additional surveys before a final status survey is the use of HSA results to release a site. Generally, the analytical data collected during the HSA are not adequate to statistically demonstrate compliance for impacted areas as described in Chapter 8. This means that the decision to release the site will be based on professional judgment. This determination will ultimately be decided by the responsible regulatory agency.

3.8 Historical Site Assessment Report

A narrative report is generally a useful product for an HSA. Use this report to summarize what is known about the site, what is assumed or inferred, activities conducted during the HSA, and all researched information. Cite a supporting reference for each factual statement given in the report. Attach copies of references (*i.e.*, those not generally available to the public) to the report. The narrative portion of the report should be written in plain English and avoid the use of technical terminology.

To encourage consistency in the content of HSA narratives, both the structure and content of each report should follow the outline shown in Figure 3.2. Additional information not identified in the outline may be requested by the regulatory agency at its discretion. The level of effort to produce the report should reflect the amount of information gathered during the HSA.

3.9 Review of the HSA

The planning team should ensure that someone (a first reviewer) conducts a detailed review of the HSA report for internal consistency and as a quality-control mechanism. A second reviewer with considerable site assessment experience should then examine the entire information package to assure consistency and to provide an independent evaluation of the HSA conclusions. The second reviewer also evaluates the package to determine if special circumstances exist where radioactivity may be present but not identified in the HSA. Both the first reviewer and a second independent reviewer should examine the HSA written products to ensure internal consistency in the report's information, summarized data, and conclusions. The site review ensures that the HSA's recommendations are appropriate.

An important quality assurance objective is to find and correct errors. A significant inconsistency indicating either an error or a flawed conclusion, if undetected, could contribute to an inappropriate recommendation. Identifying such a discrepancy directs the HSA investigator and site reviewers to reexamine and resolve the apparent conflict.

Under some circumstances, experienced investigators may have differing interpretations of site conditions and draw differing conclusions or hypotheses regarding the likelihood of contamination. Any such differences should be resolved during the review. If a reviewer's interpretations contradict those of the HSA investigator, the two should discuss the situation and reach a consensus. This aspect of the review identifies significant points about the site evaluation that may need detailed explanation in the HSA narrative report to fully support the conclusions. Throughout the review, the HSA investigator and site reviewers should keep in mind the need for conservative judgments in the absence of definitive proof to avoid underestimating the presence of contamination, which could lead to an inappropriate HSA recommendation.

| | |
|-------|--|
| 1. | Glossary of Terms, Acronyms and Abbreviations |
| 2. | Executive Summary |
| 3. | Purpose of the Historical Site Assessment |
| 4. | Property Identification |
| 4.1 | Physical Characteristics |
| 4.1.1 | Name - CERCLIS ID# (if applicable), owner/operator name, address |
| 4.1.2 | Location - street address, city, county, state, geographic coordinates |
| 4.1.3 | Topography - USGS 7.5 minute quadrangle or equivalent |
| 4.1.4 | Stratigraphy |
| 4.2 | Environmental Setting |
| 4.2.1 | geology |
| 4.2.2 | hydrogeology |
| 4.2.3 | hydrology |
| 4.2.4 | meteorology |
| 5. | Historical Site Assessment Methodology |
| 5.1 | Approach and Rationale |
| 5.2 | Boundaries of Site |
| 5.3 | Documents Reviewed |
| 5.4 | Property Inspections |
| 5.5 | Personal Interviews |
| 6. | History and Current Usage |
| 6.1 | History - years of operation, type of facility, description of operations, regulatory involvement; permits & licenses, waste handling procedures |
| 6.2 | Current Usage - type of facility, description of operations, probable source types and sizes, description of spills or releases, waste manifests, radionuclide inventories, emergency or removal actions |
| 6.3 | Adjacent Land Usage - sensitive areas such as wetlands or preschools |
| 7. | Findings |
| 7.1 | Potential Contaminants |
| 7.2 | Potential Contaminated Areas |
| 7.2.1 | Impacted Areas—known and potential |
| 7.2.2 | Non-Impacted Areas |
| 7.3 | Potential Contaminated Media |
| 7.4 | Related Environmental Concerns |
| 8. | Conclusions |
| 9. | References |
| 10. | Appendices |
| A. | Conceptual Model and Site Diagram showing Classifications |
| B. | List of Documents |
| C. | Photo documentation Log |
| | Original photographs of the site and pertinent site features |

Figure 3.2 Example of a Historical Site Assessment Report Format

4 PRELIMINARY SURVEY CONSIDERATIONS

4.1 Introduction

This chapter assists the MARSSIM user in designing a survey plan by presenting areas of consideration common to radiation surveys and site investigations in support of decommissioning. The topics discussed here should be addressed during the planning stages of each survey. Figure 4.1 illustrates the sequence of preliminary activities described in this chapter and their relationship to the survey design process.

Conducting radiological surveys in support of decommissioning serves to answer several basic questions, including:

- Is there residual radioactive contamination present from previous uses?
- What is the character (qualitative and quantitative) of the residual activity?
- Is the average residual activity level below the established derived concentration guideline level?
- Are there small localized areas of residual activity in excess of the investigation level?

The survey methods used to evaluate radiological conditions and develop answers to these questions depend on a number of factors including: contaminants, contaminant distribution, acceptable contaminant levels established by the regulatory agency, future site use, and physical characteristics of the site.

4.2 Decommissioning Criteria

The decommissioning process assures that residual radioactivity will not result in individuals being exposed to unacceptable levels of radiation or radioactive materials. Regulatory agencies establish radiation dose standards based on risk considerations and scientific data relating dose to risk. Residual levels of radioactive material that correspond to allowable radiation dose standards are calculated (derived) by analysis of various pathways and scenarios (direct radiation, inhalation, ingestion, *etc.*) through which exposures could occur. These derived levels, known as derived concentration guideline levels (DCGLs), are presented in terms of surface or mass activity concentrations. DCGLs usually refer to average levels of radiation or radioactivity above appropriate background levels. DCGLs applicable to building or other structural and miscellaneous surfaces are expressed in units of activity per surface area (typically Bq/m² or dpm/100 cm²). When applied to soil and induced activity from neutron irradiation, DCGLs are expressed in units of activity per unit of mass (typically Bq/kg or pCi/g).

Preliminary Survey Considerations

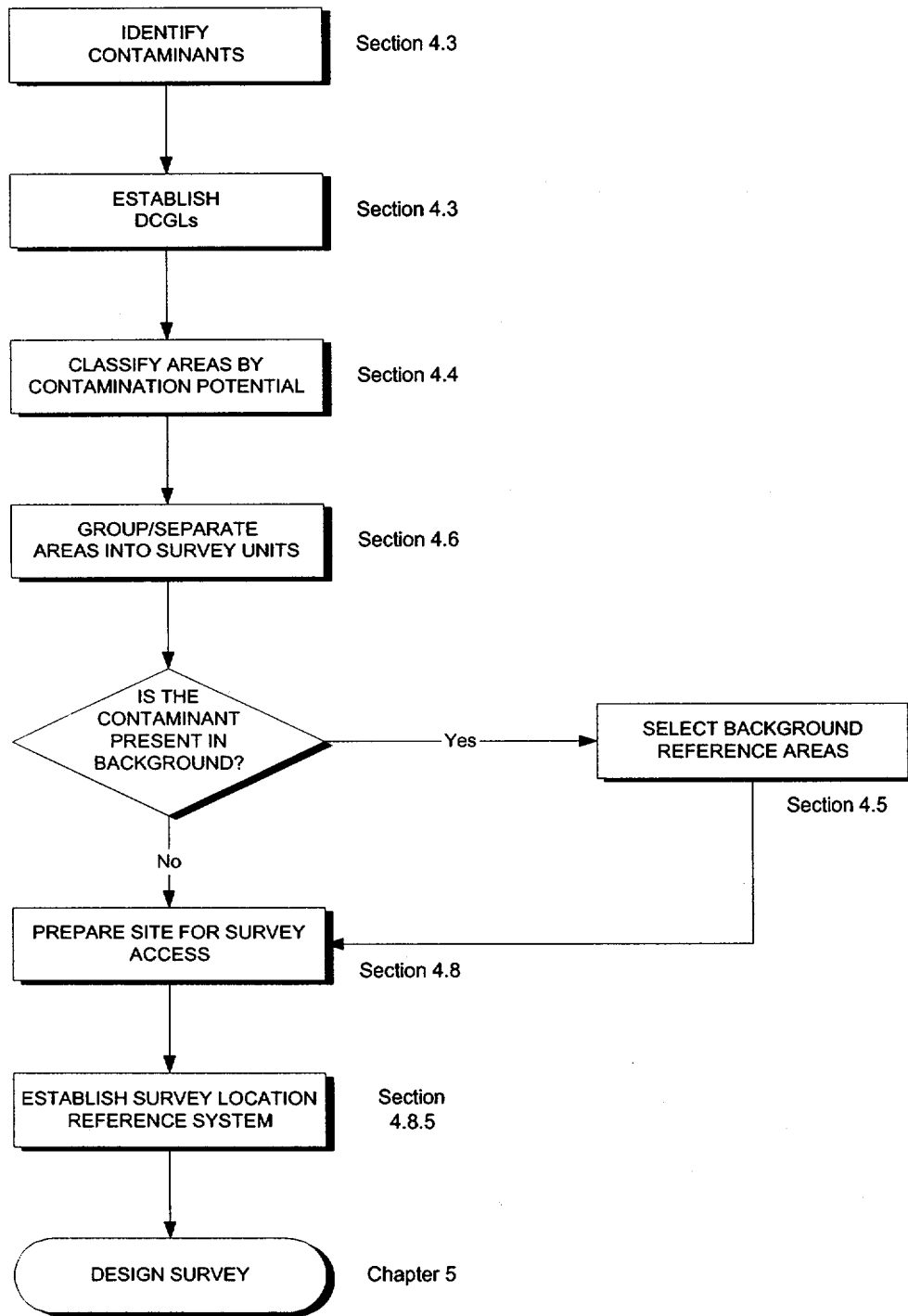


Figure 4.1 Sequence of Preliminary Activities Leading to Survey Design

The DCGL_w, based on pathway modeling, is the uniform residual radioactivity concentration level within a survey unit that corresponds to the release criterion (e.g., regulatory limit in terms of dose or risk). Note that for the majority of MARSSIM users, the DCGL will simply be obtained using regulatory agency guidance based on default parameters—other users may elect to perform site-specific pathway modeling to determine DCGLs. In both cases, the DCGL is based on the spatial distribution of the contaminant, and each derivation can produce different values depending on the specific radionuclide distribution and pathway modeling.

In addition to the numerical DCGLs, criteria include conditions for implementing those guideline levels. Conditions applicable to satisfying decommissioning objectives described in Chapter 5 are as follows:

- The uniform residual contamination above background is below the DCGL_w.
- Individual measurements or samples, representing small areas of residual radioactivity, do not exceed the DCGL_{EMC} for areas of elevated residual radioactivity. These small areas of residual radioactivity may exceed the DCGL_w established for average residual radioactivity levels in a survey unit, provided these areas of residual radioactivity satisfy the criteria of the responsible regulatory agency.

The manner in which a DCGL is applied should be clearly documented in the survey plans and reports.

4.3 Identify Contaminants and Establish DCGLs

Some objectives of the scoping and characterization surveys, as discussed in Chapter 5, include identifying site contaminants, determining relative ratios of contaminants, and establishing DCGLs and conditions for the contaminants which satisfy the requirements of the responsible agency. Identification of potential radionuclide contaminants at the site is generally performed through laboratory analyses, such as alpha and gamma spectrometry. These analyses are used to determine the relative ratios of the identified contaminants, as well as isotopic ratios for common contaminants like uranium and thorium. This information is essential in establishing and applying the DCGLs for the site. DCGLs provide the goal for essentially all aspects of designing, implementing, and evaluating the final status survey. The DCGLs discussed in this manual are limited to structure surfaces and soil contamination; the user should consult the responsible regulatory agency if it is necessary to establish DCGLs for other environmental media (e.g., ground water, and other water pathways). This section contains information regarding the selection and application of DCGLs.

The development of DCGLs is often an iterative process, where the DCGLs selected or developed early in the Radiation Survey and Site Investigation (RSSI) Process are modified as additional site-specific information is obtained from subsequent surveys. One example of the iterative nature of DCGLs is the development of final cleanup levels in EPA's Superfund program. Soil Screening Levels¹ (SSLs; EPA 1996b, EPA 1996c) are selected or developed at a point early in the process, usually corresponding to the scoping survey in MARSSIM. An SSL can be further developed, based on site-specific information, to become a preliminary remediation goal (PRG; EPA 1991h), usually at a point corresponding to the characterization survey. If the PRG is found to be acceptable during the characterization survey, it is documented as the final cleanup level in the Record of Decision (ROD) for the site. The ROD is typically in place prior to any remedial action, because the remedy is also documented in the ROD. Additional information on the Superfund program can be found in Appendix F.

4.3.1 Direct Application of DCGLs

In the simplest case, the DCGLs may be applied directly to survey data to demonstrate compliance. This involves assessing the surface activity levels and volumetric concentrations of radionuclides and comparing measured values to the appropriate DCGL. For example, consider a site that used only one radionuclide, such as ⁹⁰Sr throughout its operational lifetime. The default DCGL for ⁹⁰Sr on building surfaces and in soil may be obtained from the responsible agency. Survey measurements and samples are then compared to the surface and volume activity concentration DCGLs for ⁹⁰Sr directly to demonstrate compliance. While seemingly straightforward, this approach is not always possible (*e.g.*, when more than one radionuclide is present).

4.3.2 DCGLs and the Use of Surrogate Measurements

For sites with multiple contaminants, it may be possible to measure just one of the contaminants and still demonstrate compliance for all of the contaminants present through the use of surrogate measurements. Both time and resources can be saved if the analysis of one radionuclide is simpler than the analysis of the other. For example, using the measured ¹³⁷Cs concentration as a surrogate for ⁹⁰Sr reduces the analytical costs because wet chemistry separations do not have to be performed for ⁹⁰Sr on every sample. In using one radionuclide to measure the presence of others, a sufficient number of measurements, spatially separated throughout the survey unit, should be made to establish a "consistent" ratio. The number of measurements needed to determine the ratio is selected using the Data Quality Objectives (DQO) Process and based on the chemical, physical, and radiological characteristics of the nuclides and the site. If consistent radionuclide

¹ Soil Screening Levels are currently available for chemical contaminants and are not designed for use at sites with radioactive contamination.

ratios cannot be determined during the Historical Site Assessment (HSA) based on existing information, MARSSIM recommends that one of the objectives of scoping or characterization be a determination of the ratios rather than attempting to determine ratios based on the final status survey. If the ratios are determined using final status survey data, MARSSIM recommends that at least 10% of the measurements (both direct measurements and samples) include analyses for all radionuclides of concern.

In the use of surrogates, it is often difficult to establish a “consistent” ratio between two or more radionuclides. Rather than follow prescriptive guidance on acceptable levels of variability for the surrogate ratio, a more reasonable approach may be to review the data collected to establish the ratio and to use the DQO process to select an appropriate ratio from that data. An example is provided to illustrate the application of surrogate measurements.

Ten soil samples within the survey unit were collected and analyzed for ^{137}Cs and ^{90}Sr to establish a surrogate ratio. The ratios of ^{90}Sr to ^{137}Cs were as follows: 6.6, 5.7, 4.2, 7.9, 3.0, 3.8, 4.1, 4.6, 2.4, and 3.3. An assessment of this example data set results in an average ^{90}Sr to ^{137}Cs surrogate ratio of 4.6, with a standard deviation of 1.7. There are various approaches that may be used to develop a surrogate ratio from this data—but each must consider the variability and level of uncertainty in the data. One may consider the variability in the surrogate ratio by selecting the 95% upper bound of the surrogate ratio (to yield a conservative value of ^{90}Sr from the measured ^{137}Cs), which is 8.0 in this case. Similarly, one may select the most conservative value from the data set (7.9). The DQO process should be used to assess the use of surrogates. The benefit of using the surrogate approach is the reduced cost of not having to perform costly wet chemistry analyses on each sample. This benefit should be considered relative to the difficulty in establishing the surrogate ratio, as well as the potential consequence of unnecessary investigations that result from the error in using a “conservative” surrogate ratio. Selecting a conservative surrogate ratio ensures that potential exposures from individual radionuclides are not underestimated. The surrogate method can only be used with confidence when dealing with the same media in the same surroundings—for example, soil samples with similar physical and geological characteristics. The MARSSIM user will need to consult with the responsible regulatory agency for concurrence on the approach used to determine the surrogate ratio.

Once an appropriate surrogate ratio is determined, one needs to consider how compliance will be demonstrated using surrogate measurements. That is, the user must modify the DCGL of the measured radionuclide to account for the inferred radionuclide. Continuing with the above example, the modified DCGL for ^{137}Cs must be reduced according to the following equation:

$$DCGL_{Cs,mod} = DCGL_{Cs} \times \frac{DCGL_{Sr}}{[(C_{Sr}/C_{Cs}) \times DCGL_{Cs}] + DCGL_{Sr}} \quad 4-1$$

where C_{Sr}/C_{Cs} is the surrogate ratio of ^{90}Sr to ^{137}Cs .

Assuming that the $DCGL_{Sr}$ is 15 Bq/kg, the $DCGL_{Cs}$ is 10 Bq/kg, and the surrogate ratio is 8 (as derived previously), the modified $DCGL$ for ^{137}Cs ($DCGL_{Cs, mod}$) can be calculated using Equation 4-1:

$$DCGL_{Cs, mod} = 10 \times \frac{15}{[8 \times 10] + 15} = 1.6 \text{ Bq/kg}$$

This modified $DCGL$ is then used for survey design purposes described in Chapter 5.

The potential for shifts or variations in the radionuclide ratios means that the surrogate method should be used with caution. Physical or chemical differences between the radionuclides may produce different migration rates, causing the radionuclides to separate and changing the radionuclide ratios. Remediation activities have a reasonable potential to alter the surrogate ratio established prior to remediation. MARSSIM recommends that when the ratio is established prior to remediation, additional post-remediation samples should be collected to ensure that the data used to establish the ratio are still appropriate and representative of the existing site condition. If these additional post-remediation samples are not consistent with the pre-remediation data, surrogate ratios should be re-established.

Compliance with surface activity $DCGL$ s for radionuclides of a decay series (e.g., thorium and uranium) that emit both alpha and beta radiation may be demonstrated by assessing alpha, beta, or both radiations. However, relying on the use of alpha surface contamination measurements often proves problematic due to the highly variable level of alpha attenuation by rough, porous, and dusty surfaces. Beta measurements typically provide a more accurate assessment of thorium and uranium contamination on most building surfaces because surface conditions cause significantly less attenuation of beta particles than alpha particles. Beta measurements, therefore, may provide a more accurate determination of surface activity than alpha measurements.

The relationship of beta and alpha emissions from decay chains or various enrichments of uranium should be considered when determining the surface activity for comparison with the $DCGL_w$ values. When the initial member of a decay chain has a long half-life, the radioactivity associated with the subsequent members of the series will increase at a rate determined by the individual half-lives until all members of the decay chain are present at activity levels equal to the activity of the parent. This condition is known as secular equilibrium.

Consider an example where the average surface activity $DCGL_w$ for natural thorium is 1,000 Bq/m² (600 dpm/100 cm²), and all of the progeny are in secular equilibrium—that is, for each disintegration of ^{232}Th there are six alpha and four beta particles emitted in the thorium decay

series. Note that in this example, the surface activity $DCGL_w$ of 1,000 Bq/m² is assumed to apply to the total activity from all members of the decay chain. In this situation, the corresponding alpha activity $DCGL_w$ should be adjusted to 600 Bq/m² (360 dpm/100 cm²), and the corresponding beta activity $DCGL_w$ to 400 Bq/m² (240 dpm/100 cm²), in order to be equivalent to 1,000 Bq/m² of natural thorium surface activity. For a surface activity $DCGL_w$ of 1,000 Bq/m², the beta activity $DCGL_w$ is calculated as follows:

$$\frac{\left(\frac{1,000 \text{ Bq of chain}}{m^2} \right) \times \left(\frac{4 \beta}{\text{dis of Th-232}} \right)}{\frac{10 \text{ Bq of chain}}{1 \text{ Bq of Th-232}}} = \frac{400 \beta \text{ Bq}}{m^2} \quad 4-2$$

To demonstrate compliance with the beta activity $DCGL_w$ for this example, beta measurements (in cpm) must be converted to activity using a weighted beta efficiency that accounts for the energy and yield of each beta particle. For decay chains that have not achieved secular equilibrium, the relative activities between the different members of the decay chain can be determined as previously discussed for surrogate ratios.

Another example for the use of surrogates involves the measurement of exposure rates, rather than surface or volume activity concentrations, for radionuclides that deliver the majority of their dose through the direct radiation pathway. That is, instead of demonstrating compliance with soil or surface contamination DCGLs derived from the direct radiation pathway, compliance is demonstrated by direct measurement of exposure rates. To implement this surrogate method, Historical Site Assessment (HSA) documentation should provide reasonable assurance that no radioactive materials are buried at the site and that radioactive materials have not seeped into the soil or groundwater. This surrogate approach may still be possible for sites that contain radionuclides that *do not* deliver the majority of their dose through the direct radiation pathway. This requires that a consistent relative ratio for the radionuclides that *do* deliver the majority of their dose through the direct radiation pathway can be established. The appropriate exposure rate limit in this case accounts for the radionuclide(s) that *do not* deliver the majority of their dose to the direct radiation pathway. This is accomplished by determining the fraction of the total activity represented by radionuclide(s) that *do* deliver the majority of their dose through the direct radiation pathway, and weighting the exposure rate limit by this fraction. Note that the considerations for establishing consistent relative ratios discussed above apply to this surrogate approach as well. The responsible regulatory agency should be consulted prior to implementing this surrogate approach.

4.3.3 Use of DCGLs for Sites with Multiple Radionuclides

Typically, each radionuclide DCGL corresponds to the release criterion (*e.g.*, regulatory limit in terms of dose or risk). However, in the presence of multiple radionuclides, the total of the DCGLs for all radionuclides would exceed the release criterion. In this case, the individual DCGLs need to be adjusted to account for the presence of multiple radionuclides contributing to the total dose. One method for adjusting the DCGLs is to modify the assumptions made during exposure pathway modeling to account for multiple radionuclides. The surrogate measurements discussed in the previous section describe another method for adjusting the DCGL to account for multiple radionuclides. Other methods include the use of the unity rule and development of a gross activity DCGL for surface activity to adjust the individual radionuclide DCGLs.

The unity rule, represented in the expression below, is satisfied when radionuclide mixtures yield a combined fractional concentration limit that is less than or equal to one:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots \frac{C_n}{DCGL_n} \leq 1 \quad 4-3$$

where

C = concentration
DCGL = guideline value for each individual radionuclide (1, 2, ..., n)

For sites that have a number of significant radionuclides, a higher sensitivity will be needed in the measurement methods as the values of C become smaller. Also, this is likely to affect statistical testing considerations—specifically by increasing the numbers of data points necessary for statistical tests.

4.3.4 Integrated Surface and Soil Contamination DCGLs

Surface contamination DCGLs apply to the total of fixed plus removable surface activity. For cases where the surface contamination is due entirely to one radionuclide, the DCGL for that radionuclide is used for comparison to measurement data (Section 4.3.1).

For situations where multiple radionuclides with their own DCGLs are present, a gross activity DCGL can be developed. This approach enables field measurement of gross activity, rather than determination of individual radionuclide activity, for comparison to the DCGL. The gross activity DCGL for surfaces with multiple radionuclides is calculated as follows:

1. Determine the relative fraction (f) of the total activity contributed by the radionuclide.
2. Obtain the DCGL for each radionuclide present.
3. Substitute the values of f and DCGL in the following equation.

$$\text{Gross Activity DCGL} = \frac{1}{\left(\frac{f_1}{\text{DCGL}_1} + \frac{f_2}{\text{DCGL}_2} + \dots + \frac{f_n}{\text{DCGL}_n} \right)} \quad 4-4$$

Example

Assume that 40% of the total surface activity was contributed by a radionuclide with a DCGL of 8,300 Bq/m² (5000 dpm/100 cm²); 40% by a radionuclide with a DCGL of 1,700 Bq/m² (1000 dpm/100 cm²); and 20% by a radionuclide with a DCGL of 830 Bq/m² (500 dpm/100 cm²). Using Equation 4-4,

$$\begin{aligned} \text{Gross Activity DCGL} &= \frac{1}{\frac{0.40}{8,300} + \frac{0.40}{1,700} + \frac{0.20}{830}} \\ &= 1,900 \text{ Bq/m}^2 \end{aligned}$$

Note that Equation 4-4 may not work for sites exhibiting surface contamination from multiple radionuclides having unknown or highly variable concentrations of radionuclides throughout the site. In these situations, the best approach may be to select the most conservative surface contamination DCGL from the mixture of radionuclides present. If the mixture contains radionuclides that cannot be measured using field survey equipment, laboratory analyses of surface materials may be necessary.

Because gross surface activity measurements are not nuclide-specific, they should be evaluated by the two-sample nonparametric tests described in Chapter 8 to determine if residual contamination meets the release criterion. Therefore, gross surface activity measurements should be performed for both the survey units being evaluated and for background reference areas. The background reference areas for surface activity typically involve building surfaces and construction materials that are considered free of residual radioactivity (see Section 4.5). The total surface activity due to residual contamination should not exceed the gross activity DCGL calculated above.

For soil contamination, it is likely that specific radionuclides, rather than gross activity, will be measured for demonstrating compliance. For radionuclides that are present in natural background, the two-sample nonparametric test described in Section 8.4 should be used to determine if residual soil contamination exceeds the release criterion. The soil contamination due to residual activity should not exceed the DCGL. To account for multiple background radionuclides, the DCGL should be adjusted in a manner similar to the gross activity DCGL described above. For a known mixture of these radionuclides, each having a fixed relative fraction of the total activity, the site-specific DCGLs for each radionuclide may be calculated by first determining the gross activity DCGL and then multiplying that gross DCGL by the respective fractional contribution of each radionuclide. For example, if ^{238}U , ^{226}Ra , and ^{232}Th have DCGLs of 190 Bq/kg (5.0 pCi/g), 93 Bq/kg (2.5 pCi/g), and 37 Bq/kg (1.0 pCi/g) and activity ratios of 40%, 40%, and 20%, respectively, Equation 4-4 can be used to calculate the gross activity DCGL.

$$\text{Gross Activity DCGL} = \frac{1}{\frac{0.40}{190} + \frac{0.40}{93} + \frac{0.20}{37}}$$

$$= 85 \text{ Bq/kg}$$

The adjusted DCGLs for each of the contributory radionuclides, when present in the given activity ratios, are then 34 Bq/kg (0.40×85) for ^{238}U , 34 Bq/kg (0.40×85) for ^{226}Ra , and 17 Bq/kg (0.20×85) for ^{232}Th . Determining gross activity DCGLs to demonstrate compliance enables an evaluation of site conditions based on analysis for only one of the contributory contaminants (surrogate approach), provided the relative ratios of the contaminants do not change.

For situations where the background radionuclides occurring in background have unknown or variable relative concentrations throughout the site, it may be necessary to perform the two-sample nonparametric tests separately for each radionuclide present. The unity rule should be used to determine that the sum of each radionuclide concentration divided by its DCGL is less than or equal to one.

Therefore, at each measurement location calculate the quantity:

$$\frac{C_1}{DCGL_1} + \frac{C_2}{DCGL_2} + \dots + \frac{C_n}{DCGL_n} \quad 4-5$$

where C is the radionuclide concentration.

The values of C are the data to be used in the statistical tests to determine if the average over the survey unit exceeds one.

The same approach applies for radionuclides that are not present in background, with the exception that the one-sample nonparametric statistical test described in Section 8.3 is used in place of the two-sample nonparametric test (see Section 5.5.2.3). Again, for multiple radionuclides either the surrogate approach or the unity rule should be used to demonstrate compliance, if relative ratios are expected to change.

4.4 Classify Areas by Contamination Potential

All areas of the site will not have the same potential for residual contamination and, accordingly, will not need the same level of survey coverage to achieve the established release criteria. The process will be more efficient if the survey is designed so areas with higher potential for contamination (based in part on results of the HSA in Chapter 3) will receive a higher degree of survey effort.

Classification is a critical step in the survey design process. The working hypothesis of MARSSIM is that all impacted areas being evaluated for release have a potential for radioactive contamination above the DCGL. This initial assumption means that all areas are initially considered Class 1 areas unless some basis for reclassification as non-impacted, Class 3, or Class 2 is provided.

Areas that have no reasonable potential for residual contamination do not need any level of survey coverage and are designated as non-impacted areas. These areas have no radiological impact from site operations and are typically identified during the HSA (Chapter 3). Background reference areas are normally selected from non-impacted areas (Section 4.5).

Impacted areas are areas that have some potential for containing contaminated material. They can be subdivided into three classes:

- Class 1 areas: Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys). Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, 4) waste storage sites, and 5) areas with contaminants in discrete solid pieces of material high specific activity. Note that areas containing contamination in excess of the $DCGL_w$ prior to remediation should be classified as Class 1 areas.

Preliminary Survey Considerations

- Class 2 areas: These areas have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL_w. To justify changing an area's classification from Class 1 to Class 2, the existing data (from the HSA, scoping surveys, or characterization surveys) should provide a high degree of confidence that no individual measurement would exceed the DCGL_w. Other justifications for this change in an area's classification may be appropriate based on the outcome of the DQO process. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (e.g., process facilities), 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper walls and ceilings of some buildings or rooms subjected to airborne radioactivity, 5) areas where low concentrations of radioactive materials were handled, and 6) areas on the perimeter of former contamination control areas.
- Class 3 areas: Any impacted areas that are not expected to contain any residual radioactivity, or are expected to contain levels of residual radioactivity at a small fraction of the DCGL_w, based on site operating history and previous radiological surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and, therefore, receive the highest degree of survey effort, followed by Class 2 and then Class 3 areas.

The criteria used for designating areas as Class 1, 2, or 3 should be described in the final status survey plan. Compliance with the classification criteria should be demonstrated in the final status survey report. A thorough analysis of HSA findings (Chapter 3) and the results of scoping and characterization surveys provide the basis for an area's classification. As a survey progresses, reevaluation of this classification may be necessary based on newly acquired survey data. For example, if contamination is identified in a Class 3 area, an investigation and reevaluation of that area should be performed to determine if the Class 3 area classification is appropriate. Typically, the investigation will result in part or all of the area being reclassified as Class 1 or Class 2. If survey results identify residual contamination in a Class 2 area exceeding the DCGL or suggest that there may be a reasonable potential that contamination is present in excess of the DCGL, an investigation should be initiated to determine if all or part of the area should be reclassified to Class 1. More information on investigations and reclassifications is provided in Section 5.5.3.

4.5 Select Background Reference Areas

Certain radionuclides may also occur at significant levels as part of background in the media of interest (soil, building material, *etc.*). Examples include members of the naturally-occurring uranium, thorium, and actinium series; ^{40}K ; ^{14}C ; and tritium. ^{137}Cs and other radionuclides are also present in background as a result of nuclear weapons fallout (Wallo, *et al.*, 1994). Establishing background concentrations that describe a distribution of measurement data is necessary to identify and evaluate contributions attributable to site operations. Determining background levels for comparison with the conditions determined in specific survey units entails conducting surveys in one or more reference areas to define the radiological conditions of the site. NUREG-1505 (NRC 1997a) provides additional information on background reference areas.

A site background reference area should have similar physical, chemical, geological, radiological, and biological characteristics as the survey unit being evaluated. Background reference areas are normally selected from non-impacted areas, but are not limited to natural areas undisturbed by human activities. In some situations, a reference area may be associated with the survey unit being evaluated, but cannot be potentially contaminated by site activities. For example, background measurements may be taken from core samples of a building or structure surface, pavement, or asphalt. This option should be discussed with the responsible regulatory agency during survey planning. Generally, reference areas should not be part of the survey unit being evaluated.

Reference areas provide a location for background measurements which are used for comparisons with survey unit data. The radioactivity present in a reference area would be ideally the same as the survey unit had it never been contaminated. If a site includes physical, chemical, geological, radiological, or biological variability that is not represented by a single reference background area, selecting more than one reference area may be necessary.

It may be difficult to find a reference area within an industrial complex for comparison to a survey unit if the radionuclides of potential concern are naturally occurring. Background may vary greatly due to different construction activities that have occurred at the site. Examples of construction activities that change background include: leveling; excavating; adding fill dirt; importing rocks or gravel to stabilize soil or underlay asphalt; manufacturing asphalt with different matrix rock; using different pours of asphalt or concrete in a single survey unit; layering asphalt over concrete; layering different thicknesses of asphalt, concrete, rock, or gravel; and covering or burying old features such as railroad beds or building footings. Background variability may also increase due to the concentration of fallout in low areas of parking lots where runoff water collects and evaporates. Variations in background of a factor of five or more can occur in the space of a few hectares.

There are a number of possible actions to address these concerns. Reviewing and reassessing the selection of reference areas may be necessary. Selecting different reference areas to represent individual survey units is another possibility. More attention may also be needed in selecting survey units and their boundaries with respect to different areas of potential or actual background variability. More detailed scoping or characterization surveys may be needed to better understand background variability. Using radionuclide-specific measurement techniques instead of gross radioactivity measurement techniques may also be necessary. If a background reference area that satisfies the above recommendations is not available, consultation and negotiation with the responsible regulatory agency is recommended. Alternate approaches may include using published studies of radionuclide distributions.

Verifying that a particular background reference area is appropriate for a survey can be accomplished using the techniques described or referenced in Chapter 8. Verification provides assurance that assumptions used to design the survey are appropriate and defensible. This approach can also prevent decision errors that may result from selecting an inappropriate background reference area.

If the radionuclide contaminants of interest do not occur in background, or the background levels are known to be a small fraction of the DCGL_w (e.g., <10%), the survey unit radiological conditions may be compared directly to the specified DCGL and reference area background surveys are not necessary. If the background is not well defined at a site, and the decision maker is willing to accept the increased probability of incorrectly failing to release a survey unit (Type II error), the reference area measurements can be eliminated and a one-sample statistical test performed as described in Section 8.3.

4.6 Identify Survey Units

A survey unit is a physical area consisting of structures or land areas of specified size and shape for which a separate decision will be made as to whether or not that area exceeds the release criterion. This decision is made as a result of the final status survey. As a result, the survey unit is the primary entity for demonstrating compliance with the release criterion.

To facilitate survey design and ensure that the number of survey data points for a specific site are relatively uniformly distributed among areas of similar contamination potential, the site is divided into survey units that share a common history or other characteristics, or are naturally distinguishable from other portions of the site. A site may be divided into survey units at any time before the final status survey. For example, HSA or scoping survey results may provide sufficient justification for partitioning the site into Class 1, 2, or 3 areas. Note, however, that dividing the site into survey units is critical only for the final status survey—scoping, characterization, and remedial action support surveys may be performed without dividing the site into survey units.

A survey unit should not include areas that have different classifications. The survey unit's characteristics should be generally consistent with exposure pathway modeling that is used to convert dose or risk into radionuclide concentrations. For indoor areas classified as Class 1, each room may be designated as a survey unit. Indoor areas may also be subdivided into several survey units of different classification, such as separating floors and lower walls from upper walls and ceilings (and other upper horizontal surfaces) or subdividing a large warehouse based on floor area.

Survey units should be limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. The suggested areas for survey units are as follows:

| <u>Classification</u> | <u>Suggested Area</u> |
|-----------------------|-------------------------------------|
| Class 1 | |
| Structures | up to 100 m ² floor area |
| Land areas | up to 2,000 m ² |
| Class 2 | |
| Structures | 100 to 1,000 m ² |
| Land areas | 2,000 to 10,000 m ² |
| Class 3 | |
| Structures | no limit |
| Land areas | no limit |

The limitation on survey unit size for Class 1 and Class 2 areas ensures that each area is assigned an adequate number of data points. The rationale for selecting a larger survey unit area should be developed using the DQO Process (Section 2.3) and fully documented. Because the number of data points (determined in Sections 5.5.2.2 or 5.5.2.3) is independent of the survey unit size, disregarding locating small areas of elevated activity, the survey coverage in an area is determined by dividing the fixed number of data points obtained from the statistical tests by the survey unit area. That is, if the statistical test estimates that 20 data points are necessary to demonstrate compliance, then the survey coverage is determined by dividing 20 by the area over which the data points are distributed.

Special considerations may be necessary for survey units with structure surface areas less than 10 m² or land areas less than 100 m². In this case, the number of data points obtained from the statistical tests is unnecessarily large and not appropriate for smaller survey unit areas. Instead, some specified level of survey effort should be determined based on the DQO process and with the concurrence of the responsible regulatory agency. The data generated from these smaller survey units should be obtained based on judgment, rather than on systematic or random design, and compared individually to the DCGLs.

4.7 Select Instruments and Survey Techniques

Based on the potential radionuclide contaminants, their associated radiations, and the types of residual contamination categories (*e.g.*, soil, structure surfaces) to be evaluated, the detection sensitivities of various instruments and techniques are determined and documented. Instruments should be identified for each of the three types of measurements: 1) scans, 2) direct measurements, and 3) laboratory analysis of samples. In some cases, the same instrument (*e.g.*, sodium iodide detector) or same type of instrument (*e.g.*, gas-flow proportional counter) may be used for performing several types of measurements. Once the instruments are selected, appropriate survey techniques and standard operating procedures (SOPs) should be developed and documented. The survey techniques describe how the instrument will be used to perform the required measurements.

Chapter 6 of this manual, NRC report NUREG-1507 (NRC 1997b), and draft NRC report NUREG-1506 (NRC 1995) discuss the concept of detection sensitivities and provide guidance on determining sensitivities and selecting appropriate measurement methods. Chapter 6 also discusses instruments and survey techniques for scans and direct measurements, while Chapter 7 provides guidance on sampling and laboratory analysis. Appendix H describes typical field and laboratory equipment plus associated cost and instrument sensitivities.

4.7.1 Selection of Instruments

Choose reliable instruments that are suited to the physical and environmental conditions at the site and capable of detecting the radiations of concern to the appropriate minimum detectable concentration (MDC). During survey design, it is generally considered good practice to select a measurement system with an MDC between 10-50% of the DCGL. Sometimes this goal may not be achievable based on site-specific conditions (*e.g.*, best available technology, cost restrictions).

The MDC is calculated based on an hypothesis test for individual measurements (see Section 6.7), and results below the MDC are variable and lead to a high value for σ of the measured values in the survey unit or reference area. This high value for σ can be accounted for using the statistical tests described in Chapter 8 for the final status survey, but a large number of measurements are needed to account for the variability. σ is defined as the standard deviation of the measurements in the survey unit.

Early in decommissioning, during scoping and characterization, low MDCs help in the identification of areas that can be classified as non-impacted or Class 3 areas. These decisions are usually based on fewer numbers of samples, and each measurement is evaluated individually. Using an optimistic estimation of the MDC (see Section 2.3.5) for these surveys may result in the misclassification of a survey unit and cleaning up an uncontaminated area or performing a final status survey in a contaminated area. Selecting a measurement technique with a well defined

MDC or a conservative estimate of the MDC ensures the usefulness of the data for making decisions for planning the final status survey. For these reasons, MARSSIM recommends that a realistic or conservative estimate of the MDC be used instead of an optimistic estimate. A conservative estimate of the MDC uses reasonably conservative values for parameters with a high level of uncertainty, and results in a MDC value that is higher than a non-conservative or optimistic estimate.

The instrument should be calibrated for the radiations and energies of interest at the site. This calibration should be traceable to an accepted standards organization such as the National Institute of Science and Technology (NIST). Routine operational checks of instrument performance should be conducted to assure that the check source response is maintained within acceptable ranges and that any changes in instrument background are not attributable to contamination of the detector. If the radionuclide contaminants cannot be detected at desired levels by direct measurement (Section 6.7), the portion of the survey dealing with measurements at discrete locations should be designed to rely primarily on sampling and laboratory analysis (Chapter 7).

Assuming the contaminants can be detected, either directly or by measuring a surrogate radionuclide in the mixture, the next decision point depends on whether the radionuclide being measured is present in background. Gross measurement methods will likely be more appropriate for measuring surface contamination in structures, scanning for locations of elevated activity, and determining exposure rates. Nuclide-specific measurement techniques, such as gamma spectrometry, provide a marked increase in detection sensitivity over gross measurements because of their ability to screen out contributions from other sources. Figure 4.2 illustrates the sequence of steps in determining if direct measurement techniques can be applied at a particular site, or if laboratory analysis is more appropriate. Scanning surveys are typically performed at all sites. The selection of appropriate instruments for scanning, direct measurement, and sampling and analysis should be survey specific.

4.7.2 Selection of Survey Techniques

In practice, the DQO process is used to obtain a proper balance among the use of various measurement techniques. In general, there is an inverse correlation between the cost of a specific measurement technique and the detection levels being sought. Depending on the survey objectives, important considerations include survey costs and choosing the optimum instrumentation and measurement mix.

A certain minimum number of direct measurements or samples will be needed to demonstrate compliance with the release criterion based on the nonparametric statistical tests (see Section 5.5.2). In addition, the potential for areas of elevated contamination will have to be considered for designing scanning surveys. Areas of elevated activity may also affect the number of measurements; however, scanning with survey instruments should generally be sufficient to

Preliminary Survey Considerations

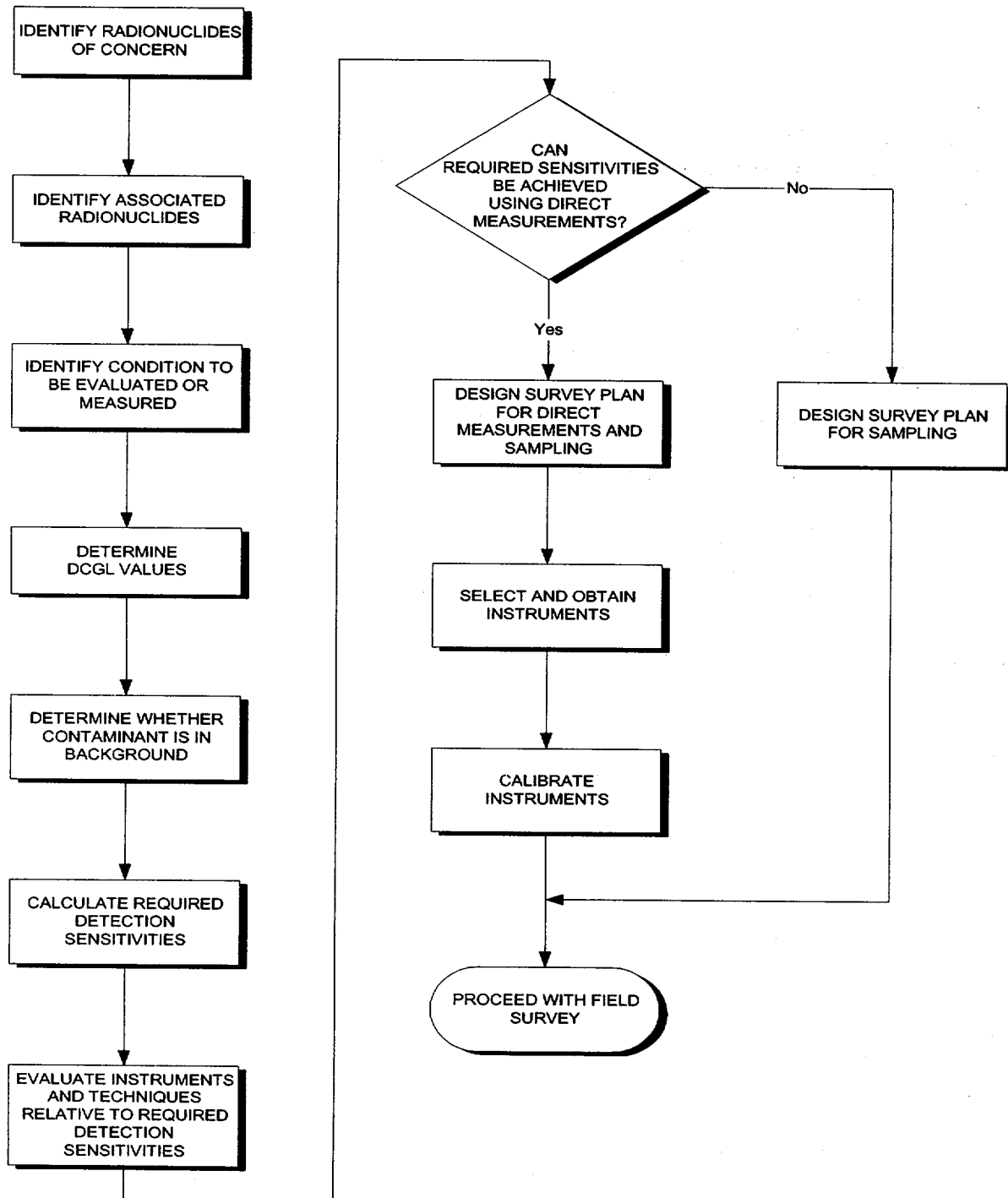


Figure 4.2 Flow Diagram for Selection of Field Survey Instrumentation for Direct Measurements and Analysis of Samples (Refer to Section 4.7)

ensure that no areas with unusually high levels of radioactivity are left in place. Some measurements may also provide information of a qualitative nature to supplement other measurements. An example of such an application is *in situ* gamma spectrometry to demonstrate the absence (or presence) of specific contaminants.

Table 4.1 presents a list of common contaminants along with recommended survey methods that have proven to be effective based on past survey experience in the decommissioning industry. This table provides a general indication of the detection capability of commercially-available instruments. As such, Table 4.1 may be used to provide an initial evaluation of instrument capabilities for some common radionuclides at the example DCGLs listed in the table. For example, consider the contamination of a surface with ^{241}Am . Table 4.1 indicates that ^{241}Am is detectable at the example DCGLs, and that viable direct measurement instruments include gas-flow proportional (α mode) and alpha scintillation detectors. Table 4.1 should not be interpreted as providing specific values for an instrument's detection sensitivity, which is discussed in Section 6.7. In addition, NRC draft report NUREG-1506 (NRC 1995) provides further information on factors that may affect survey instrumentation selection.

4.7.3 Criteria for Selection of Sample Collection and Direct Measurement Methods

Sample characteristics such as sample depth, volume, area, moisture level, and composition, as well as sample preparation techniques which may alter the sample, are important planning considerations for Data Quality Objectives. Sample preparation may include, but is not limited to, removing extraneous material, homogenizing, splitting, drying, compositing, and final preparation of samples. As is the case for determining survey unit characteristics, the physical sample characteristics and sampling method should be consistent with the dose or risk pathway modeling that is used to determine radionuclide DCGL's. If a direct measurement method is used, it should also be consistent with the pathway modeling.

For example, a sample depth of 15 cm (6 in.) for soil samples might be specified during the DQO process for a final status survey because this corresponds to the soil mixing or plow depth in several environmental pathway models (Yu *et al.*, 1993, NRC 1992b). If contamination exists at a depth less than this, a number of models uniformly mix it throughout this depth to simulate the soil mixing associated with plowing. Similarly, models may be based on dry weight, which may necessitate either drying samples or data transformation to account for dry weight.

The DQOs and subsequent direction to the laboratory for analysis might include removal of material not relevant for characterizing the sample, such as pieces of glass, twigs, or leaves. Table 4.2 provides examples of how a particular field soil composition of fine-, medium-, and coarse-grained materials might determine laboratory analysis DQOs for particular radionuclides. Fine materials consist of clay (less than 0.002 mm) and silt (0.002 to 0.062 mm). Medium materials consist of sand, which can be further divided into very fine, fine, medium, coarse, and very coarse sand. Coarse materials consist of gravel, which is composed of pebbles (2 to 64 mm), cobbles (64 to 256 mm), and boulders (greater than 256 mm) (Friedman 1978).

Table 4.1 Selection of Direct Measurement Techniques Based on Experience

| Nuclide | Structure Surfaces | | Land Areas | | Direct Measurement Instruments ² | | |
|---|---|------------|--------------------------------------|-----------------|---|----------------|-------------------|
| | Example DCGL ¹ (Bq/m ²) | Detectable | Example DCGL ¹ (Bq/kg) | Detectable | Surface Activity | Soil Activity | Exposure Rate |
| ³ H | 1.6x10 ⁶ | No | 1.5x10 ⁴ | No | ND ⁶ | ND | ND |
| ¹⁴ C | 4.7x10 ⁵ | Yes | 1.4x10 ³ | No | GPB | ND | ND |
| ⁵⁴ Mn | 1.3x10 ⁴ | Yes | 450 | Yes | GPB⁷ ,GM | γS,ISγ | PIC,γS,ISγ |
| ⁵⁵ Fe | 1.8x10 ⁶ | No | 4.1x10 ⁵ | No ⁵ | ND | ND(ISγ) | ND(ISγ) |
| ⁶⁰ Co | 3.1x10 ³ | Yes | 110 | Yes | GPB ,GM | γS,ISγ | PIC,γS,ISγ |
| ⁶³ Ni | 1.5x10 ⁶ | Yes | 2.8x10 ⁵ | No | GPB | ND | ND |
| ⁹⁰ Sr | 6.0x10 ³ | Yes | 420 | No ⁵ | GPB ,GM | ND (GM,GPB) | ND |
| ⁹⁹ Tc | 6.4x10 ⁵ | Yes | 1.9x10 ³ | No | GPB ,GM | ND | ND |
| ¹³⁷ Cs | 8.2x10 ³ | Yes | 400 | Yes | GPB ,GM | γS,ISγ | PIC,γS,ISγ |
| ¹⁵² Eu | 6.6x10 ³ | Yes | 240 | Yes | GPB ,GM | γS,ISγ | PIC,γS,ISγ |
| ²²⁶ Ra (C) ³ | 970 | Yes | 210 | Yes | GPα,αS | γS,ISγ | PIC,γS,ISγ |
| ²³² Th (C) ³ | 340 | Yes | 320 | Yes | GPα,αS,GPB | γS,ISγ | PIC,γS,ISγ |
| U ⁴ | 560 | Yes | 710 | Yes | GPα,αS,GPB,ISγ | γS,ISγ, GPB | PIC,γS,ISγ |
| ²³⁹ Pu, ²⁴⁰ Pu, ²⁴¹ Pu | 120 | Yes | 70 | No ⁵ | GPα,αS | ND (ISγ) | ND |
| ²⁴¹ Am | 110 | Yes | 70 | Yes | GPα,αS | γS,ISγ | PIC,γS,ISγ |

¹ Example DCGLs based on values given in NRC draft report NUREG-1500 (NRC 1994c).

² GPα = Gas-flow proportional counter (α mode)

GM = Geiger-Mueller survey meter

GPβ = Gas-flow proportional counter (β mode)

PIC = Pressurized ionization chamber

αS = Alpha scintillation survey meter

γS = gamma scintillation (gross)

ISγ = *in situ* gamma spectrometry

³ For decay chains having two or more radionuclides of significant half-life that reach secular equilibrium.

The notation "(c)" indicates the direct measurement techniques assume the presence of progeny in the chain.

⁴ Depleted, natural, and enriched.

⁵ Possibly detectable at limits for areas of elevated activity.

⁶ Not detectable.

⁷ Bold indicates the preferred method where alternative methods are available.

Table 4.2 Example of DQO Planning Considerations

Separate out and evaluate fine-grain material because resuspension is associated with the fine grain fraction for the air pathway.

If contamination resides on sand, pebbles, and cobbles, analyze these materials for direct exposure pathway and analyze the fine-grain fraction for the air pathway.

Separation and homogenization are not necessary for analyses because direct exposure pathway depends upon the average concentration and presence of cobbles will usually not impact laboratory analysis.

Determine if pathway modeling considered the presence of cobbles.

Separate, homogenize, and evaluate fine-grain material because plant root uptake is associated with the fine-grain fraction for the plant ingestion pathway.

Separate, homogenize, and evaluate fine-grain materials because of their relevance for the contaminant source term for contaminant migration to the sub-surface for the water pathway.

Both sample depth and area are considerations in determining appropriate sample volume, and sample volume is a key consideration for determining the laboratory MDC. The depth should also correlate with the conceptual model developed in Chapter 3 and upgraded throughout the Radiation Survey and Site Investigation (RSSI) Process. For example, if data collected during the Historical Site Assessment indicate contamination may exist to a depth of greater than 15 cm (6 in.), then samples should be deep enough to support the survey objectives, such as for the scoping or characterization survey. Taking samples as a function of depth might also be a survey design objective, such as for scoping, characterization, or remediation support.

The depth and area of the sample should be recorded as well as any observations, such as the presence of materials noted during sampling. Chapter 6 and Chapter 7 present more detail regarding the application of these survey planning considerations.

4.8 Site Preparation

Site preparation involves obtaining consent for performing the survey, establishing the property boundaries, evaluating the physical characteristics of the site, accessing surfaces and land areas of interest, and establishing a reference coordinate system. Site preparation may also include removing equipment and materials that restrict access to surfaces. The presence of furnishings or equipment will restrict access to building surfaces and add additional items that the survey should address.

4.8.1 Consent for Survey

When facilities or sites are not owned by the organization performing the surveys, consent from the site or equipment owner should be obtained before conducting the surveys. All appropriate local, State, and Federal officials as well as the site owner and other affected parties should be notified of the survey schedule. Section 3.5 discusses consent for access, and additional guidance based on the CERCLA program is available from EPA (EPA 1987d).

4.8.2 Property Boundaries

Property boundaries may be determined from property survey maps furnished by the owners or from plat maps obtained from city or county tax maps. Large-area properties and properties with obscure boundaries or missing survey markers may require the services of a professional land surveyor.

If the radiological survey is only performed inside buildings, a tax map with the buildings accurately located will usually suffice for site/building location designation.

4.8.3 Physical Characteristics of Site

The physical characteristics of the site will have a significant impact on the complexity, schedule, and cost of a survey. These characteristics include the number and size of structures, type of building construction, wall and floor penetrations, pipes, building condition, total area, topography, soil type, and ground cover. In particular, the accessibility of structures and land areas (Section 4.8.4) has a significant impact on the survey effort. In some cases survey techniques (*e.g.*, *in situ* gamma spectrometry discussed in Chapter 6) can preclude or reduce the need to gain physical access or use intrusive techniques. This should be considered during survey planning.

4.8.3.1 Structures

Building design and condition will have a marked influence on the survey efforts. The time involved in conducting a survey of building interior surfaces is essentially directly proportional to the total surface area. For this reason the degree of survey coverage decreases as the potential for residual activity decreases. Judgment measurements and sampling, which are performed in addition to the measurements performed for the nonparametric tests, are recommended in areas likely to have accumulated deposits of residual activity. As discussed in Section 5.5.3.3 and Section 8.5, judgment measurements and samples are compared directly to the appropriate DCGL.

The condition of surfaces after decontamination may affect the survey process. Removing contamination that has penetrated a surface usually involves removing the surface material. As a result, the floors and walls of decontaminated facilities are frequently badly scarred or broken up and are often very uneven. Such surfaces are more difficult to survey because it is not possible to maintain a fixed distance between the detector and the surface. In addition, scabbled or porous surfaces may significantly attenuate radiations—particularly alpha and low-energy beta particles. Use of monitoring equipment on wheels is precluded by rough surfaces, and such surfaces also pose an increased risk of damage to fragile detector probe faces. These factors should be considered during the calibration of survey instruments; NRC report NUREG-1507 (NRC 1997b) provides additional information on how to address these surface conditions. The condition of the building should also be considered from a safety and health standpoint before a survey is conducted. A structural assessment may be needed to determine whether the structure is safe to enter.

Expansion joints, stress cracks, and penetrations into floors and walls for piping, conduit, and anchor bolts, *etc.*, are potential sites for accumulation of contamination and pathways for migration into subfloor soil and hollow wall spaces. Drains, sewers, and septic systems can also become contaminated. Wall/floor interfaces are also likely locations for residual contamination. Coring, drilling, or other such methods may be necessary to gain access for survey. Intrusive surveying may require permitting by local regulatory authorities. Suspended ceilings may cover areas of potential contamination such as ventilation ducts and fixtures.

Exterior building surfaces will typically have a low potential for residual contamination, however, there are several locations that should be considered during survey planning. If there are roof exhausts, roof accesses that allow for radioactive material movement, or the facility is proximal to the air effluent discharge points, the possibility of roof contamination should be considered. Because roofs are periodically resurfaced, contaminants may be trapped in roofing material, and sampling this material may be necessary. Roof drainage points such as driplines along overhangs, downspouts, and gutters are also important survey locations. Wall penetrations for process equipment, piping, and exhaust ventilation are potential locations for exterior contamination.

Window ledges and outside exits (doors, doorways, landings, stairways, *etc.*) are also building exterior surfaces that should be addressed.

4.8.3.2 Land Areas

Depending upon site processes and operating history, the radiological survey may include varying portions of the land areas. Potentially contaminated open land or paved areas to be considered include storage areas (*e.g.*, equipment, product, waste, and raw material), liquid waste collection lagoons and sumps, areas downwind (based on predominant wind directions on an average annual basis, if possible) of stack release points, and surface drainage pathways. Additionally, roadways and railways that may have been used for transport of radioactive or contaminated materials that may not have been adequately contained could also be potentially contaminated.

Buried piping, underground tanks, sewers, spill areas, and septic leach fields that may have received contaminated liquids are locations of possible contamination may necessitate sampling of subsurface soil (Section 7.5.3). Information regarding soil type (*e.g.*, clay, sand) may provide insight into the retention or migration characteristics of specific radionuclides. The need for special sampling by coring or split-spoon equipment should be anticipated for characterization surveys.

If radioactive waste has been removed, surveys of excavated areas will be necessary before backfilling. If the waste is to be left in place, subsurface sampling around the burial site perimeter to assess the potential for future migration may be necessary.

Additionally, potentially contaminated rivers, harbors, shorelines, and other outdoor areas may require survey activities including environmental media (*e.g.*, sediment, marine biota) associated with these areas.

4.8.4 Clearing to Provide Access

In addition to the physical characteristics of the site, a major consideration is how to address inaccessible areas that have a potential for residual radioactivity. Inaccessible areas may need significant effort and resources to adequately survey. This section provides a description of common inaccessible areas that may have to be considered. The level of effort expended to access these difficult-to-reach areas should be commensurate with the potential for residual activity. For example, the potential for the presence of residual activity behind walls should be established before significant effort is expended to remove drywall.

4.8.4.1 Structures

Structures and indoor areas should be sufficiently cleared to permit completion of the survey. Clearing includes providing access to potentially contaminated interior surfaces (*e.g.*, drains, ducting, tanks, pits, ceiling areas, and equipment) by removing covers, disassembly, or other means of producing adequate openings.

Building features such as ceiling height, construction materials, ducts, pipes, *etc.*, will determine the ease of accessibility of various surfaces. Scaffolding, cranes, lifts, or ladders may be necessary to reach some surfaces, and dismantling portions of the building may be required.

The presence of furnishings and equipment will restrict access to building surfaces and add additional items that the survey should address. Remaining equipment indirectly involved in the process may need to be dismantled in order to evaluate the radiological status, particularly of inaccessible parts of the equipment. Removing or relocating certain furnishings, such as lab benches and hoods, to obtain access to potentially contaminated floors and walls may also be necessary. The amount of effort and resources dedicated to such removal or relocation activities should be commensurate with the potential for contamination. Where the potential is low, a few spot-checks may be sufficient to provide confidence that covered areas are free of contamination. In other cases, complete removal may be warranted.

Piping, drains, sewers, sumps, tanks, and other components of liquid handling systems present special difficulties because of the inaccessibility of interior surfaces. Process information, operating history, and preliminary monitoring at available access points will assist in evaluating the extent of sampling and measurements included in the survey.

If the building is constructed of porous materials (*e.g.*, wood, concrete) and the surfaces were not sealed, contamination may be found in the walls, floors, and other surfaces. It may be necessary to obtain cores of these surfaces for laboratory analysis.

Another accessibility problem is the presence of contamination beneath tile or other floor coverings. This often occurs because the covering was placed over contaminated surfaces, or the joints in tile were not sealed to prevent penetration. The practice in some facilities has been to "fix" contamination (particularly alpha emitters) by painting over the surface of the contaminated area. Thus, actions to obtain access to potentially contaminated surfaces, such as removing wall and floor coverings (including paint, wax, or other sealer) and opening drains and ducts, may be necessary to enable representative measurements of the contaminant. If alpha radiation or very low energy beta radiation is to be measured, the surface should be free of overlying material, such as dust and water, which may significantly attenuate the radiations.

4.8.4.2 Land Areas

If ground cover needs to be removed or if there are other obstacles that limit access by survey personnel or necessary equipment, the time and expense of making land areas accessible should be considered. In addition, precautionary procedures need to be developed to prevent spreading surface contamination during ground cover removal or the use of heavy equipment.

Removal or relocation of equipment and materials that may entail special precautions to prevent damage or maintain inventory accountability should be performed by the property owner whenever possible. Clearing open land of brush and weeds will usually be performed by a professional land-clearing organization under subcontract arrangements. However, survey personnel may perform minor land-clearing activities as needed.

An important consideration prior to clearing is the possibility of bio-uptake and consequent radiological contamination of the material to be cleared. Special precautions to avoid exposure of personnel involved in clearing activities may be necessary. Initial radiological screening surveys should be performed to ensure that cleared material or equipment is not contaminated.

The extent of site clearing in specific areas depends primarily on the potential for radioactive contamination existing in those areas where: 1) the radiological history or results of previous surveys do not indicate potential contamination of an area (it may be sufficient to perform only minimum clearing to establish a reference coordinate system); 2) contamination is known to exist or a high potential for contamination necessitates completely clearing an area to provide access to all surfaces; and 3) new findings as the survey progresses may indicate that additional clearing be performed.

Open land areas may be cleared by heavy machinery (*e.g.*, bulldozers, bushhogs, and hydroaxes). However, care should be exercised to prevent relocation of surface contamination or damage to site features such as drainage ditches, utilities, fences, and buildings. Minor land clearing may be performed using manually operated equipment such as brushhooks, power saws, knives, and string trimmers. Brush and weeds should be cut to the minimum practical height necessary to facilitate measurement and sampling activities (approximately 15 cm). Care should be exercised to prevent unnecessary damage to or removal of mature trees or shrubs.

Potential ecological damage that might result from an extensive survey should be considered. If a survey is likely to result in significant or permanent damage to the environment, appropriate environmental analyses should be conducted prior to initiating the survey. In addition, environmental hazards such as poison ivy, ticks carrying Lyme disease, and poisonous snakes, spiders, or insects should be noted. These hazards can affect the safety and health of the workers as well as the schedule for performing the survey.

4.8.5 Reference Coordinate System

Reference coordinate systems are established at the site to:

- facilitate selection of measurement and sampling locations
- provide a mechanism for referencing a measurement to a specific location so that the same survey point can be relocated

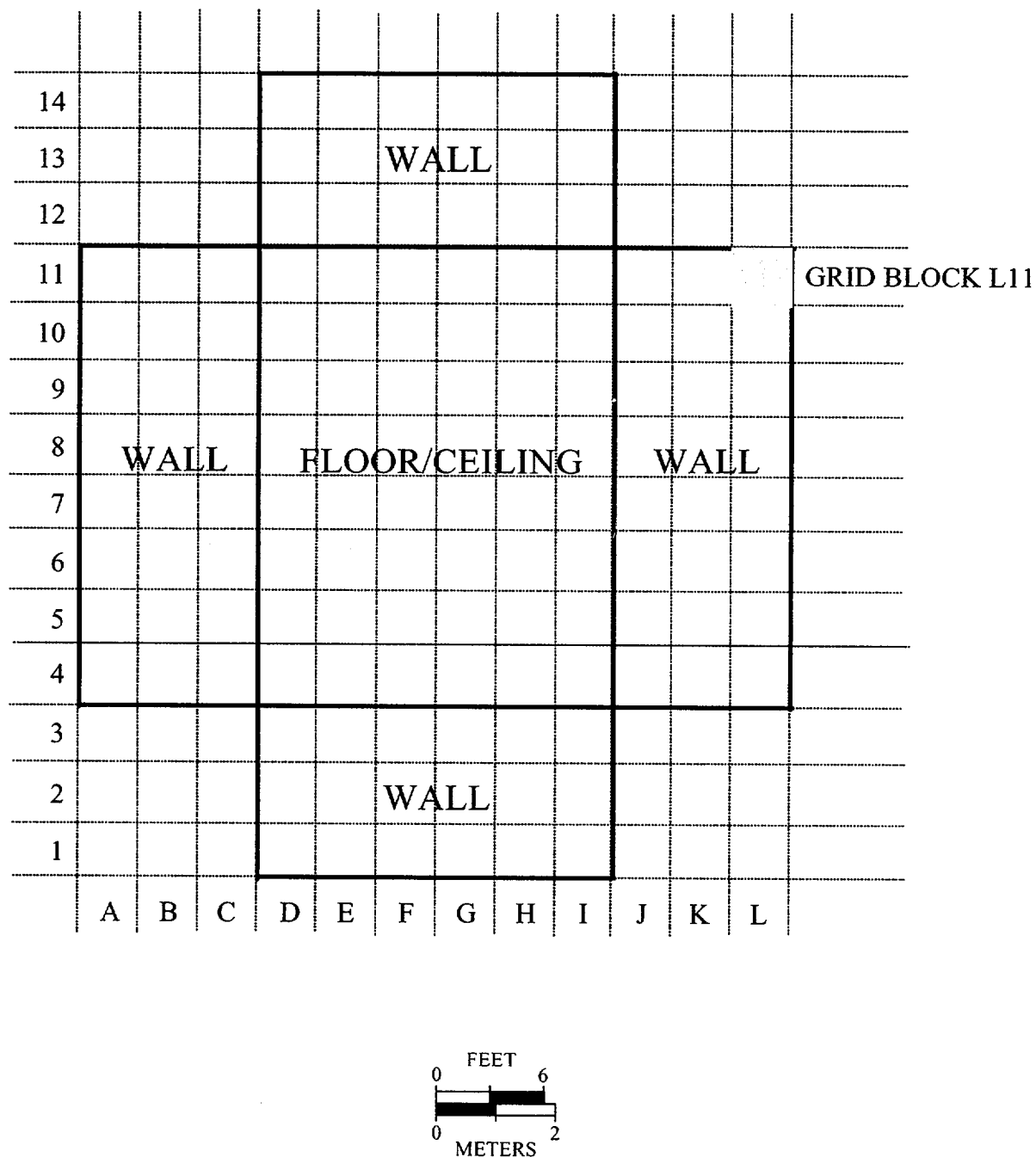
A survey reference coordinate system consists of a grid of intersecting lines, referenced to a fixed site location or benchmark. Typically, the lines are arranged in a perpendicular pattern, dividing the survey location into squares or blocks of equal area; however, other types of patterns (*e.g.*, three-dimensional, polar) have been used.

The reference coordinate system used for a particular survey should provide a level of reproducibility consistent with the objectives of the survey. For example, a commercially available global positioning system will locate a position within tens of meters, while a differential global positioning system (DGPS) provides precision on the order of a few centimeters (see Section 6.10.1.1). On the other hand, a metal bar can be driven into the ground to provide a long-term reference point for establishing a local reference coordinate system.

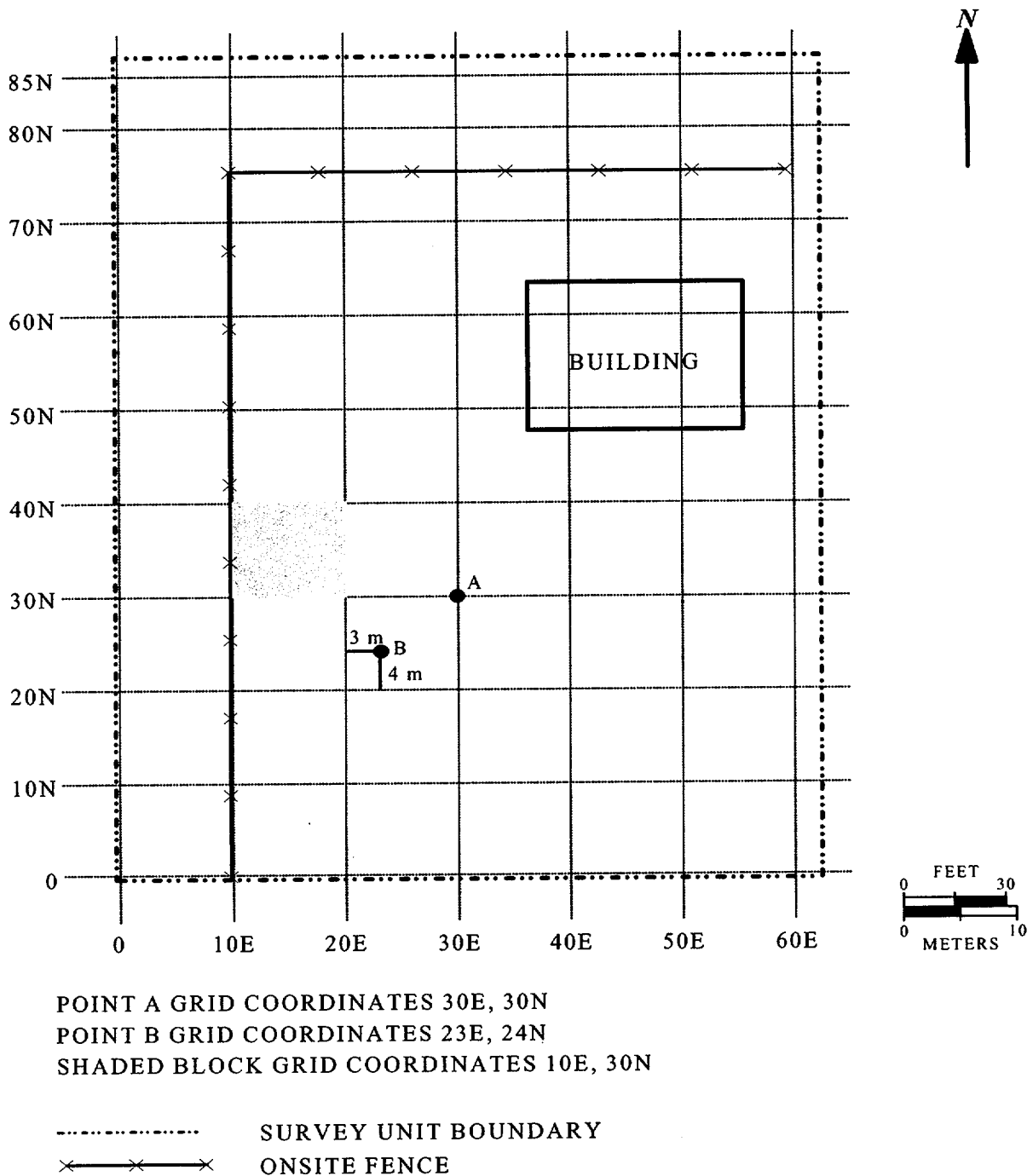
Reference coordinate system patterns on horizontal surfaces are usually identified numerically on one axis and alphabetically on the other axis or in distances in different compass directions from the grid origin. Examples of structure interior and land area grids are shown in Figures 4.3 through 4.5. Grids on vertical surfaces may include a third designator, indicating position relative to floor or ground level. Overhead measurement and sampling locations (*e.g.*, ceiling and overhead beams) are referenced to corresponding floor grids.

For surveys of Class 1 and Class 2 areas, basic grid patterns at 1 to 2 meter intervals on structure surfaces and at 10 to 20 meter intervals of land areas may be sufficient to identify survey locations with a reasonable level of effort, while not being prohibitive in cost or difficulty of installation. Gridding of Class 3 areas may also be necessary to facilitate referencing of survey locations to a common system or origin but, for practical purposes, may typically be at larger intervals—*e.g.*, 5 to 10 meters for large structural surfaces and 20 to 50 meters for land areas.

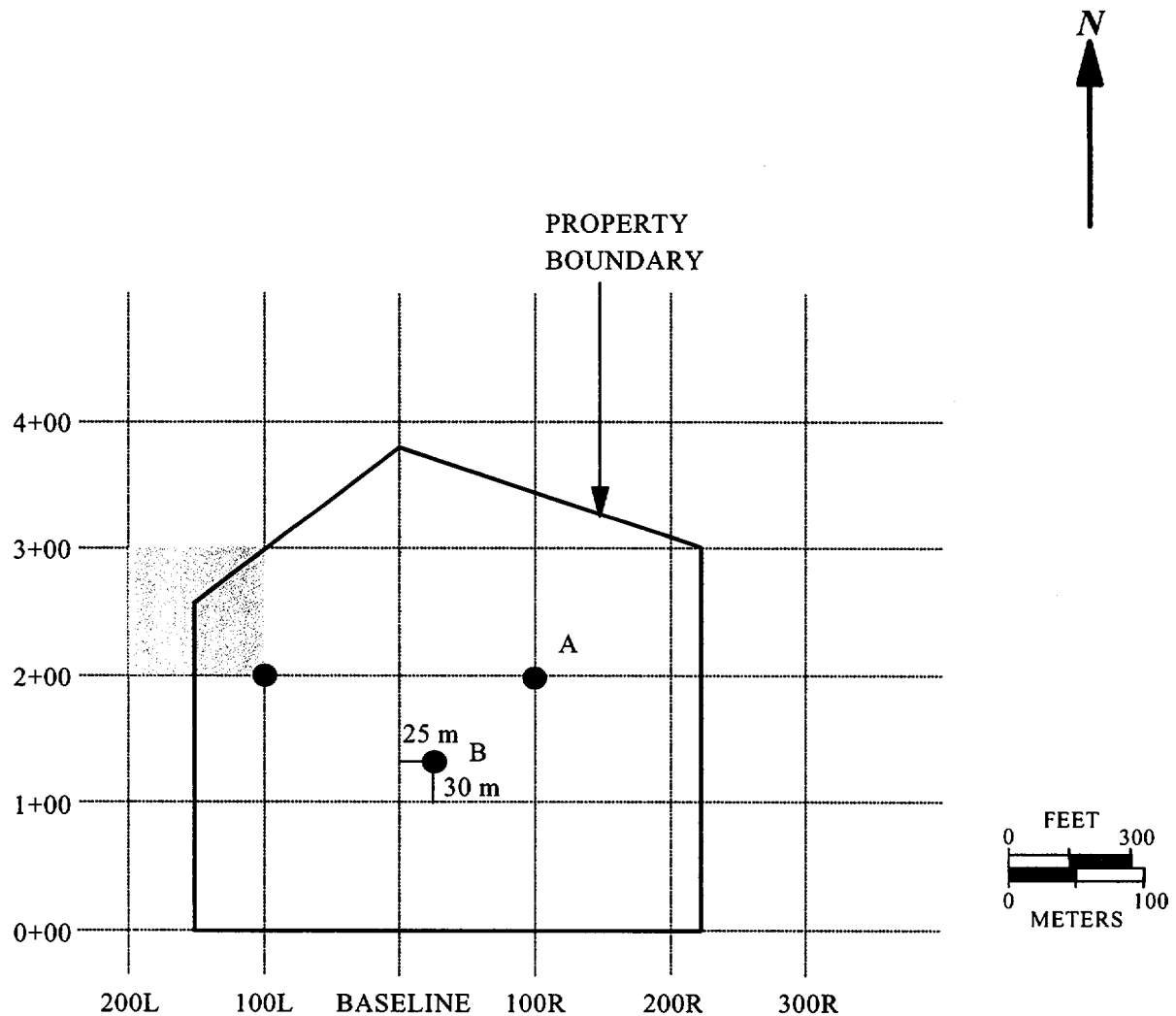
Reference coordinate systems on structure surfaces are usually marked by chalk line or paint along the entire grid line or at line intersections. Land area reference coordinate systems are usually marked by wooden or metal stakes, driven into the surface at reference line intersections. The selection of an appropriate marker depends on the characteristics and routine uses of the surface. Where surfaces prevent installation of stakes, the reference line intersection can be marked by painting.



**Figure 4.3 Indoor Grid Layout with Alphanumeric Grid Block Designation:
Walls and Floors are Diagrammed as Though They Lay
Along the Same Horizontal Plane**



**Figure 4.4 Example of a Grid System for Survey of Site Grounds
 Using Compass Directions**



POINT A GRID COORDINATES 100R, 2+00

POINT B GRID COORDINATES 25R, 1+30

SHADED BLOCK GRID COORDINATES 200L, 2+00

**Figure 4.5 Example of a Grid System for Survey of Site Grounds
Using Distances Left or Right of the Baseline**

Three basic coordinate systems are used for identifying points on a reference coordinate system. The reference system shown in Figure 4.3 references grid locations using numbers on the vertical axis and letters on the horizontal axis. The reference system shown on Figure 4.4 references distances from the 0,0 point using the compass directions N (north), S (south), E (east), and W (west). The reference system shown in Figure 4.5 references distances along and to the R (right) or L (left) of the baseline. In addition, a less frequently used reference system is the polar coordinate system, which measures distances along transects from a central point. Polar coordinate systems are particularly useful for survey designs to evaluate effects of stack emissions, where it may be desirable to have a higher density of samples collected near the stack and fewer samples with increasing distance from the stack.

Figure 4.5 shows an example grid system for an outdoor land area. The first digit or set of digits includes an L or R (separated from the first set by a comma) to indicate the distance from the baseline in units (meters) and the direction (left or right) from the baseline. The second digit or set of digits refers to the perpendicular distance from the 0,0 point on the baseline and is measured in hundreds of units. Point A in the example of a reference coordinate system for survey of site grounds, Figure 4.5, is identified 100R, 2+00 (*i.e.*, 200 m from the baseline and 100 m to the right of the baseline). Fractional distances between reference points are identified by adding the distance beyond the reference point and are expressed in the same units used for the reference coordinate system dimensions. Point B on Figure 4.5 is identified 25R, 1+30.

Open land reference coordinate systems should be referenced to a location on an existing State or local reference system or to a U.S. Geological Survey (USGS) bench mark. (This may require the services of a professional land surveyor.) Global positioning systems (GPS) are capable of locating reference points in terms of latitude and longitude (Section 6.10.1 provides descriptions of positioning systems).

Following establishment of the reference coordinate system, a drawing is prepared by the survey team or the land surveyor. This drawing indicates the reference lines, site boundaries, and other pertinent site features and provides a legend showing the scale and a reference compass direction. The process used to develop the reference coordinate system should be recorded in the survey planning documentation (*e.g.*, the Quality Assurance Project Plan or QAPP). Any deviations from the requirements developed during planning should be documented when the reference coordinate system is established.

It should be noted that the reference coordinate systems described in this section are intended primarily for reference purposes and do not necessarily dictate the spacing or location of survey measurements or samples. Establishment of a measurement grid to demonstrate compliance with the DCGL is discussed in Section 5.5.2.5 and Chapter 8.

4.9 Quality Control

Site surveys should be performed in a manner that ensures results are accurate and sources of uncertainty are identified and controlled. This is especially the case for final status surveys that are vital to demonstrating a facility satisfies pre-established release criteria. Quality control (QC) and quality assurance (QA) are initiated at the start of a project and integrated into all surveys as DQOs are developed. This carries over to the writing of a Quality Assurance Project Plan (QAPP), which applies to each aspect of a survey. Section 9.2 provides guidance on developing a QAPP. Data quality is routinely a concern throughout the RSSI Process, and one should recognize that QA/QC procedures will change as data are collected and analyzed, and as DQOs become more rigorous for the different types of surveys that lead up to a final status survey.

In general, surveys performed by trained individuals are conducted with approved written procedures and properly calibrated instruments that are sensitive to the suspected contaminant. However, even the best approaches for properly performing measurements and acquiring accurate data need to consider QC activities. QC activities are necessary to obtain additional quantitative information to demonstrate that measurement results have the required precision and are sufficiently free of errors to accurately represent the site being investigated. The following two questions are the main focus of the rationale for the assessment of errors in environmental data collection activities (EPA 1990).

- How many and what type of measurements are required to assess the quality of data from an environmental survey?
- How can the information from the quality assessment measurements be used to identify and control sources of error and uncertainties in the measurement process?

These questions are introduced as part of guidance that also includes an example to illustrate the planning process for determining a reasonable number of quality control (QC) measurements. This guidance also demonstrates how the information from the process may be used to document the quality of the measurement data. This process was developed in terms of soil samples collected in the field and then sent to a laboratory for analysis (EPA 1990). For MARSSIM, these questions may be asked in relation to measurements of surface soils and building surfaces both of which include sampling, scanning, and direct measurements.

Quality control may be thought of in three parts: 1) determining the type of QC samples needed to detect precision or bias; 2) determining the number of samples as part of the survey design; and 3) scheduling sample collections throughout the survey process to identify and control sources of error and uncertainties. Section 4.9.1 introduces the concepts of precision and bias related to survey measurements and briefly discusses the types of QC measurements needed to detect and quantify precision and bias. Section 6.2 and Section 7.2 provide more detailed guidance on the

types of QC measurements. The number of QC measurements is addressed in Section 4.9.2, while Section 4.9.3 and Section 9.3 contain information on identifying and controlling sources of uncertainty. Overall, survey activities associated with MARSSIM include obtaining the additional information related to QA of both field and laboratory activities.

4.9.1 Precision and Systematic Errors (Bias)

Precision is a measure of agreement among repeated measurements. Precision is discussed further in Appendix N in statistical terms. Table N.2 presents the minimum considerations, impacts of not meeting these considerations, and corrective actions associated with assessing precision. Systematic errors, also called bias, accumulate during the measurement process and result from faults in sampling designs and procedures, analytical procedures, sample contamination, losses, interactions with containers, deterioration, inaccurate instrument calibration, and other sources. Bias causes the mean value of the sample data to be consistently higher or lower than the true mean value. Appendix N also discusses bias, and Table N.3 presents the minimum considerations associated with assessing bias, the impacts if the considerations are not met, and related corrective actions. Laboratories typically introduce QC samples into their sample load to assess possible bias. In simplest terms, spikes, repeated measurements, and blanks are used to assess bias, precision, and contamination, respectively. See Section 6.2 for further discussion of specific measurements for determining precision and bias for scans and direct measurements and Section 7.2 for further discussion of specific measurements for determining precision and bias for samples.

Field work using scanning or direct measurements eliminates some sources of error because samples are not removed, containerized, nor transported to another location for analysis. The operator's technique or field instrument becomes the source of bias. In this case, detecting bias might incorporate field replicates (see Section 7.2.2.1) by having a second operator to revisit measurement locations and following the same procedure with the same instrument as was used by the first operator. This is an approach used to assess precision of measurements. A field instrument's calibration can also be checked by one or more operators during the course of a survey and recorded on a control chart. Differences in set up or handling of instruments by different operators may reveal a significant source of bias that is quite different from sources of bias associated with laboratory work.

The following factors should be considered when evaluating sources of bias, error, and uncertainty. Contamination is an added factor to consider for each of the following items.

- sample collection methods
- handling and preparation of samples
- homogenization and aliquots of laboratory samples
- field methods for sampling, scanning, or direct measurements

Preliminary Survey Considerations

- laboratory analytical process
- total bias contributed by all sources

The magnitude of the measurement system variability should be evaluated to determine if the variability approaches or exceeds the true but unknown variability in the population of interest. Errors, bias, or data variability may accumulate to the point of rendering data unusable to achieve survey objectives. Systematic investigations of field or laboratory processes can be initiated to assess and identify the extent of errors, bias, and data variability and to determine if the DQOs are achieved. An important aspect of each QC determination is the representative nature of a sample or measurement (see Appendix N for a description of representativeness). If additional samples or measurements are not taken according to the appropriate method, the resulting QC information will be invalid or unusable. For example, if an inadequate amount of sample is collected, the laboratory analytical procedure may not yield a proper result. The QC sample must represent the sample population being studied. Misrepresentation itself creates a bias that if undetected leads to inaccurate conclusions concerning an analysis. At the very least, misrepresentation leads to a need for additional QA investigation.

4.9.2 Number of Quality Control Measurements

The number of QC measurements is determined by the available resources and the degree to which one needs assurance that a measurement process is adequately controlled. The process is simplified, for example, when the scope of a survey is narrowed to a single method, one sampling crew, and a single laboratory to analyze field samples. Increasing the number of samples and scheduling sample collections and analyses over time or at different laboratories increases the level of difficulty and necessitates increasing the number of QC measurements. The number of QC measurements may also be driven upward as the action level approaches a given instrument's detection limit. This number is determined on a case-by-case basis, where the specific contaminant and instruments are assessed for detecting a particular radionuclide.

A widely used standard practice is to collect a set percentage, such as 5% (EPA 1987b), of samples for QA purposes. However, this practice has disadvantages. For example, it provides no real assessment of the uncertainties for a relatively small sample size. For surveys where the required number of measurements increases, there may be a point beyond which there is little added value in performing additional QC measurements. Aside from cost, determining the appropriate number of QC measurements essentially depends on site-specific factors. For example, soil may present a complex and variable matrix requiring many more QC measurements for surface soils than for building surfaces.

A performance based alternative (EPA 1990) to a set percentage or rule of thumb can be implemented. First, potential sources of error or uncertainty, the likelihood of occurrence, and the consequences in the context of the DQOs should be determined. Then, the appropriate type

and number of QC measurements based on the potential error or uncertainty are determined. For example, field replicate samples (*i.e.*, a single sample that is collected, homogenized, and split into equivalent fractions in the field) are used to estimate the combined contribution of several sources of variation. Hence, the number of field replicate samples to be obtained in the study should be dictated by how precise the estimate of the total measurement should be.

Factors influencing this estimate include the

- number of measurements
- number and experience of personnel involved
- current and historical performance of sampling and analytical procedures used
- the variability of survey unit and background reference area radioactivity measurement systems used
- number of laboratories used
- the level of radioactivity in the survey unit (which for a final status survey should be low)
- how close an action level (*e.g.*, DCGL) is to a detection limit (which may represent a greater concern after reducing or removing radionuclide concentrations by remediation)

The precision of an estimate of the “true” variance for precision or bias within a survey design depends on the number of degrees of freedom used to provide the estimate. Table 4.3 provides the one-sided upper confidence limits for selected degrees of freedom assuming the results of the measurements are normally distributed. Confidence limits are provided for 90, 95, 97.5, and 99 percent confidence levels. At the stated level of confidence, the “true” variance of the estimate of precision or bias for a specified number of QC measurements will be between zero and the multiple of the estimated variance listed in Table 4.3. For example, for five degrees of freedom one would be 90% confident that the true variance for precision falls between zero and 3.10 times the estimated variance. The number of QC measurements is equal to one greater than the degrees of freedom.

When planning surveys, the number of each type of QC measurement can be obtained from Table 4.3. For example, if the survey objective is to estimate the variance in the bias for a specific measurement system between zero and two times the estimated variance at a 95% confidence level, 15 degrees of freedom or 16 measurements of a material with known concentration (*e.g.*, performance evaluation samples) would be indicated. MARSSIM recommends that the survey objective be set such that the true variance falls between zero and two times the estimated variance. The level of confidence is then determined on a site-specific basis to adjust the number of each type of QC measurement to the appropriate level (*i.e.*, 11, 16, 21 or 31 measurements). The results of the QC measurements are evaluated during the assessment phase of the data life cycle (see Section 9.3 and Appendix N).

Table 4.3 Upper Confidence Limits for the True Variance as a Function of the Number of QC Measurements Used to Determine the Estimated Variance (EPA 1990)

| Degrees of Freedom* | Level of Confidence (%) | | | |
|---------------------|-------------------------|-------|-------|-------|
| | 90 | 95 | 97.5 | 99 |
| 2 | 9.49 | 19.49 | 39.21 | 99.50 |
| 5 | 3.10 | 4.34 | 6.02 | 9.02 |
| 10 | 2.05 | 2.54 | 3.08 | 3.91 |
| 15 | 1.76 | 2.07 | 2.40 | 2.87 |
| 20 | 1.61 | 1.84 | 2.08 | 2.42 |
| 25 | 1.52 | 1.71 | 1.91 | 2.17 |
| 30 | 1.46 | 1.62 | 1.78 | 2.01 |
| 40 | 1.38 | 1.51 | 1.64 | 1.80 |
| 50 | 1.33 | 1.44 | 1.61 | 1.68 |
| 100 | 1.21 | 1.28 | 1.35 | 1.43 |

* To obtain the necessary number of quality control measurements, add one to the degrees of freedom.

Example:

A site is contaminated with ^{60}Co and consists of four Class 1 interior survey units, nine Class 2 interior survey units, two Class 3 interior survey units, and one Class 3 exterior survey unit. Three different measurement systems are specified in the survey design for performing scanning surveys, one measurement system is specified for performing direct measurements for interior survey units, and one measurement system is specified for measuring samples collected from the exterior survey unit.

Repeated measurements are used to estimate precision. For scan surveys there is not a specified number of measurements. 10% of the scans in each Class 1 survey unit were repeated as replicates to measure operator precision (see Section 6.2.2.1) within 24 hours of the original scan survey. 5% of each Class 2 and Class 3 survey unit were similarly repeated as replicates to measure operator precision. The results of the repeated scans were evaluated based on professional judgment. For direct measurements and sample collection activities, a 95% confidence level was selected as consistent with the objectives of the survey. Using Table 4.3, it was determined that 16 repeated measurements were required for both the direct measurement technique and the sample collection and laboratory measurement technique. Because 72 direct measurements would be performed in Class 1 survey units, 99 in Class 2 survey units, and 20 in Class 3 survey units, it was anticipated that at least 16 direct measurements would have sufficient activity above

background to perform repeated measurements and obtain usable results (see Section 5.5.2 for guidance on determining the number of measurements and Appendix A for a more detailed discussion of the example site). The 16 direct measurement locations to be repeated would be selected based on the results of the direct measurements and would represent the entire usable range of activity found in the survey units rather than measuring the 16 locations with the highest activities. (The usable range of activity includes the highest measurement result in the survey unit and the lowest measurement result with an acceptable measurement uncertainty compared to the desired level of precision.) The repeated measurements would be performed by different operators using the same equipment, but they would not know the results of the original survey. To ensure that the measurements would be valid, the QC measurements to check for contamination would be performed at the same time. Because the laboratory's QA program called for periodic checks on the precision of the laboratory instruments, the total survey design precision for laboratory measurements was measured. Because the only samples collected would come from a Class 3 area, the sample activities were expected to be close to or below the measurement system MDC. This meant that field replicate samples would not provide any usable information. Also, QC samples for bias were repeated to obtain a usable estimate of precision for the survey design.

Measurements of materials with known concentrations above background (*e.g.*, performance evaluation samples) and known concentrations at or below background (*e.g.*, field blanks) are used to estimate bias. For scan surveys, the repeated scanning performed to estimate precision would also serve as a check for contamination using blanks. Because there was no appropriate material of known concentration on which to perform bias measurements, the calibration checks were used to demonstrate that the instruments were reading properly during the surveys. A control chart was developed using the instrument response for an uncalibrated check source. Measurements were obtained using a specified source-detector alignment that could be easily repeated. Measurements were obtained at several times during the day over a period of several weeks prior to taking the instruments into the field. Calibration checks were performed before and after each survey period in the field and the results immediately plotted on the control chart to determine if the instrument was performing properly. This method was also adopted for the direct measurement system. 20 samples were required by the survey design for the Class 3 exterior survey unit. To ensure that the samples were truly blind for the laboratory, samples three times the requested volume were collected. These samples were sent to a second laboratory for preparation. Each sample was weighed, dried, and reweighed to determine the moisture content. Then each sample was ground to a uniform particle size of 1 mm (approximately 16 mesh) and divided into three separate aliquots (each aliquot was the same size). For each sample one aliquot was packaged for transport to the laboratory performing the analysis. After these samples were packaged, 16 of the samples had both of the remaining aliquots spiked with the same level of activity using a source

solution traceable to the National Institute of Science and Technology (NIST). The 16 samples each had a different level of activity within a range that was accepted by the laboratory performing the analysis. These 32 samples were also packaged for transport to the laboratory. In addition, 16 samples of a soil similar to the soil at the site were prepared as blanks to check against contamination. The 20 samples, 32 spikes, and 16 blanks were transported to the laboratory performing the analyses in a single shipment so that all samples were indistinguishable from each other except by the sample identification.

4.9.3 Controlling Sources of Error

During the performance of a survey, it is important to identify sources of error and uncertainty early in the process so that problems can be resolved. The timing of the QC measurements within the survey design can be very important. In order to identify problems as early as possible, it may be necessary to perform a significant number of QC measurements early in the survey. This can be especially important for surveys utilizing an innovative or untested survey design. Survey designs that have been used previously and produced reliable results may be able to space the QC measurement evenly throughout the survey, or even wait to have samples analyzed at the end of the survey, as long as the objectives of the survey are achieved.

For example, a survey design requires a new scanning method to be used for several survey units when there are little performance data available for this technique. To ensure that the technique is working properly, the first few survey units are re-scanned to provide an initial estimate of the precision and bias. After the initial performance of the techniques has been verified, a small percentage of the remaining survey units is re-scanned to demonstrate that the technique is operating properly for the duration of the survey.

Identifying sources of error and uncertainty is only the first step. Once the sources of uncertainty have been identified, they should be minimized and controlled for the rest of the survey. Section 9.3 discusses the assessment of survey data and provides guidance on corrective actions that may be appropriate for controlling sources of error or uncertainty after they have been identified.

4.10 Health and Safety

Consistent with the approach for any operation, activities associated with the radiological surveys should be planned and monitored to assure the health and safety of the worker and other personnel, both onsite and offsite, are adequately protected. At the stage of determining the final status of the site, residual radioactivity is expected to be below the DCGL values; therefore, the final status survey should not include radiation protection controls. However, radiation protection controls may be necessary when performing scoping or characterization surveys where the potential for significant levels of residual radioactivity is unknown.

Significant health and safety concerns during any radiological survey include the potential industrial hazards commonly found at a construction site, such as exposed electrical circuitry, excavations, enclosed work spaces, hazardous atmospheres, insects, poisonous snakes, plants, and animals, unstable surfaces (*e.g.*, wet or swamp soil), heat and cold, sharp objects or surfaces, falling objects, tripping hazards, and working at heights. The survey plan should incorporate objectives and procedures for identifying and eliminating, avoiding, or minimizing these potential safety hazards.

5 SURVEY PLANNING AND DESIGN

5.1 Introduction

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

5.2 Scoping Surveys

5.2.1 General

If the data collected during the Historical Site Assessment (HSA) indicate that a site or area is impacted, a scoping survey could be performed. The objective of this survey is to augment the HSA for sites with potential residual contamination. Specific objectives may include:

1) performing a preliminary risk assessment and providing data to complete the site prioritization scoring process (CERCLA and RCRA sites only), 2) providing input to the characterization survey design, if necessary, 3) supporting the classification of all or part of the site as a Class 3 area for planning the final status survey, 4) obtaining an estimate of the variability in the residual radioactivity concentration for the site, and 5) identifying non-impacted areas that may be appropriate for reference areas and estimating the variability in radionuclide concentrations when the radionuclide of interest is present in background.

Scoping survey information needed when conducting a preliminary risk assessment (as noted above for CERCLA and RCRA sites) includes the general radiation levels at the site and gross levels of residual contamination on building surfaces and in environmental media. If unexpected

conditions are identified that prevent the completion of the survey, the MARSSIM user should contact the responsible regulatory agency for further guidance. Sites that meet the National Contingency Plan criteria for a removal should be referred to the Superfund Removal program (EPA 1988c).

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

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

5.2.2 Survey Design

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

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

For scoping surveys that potentially serve to release the site from further consideration, the survey design should consist of sampling based on the HSA data and professional judgment. If residual

radioactivity is *not* identified during judgment sampling, it may be appropriate to classify the area as Class 3 and perform a final status survey for Class 3 areas. Refer to Section 5.5 for a description of final status surveys. However, collecting additional information during subsequent surveys (*e.g.*, characterization surveys) may be necessary to make a final determination as to area classification.

5.2.3 Conducting Surveys

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

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

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

5.2.4 Evaluating Survey Results

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

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

5.2.5 Documentation

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

EXAMPLE SCOPING SURVEY CHECKLIST

SURVEY DESIGN

- _____ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be appropriate for the specified survey objectives.
- _____ Review the Historical Site Assessment for:
 - _____ Operational history (*e.g.*, problems, spills, releases, or notices of violation) and available documentation (*e.g.*, radioactive materials license).
 - _____ Other available resources—site personnel, former workers, residents, *etc.*
 - _____ Types and quantities of materials that were handled and where radioactive materials were stored, handled, moved, relocated, and disposed.
 - _____ Release and migration pathways.
 - _____ Areas that are potentially affected and likely to contain residual contamination.
Note: Survey activities will be concentrated in these areas.
 - _____ Types and quantities of materials likely to remain onsite—consider radioactive decay.
- _____ Select separate DCGLs for the site based on the HSA review. (It may be necessary to assume appropriate regulatory DCGLs in order to permit selection of survey methods and instrumentation for the expected contaminants and quantities.)

CONDUCTING SURVEYS

- _____ Follow the survey design documented in the QAPP. Record deviations from the stated objectives or documented SOPs and document additional observations made when conducting the survey.
- _____ Select instrumentation based on the specific DQOs of the survey. Consider detection capabilities for the expected contaminants and quantities.
- _____ Determine background activity and radiation levels for the area; include direct radiation levels on building surfaces, radionuclide concentrations in media, and exposure rates.

Survey Planning and Design

- _____ Record measurement and sample locations referenced to grid coordinates or fixed site features.
- _____ For scoping surveys that are conducted as Class 3 area final status surveys, follow guidance for final status surveys.
- _____ Conduct scoping survey, which involves judgment measurements and sampling based on HSA results:
 - _____ Perform investigatory surface scanning.
 - _____ Conduct limited surface activity measurements.
 - _____ Perform limited sample collection (smears, soil, water, vegetation, paint, building materials, subsurface materials).
 - _____ Maintain sample tracking.

EVALUATING SURVEY RESULTS

- _____ Compare survey results with the DQOs.
- _____ Identify radionuclides of concern.
- _____ Identify impacted areas and general extent of contamination.
- _____ Estimate the variability in the residual radioactivity levels for the site.
- _____ Adjust DCGLs based on survey findings (the DCGLs initially selected may not be appropriate for the site).
- _____ Determine the need for additional action (e.g., none, remediate, more surveys)
- _____ Prepare report for regulatory agency (determine if letter report is sufficient).

5.3 Characterization Surveys

5.3.1 General

Characterization surveys may be performed to satisfy a number of specific objectives. Examples of characterization survey objectives include: 1) determining the nature and extent of radiological contamination, 2) evaluating remediation alternatives (e.g., unrestricted use, restricted use, onsite disposal, off-site disposal, etc.), 3) input to pathway analysis/dose or risk assessment models for determining site-specific DCGLs (Bq/kg, Bq/m²), 4) estimating the occupational and public health and safety impacts during decommissioning, 5) evaluating remediation technologies, 6) input to final status survey design, and 7) Remedial Investigation/Feasibility Study requirements (CERCLA sites only) or RCRA Facility Investigation/Corrective Measures Study requirements (RCRA sites only).

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

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

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

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

5.3.2 Survey Design

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

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

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

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

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

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

5.3.3 Conducting Surveys

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

5.3.3.1 Structure Surveys

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

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

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

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

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

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

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

5.3.3.2 Land Area Surveys

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

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

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

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

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

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

5.3.3.3 Other Measurements/Sampling Locations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.3.4 Evaluating Survey Results

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

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

5.3.5 Documentation

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

EXAMPLE CHARACTERIZATION SURVEY CHECKLIST

SURVEY DESIGN

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

CONDUCTING SURVEYS

- _____ Select instrumentation based on detection capabilities for the expected contaminants and quantities and a knowledge of the appropriate DCGLs.
- _____ Determine background activity and radiation levels for the area; include surface activity levels on building surfaces, radionuclide concentrations in environmental media, and exposure rates.
- _____ Establish a reference coordinate system. Prepare scale drawings for surface water and ground-water monitoring well locations.

- _____ Perform thorough surface scans of all potentially contaminated areas, (e.g., indoor areas include expansion joints, stress cracks, penetrations into floors and walls for piping, conduit, and anchor bolts, and wall/floor interfaces); outdoor areas include radioactive material storage areas, areas downwind of stack release points, surface drainage pathways, and roadways that may have been used for transport of radioactive or contaminated materials.
- _____ Perform systematic surface activity measurements.
- _____ Perform systematic smear, surface and subsurface soil and media, sediment, surface water and groundwater sampling, if appropriate for the site.
- _____ Perform judgment direct measurements and sampling of areas of elevated activity of residual radioactivity to provide data on upper ranges of residual contamination levels.
- _____ Document survey and sampling locations.
- _____ Maintain chain of custody of samples when necessary.

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

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

EVALUATING SURVEY RESULTS

- _____ Compare survey results with DCGLs. Differentiate surfaces/areas as exceeding DCGLs, not exceeding DCGLs, or not contaminated.
- _____ Evaluate all locations of elevated direct measurements and determine the need for additional measurements/samples.
- _____ Prepare site characterization survey report.

5.4 Remedial Action Support Surveys

5.4.1 General

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

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

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

5.4.2 Survey Design

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

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

5.4.3 Conducting Surveys

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

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

5.4.4 Evaluating Survey Results

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

5.4.5 Documentation

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

EXAMPLE REMEDIAL ACTION SUPPORT SURVEY CHECKLIST

SURVEY DESIGN

- _____ Enumerate DQOs: State the objectives of the survey; survey instrumentation capabilities should be able to detect residual contamination at the DCGL.
- _____ Review the remediation plans.
- _____ Determine applicability of monitoring surfaces/soils for the radionuclides of concern. Note: Remedial action support surveys may not be feasible for surfaces contaminated with very low energy beta emitters or for soils or media contaminated with pure alpha emitters.
- _____ Select simple radiological parameters (*e.g.*, surface activity) that can be used to make immediate in-field decisions on the effectiveness of the remedial action.

CONDUCTING SURVEYS

- _____ Select instrumentation based on its detection capabilities for the expected contaminants.
- _____ Perform scanning and surface activity measurements near the surface being decontaminated.
- _____ Survey soil excavations and perform field evaluation of samples (*e.g.*, gamma spectrometry of undried/non-homogenized soil) as remedial actions progress.

EVALUATING SURVEY RESULTS

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

5.5 Final Status Surveys

5.5.1 General

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

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

5.5.2 Survey Design

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

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

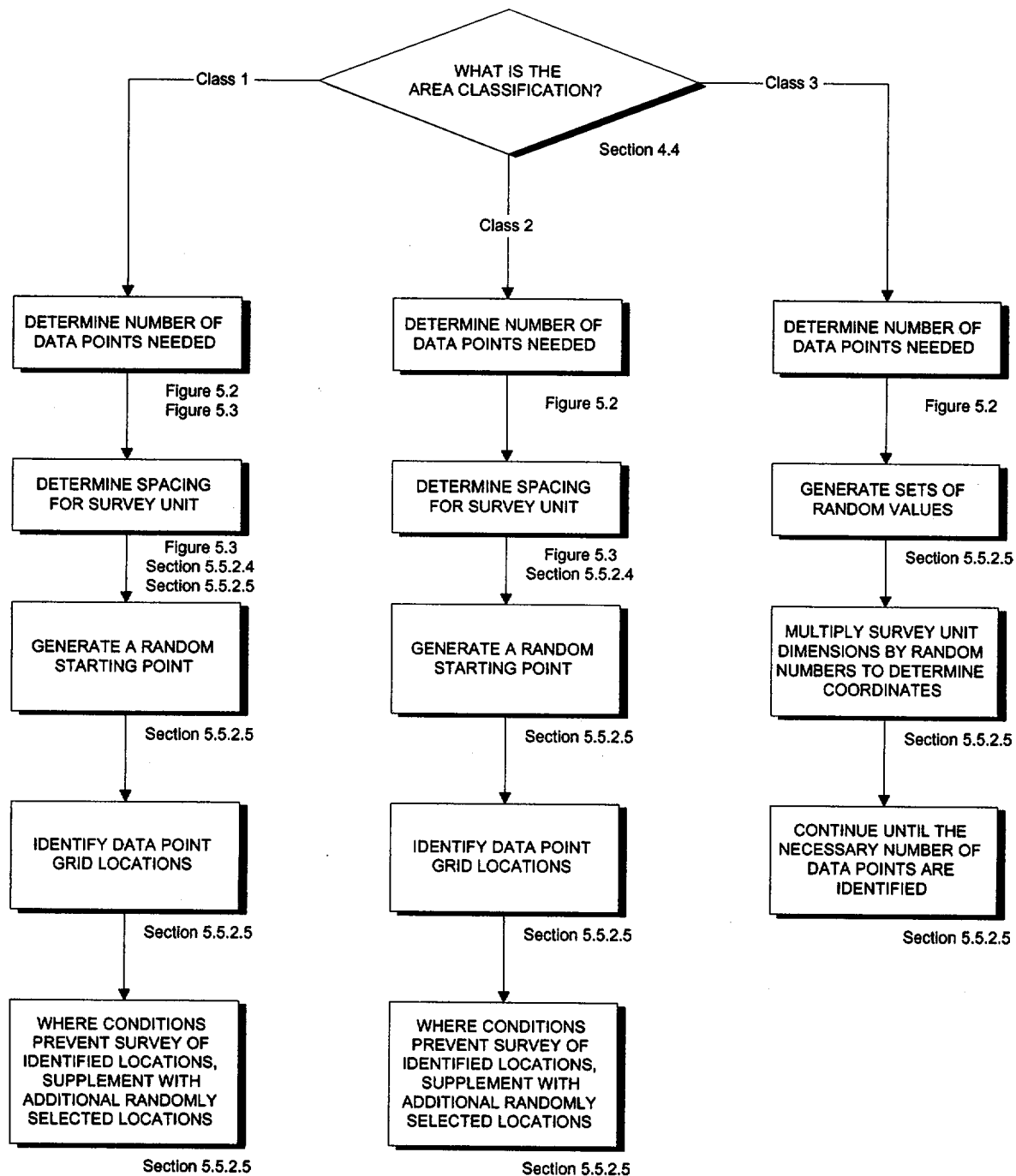


Figure 5.1 Flow Diagram Illustrating the Process for Identifying Measurement Locations (Refer to Section 5.5.2.5)

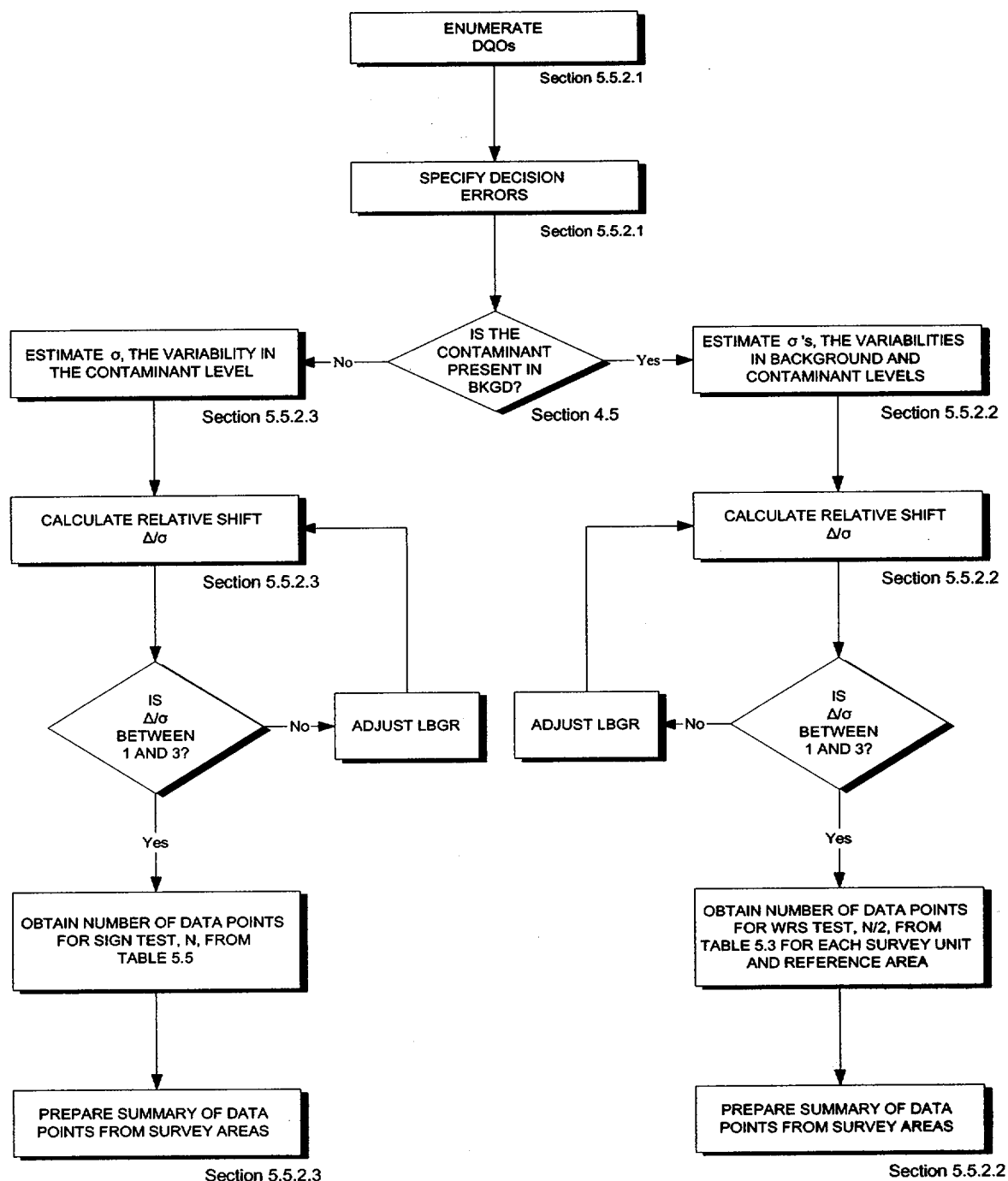


Figure 5.2 Flow Diagram for Identifying the Number of Data Points, N, for Statistical Tests

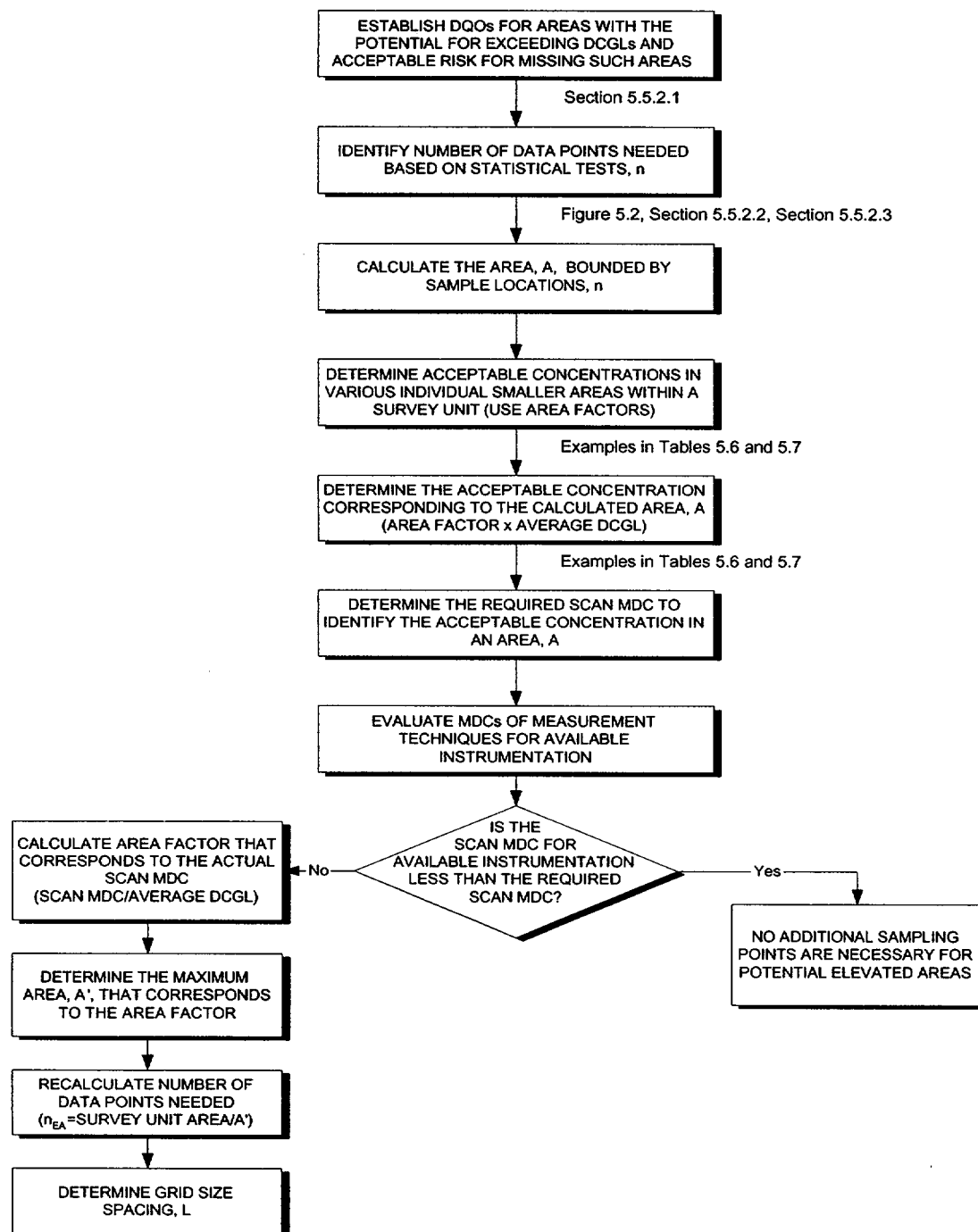


Figure 5.3 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units (Refer to Section 5.5.2.4)

5.5.2.1 Application of Decommissioning Criteria

The DQO Process, as it is applied to decommissioning surveys, is described in more detail in Appendix D of this manual and in EPA and NRC guidance documents (EPA 1994, 1987b, 1987c; NRC 1997a). As part of this process, the objective of the survey and the null and alternative hypotheses should be clearly stated. The objective of final status surveys is typically to demonstrate that residual radioactivity levels meet the release criterion. In demonstrating that this objective is met, the null hypothesis (H_0) tested is that residual contamination exceeds the release criterion; the alternative hypothesis (H_a) is that residual contamination meets the release criterion.

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

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

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

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

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

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

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

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

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

The value selected as an estimate of σ for a survey unit may be based on data collected only from within that survey unit or from data collected from a much larger area of the site. Note that survey units are not finalized until the planning stage of the final status survey. This means that there may be some difficulty in determining which individual measurements from a preliminary survey may later represent a particular survey unit. For many sites, the most practical solution is to estimate σ for each area classification (i.e., Class 1, Class 2, and Class 3) for both interior and

exterior survey units. This will result in all exterior Class 3 survey units using the same estimate of σ , all exterior Class 2 survey units using a second estimate for σ , and all exterior Class 1 survey units using a third estimate for σ . If there are multiple types of surfaces within an area classification, additional estimates of σ may be required. For example, a Class 2 concrete floor may require a different estimate of σ than a Class 2 cinder block wall, or a Class 3 unpaved parking area may require a different estimate of σ than a Class 3 lawn. In addition, MARSSIM recommends that a separate estimate of σ be obtained for every reference area.

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

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

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

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

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

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

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

If $\Delta/\sigma > 4.0$, use $P_r = 1.000000$

Table 5.2 Percentiles Represented by Selected Values of α and β

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

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

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

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

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

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

Example:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Example:

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

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

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

Table 5.5 Values of N for Use with the Sign Test

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

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

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

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

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

5.5.2.4 Determining Data Points for Small Areas of Elevated Activity

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

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

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

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

Tables 5.6 and 5.7 provide examples of area factors generated using exposure pathway models. The outdoor area factors listed in Table 5.6 were calculated using RESRAD 5.6. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/kg (1 pCi/g). The area of contamination in RESRAD 5.6 defaults to 10,000 m². Other than changing the area (*i.e.*, 1, 3, 10, 30, 100, 300, 1,000, or 3,000 m²), the RESRAD default values were not changed. The area factors were then computed by taking the ratio of the dose or risk per unit concentration generated by RESRAD for the default 10,000 m² to that generated for the other areas listed. If the $DCGL$ for residual radioactivity distributed over 10,000 m² is multiplied by this value, the resulting concentration distributed over the specified smaller area delivers the same calculated dose. The indoor area factors listed in Table 5.7 were calculated in a similar manner using RESRAD-BUILD 1.5. For each radionuclide, all exposure pathways were calculated assuming a concentration of 37 Bq/m² (1 pCi/m²). The area of contamination in RESRAD-BUILD 1.5 defaults to 36 m². The other areas compared to this value were 1, 4, 9, 16, or 25 m². Removable surface contamination was assumed to be 10%. No other changes to the default values were made. Note that the use of RESRAD to determine area factors is for illustration purposes only. The MARSSIM user should consult with the responsible regulatory agency for guidance on acceptable techniques to determine area factors.

The minimum detectable concentration (MDC) of the scan procedure—needed to detect an area of elevated activity at the limit determined by the area factor—is calculated as follows:

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

The actual MDCs of scanning techniques are then determined for the available instrumentation (see Section 6.7). The actual MDC of the selected scanning technique is compared to the required scan MDC. If the actual scan MDC is less than the required scan MDC, no additional sampling points are necessary for assessment of small areas of elevated activity. In other words, the scanning technique exhibits adequate sensitivity to detect small areas of elevated activity.

Table 5.6 Illustrative Examples of Outdoor Area Dose Factors*

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

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

Table 5.7 Illustrative Examples of Indoor Area Dose Factors*

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

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

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

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

The size of the area of elevated activity (in m²) that corresponds to this area factor is then obtained from specific regulatory agency guidance, and may be similar to those illustrated in Table 5.6 or Table 5.7. The data needs for assessing small areas of elevated activity can then be determined by dividing the area of elevated activity acceptable to the regulatory agency into the survey unit area. For example, if the area of elevated activity is 100 m² (from Table 5.6) and the survey unit area is 2,000 m², then the calculated number of survey locations is 20. The calculated number of survey locations, n_{EA} , is used to determine a revised spacing, L , of the systematic pattern (refer to Section 5.5.2.5). Specifically, the spacing, L , of the pattern (when driven by the areas of elevated activity) is given by:

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

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

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

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

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

Example 1:

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

Example 2:

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

5.5.2.5 Determining Survey Locations

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

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

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

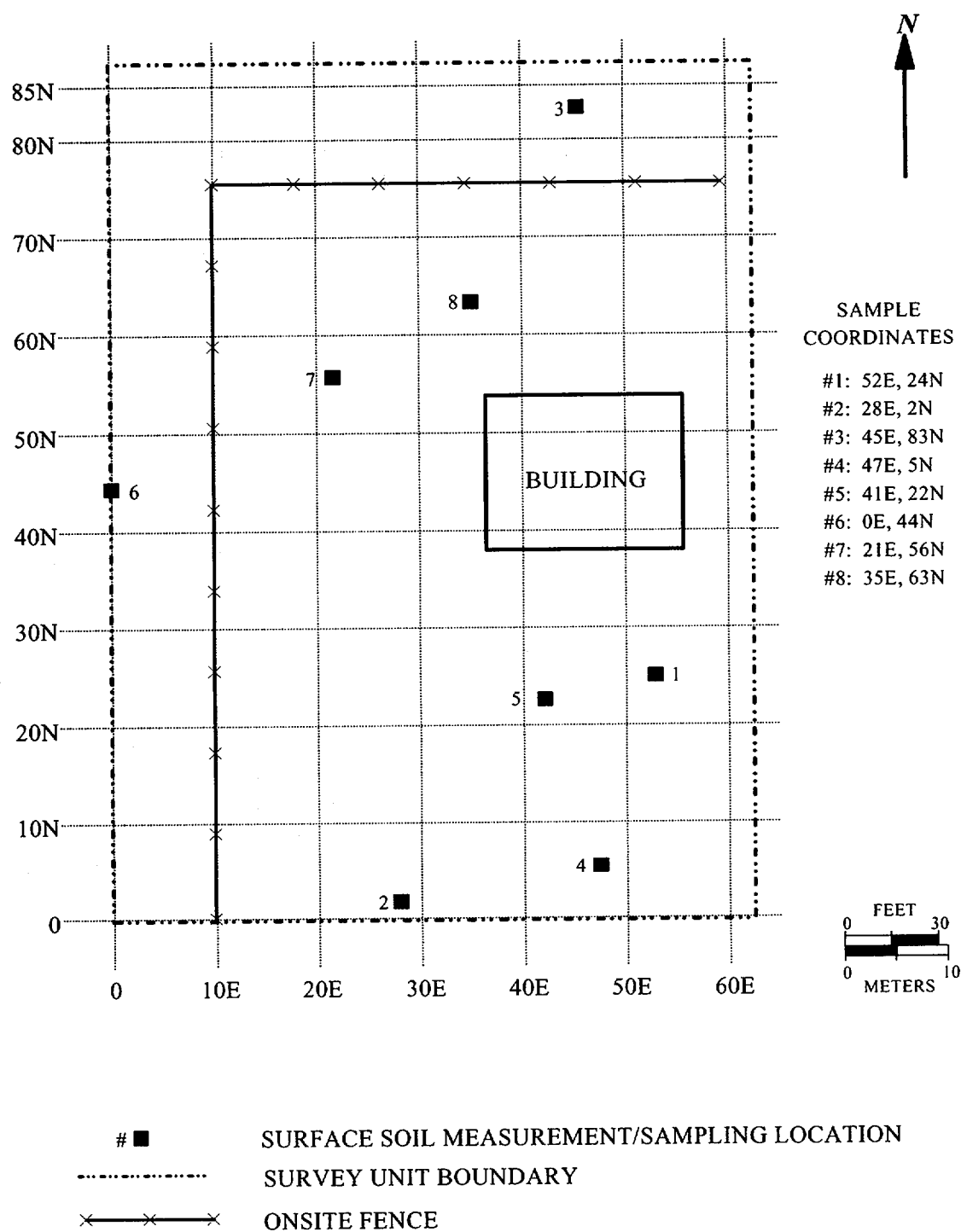


Figure 5.4 Example of a Random Measurement Pattern

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

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

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

where A is the area of the survey unit.

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

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

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

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

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

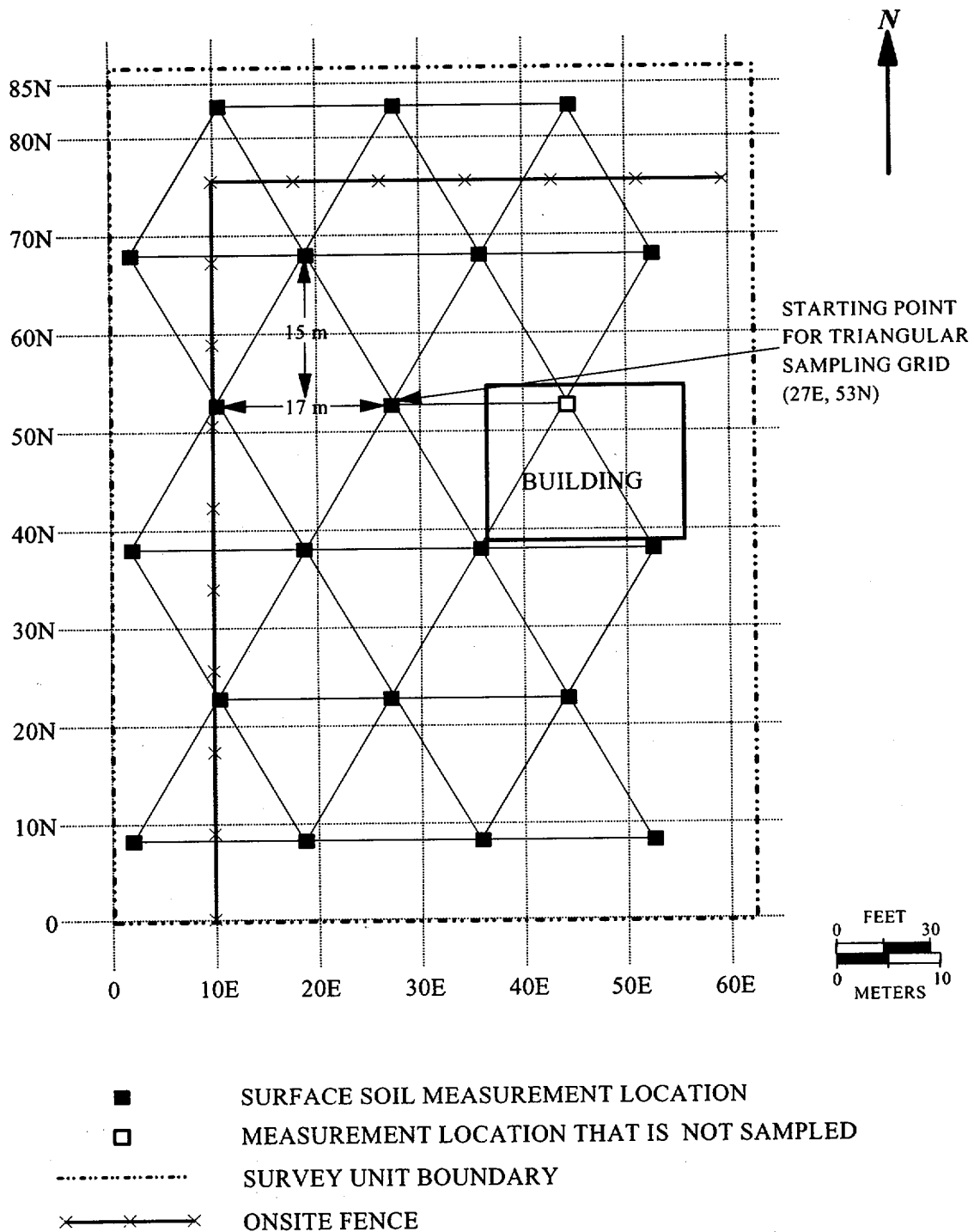


Figure 5.5 Example of a Random-Start Triangular Grid Measurement Pattern

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

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

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

5.5.2.6 Determining Investigation Levels

An important aspect of the final status survey is the design and implementation of investigation levels. Investigation levels are radionuclide-specific levels of radioactivity used to indicate when additional investigations may be necessary. Investigation levels also serve as a quality control check to determine when a measurement process begins to get out of control. For example, a measurement that exceeds the investigation level may indicate that the survey unit has been improperly classified (see Section 4.4) or it may indicate a failing instrument.

When an investigation level is exceeded, the first step is to confirm that the initial measurement/sample actually exceeds the particular investigation level. This may involve taking further measurements to determine that the area and level of the elevated residual radioactivity are such that the resulting dose or risk meets the release criterion.² Depending on the results of the investigation actions, the survey unit may require reclassification, remediation, and/or resurvey. Table 5.8 illustrates an example of how investigation levels can be developed.

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

Table 5.8 Example Final Status Survey Investigation Levels

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

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

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

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

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

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

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

5.5.3 Developing an Integrated Survey Strategy

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

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

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

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

Table 5.9 Recommended Survey Coverage for Structures and Land Areas

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

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

Scanning surveys in Class 2 areas are also primarily performed to find areas of elevated activity not detected by the measurements using the systematic pattern. However, the measurement locations are not adjusted based on sensitivity of the scanning technique and scanning is performed in portions of the survey unit. The level of scanning effort should be proportional to the potential for finding areas of elevated activity based on the conceptual site model developed and refined from Section 3.6.4. A larger portion of the survey unit would be scanned in Class 2 survey units that have residual radioactivity close to the release criterion, but for survey units that are closer to background scanning, a smaller portion of the survey unit may be appropriate. Class 2 survey units have a lower probability for areas of elevated activity than Class 1 survey units, but some portions of the survey unit may have a higher potential than others. Judgmental scanning surveys focus on the portions of the survey unit with the highest probability for areas of

elevated activity. If the entire survey unit has an equal probability for areas of elevated activity, or the judgmental scans don't cover at least 10% of the area, systematic scans along transects of the survey unit or scanning surveys of randomly selected grid blocks are performed.

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

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

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

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

5.5.3.1 Structure Surveys

Class 1 Areas. Surface scans are performed over 100% of structure surfaces for radiations which might be emitted from the potential radionuclide contaminants. Locations of direct radiation, distinguishable above background radiation, are identified and evaluated. Results of initial and followup direct measurements and sampling at these locations are recorded and documented in the final status survey report. Measurements of total and removable contamination are performed

at locations identified by scans and at previously determined locations (Section 5.5.2.5). Where gamma emitting radionuclides are present, *in situ* gamma spectroscopy may be used to identify the presence of specific radionuclides or to demonstrate compliance with the release criterion.

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

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

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

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

few locations in each structure in a Class 3 area. A gamma spectroscopy system might even be an appropriate substitution for surface scans.

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

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

5.5.3.2 Land Area Surveys

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

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

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

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

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

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

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

5.5.3.3 Other Measurement/Sampling Locations

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

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

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

5.5.4 Evaluating Survey Results

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

5.5.5 Documentation

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

EXAMPLE FINAL STATUS SURVEY CHECKLIST

SURVEY PREPARATIONS

- _____ Ensure that residual radioactivity limits have been determined for the radionuclides present at the site, typically performed during earlier surveys associated with the decommissioning process.
- _____ Identify the radionuclides of concern. Determine whether the radionuclides of concern exist in background. This will determine whether one-sample or two-sample tests are performed to demonstrate compliance. Two-sample tests are performed when radionuclides are present in the natural background; one-sample tests may be performed if the radionuclide is not present in background.
- _____ Segregate the site into Class 1, Class 2, and Class 3 areas, based on contamination potential.
- _____ Identify survey units.
- _____ Select representative reference (background) areas for both indoor and outdoor survey areas. Reference areas are selected from non-impacted areas and
 - _____ are free of contamination from site operations,
 - _____ exhibit similar physical, chemical, and biological characteristics of the survey area,
 - _____ have similar construction, but have no history of radioactive operations.
- _____ Select survey instrumentation and survey techniques. Determine MDCs (select instrumentation based on the radionuclides present) and match between instrumentation and DCGLs—the selected instruments should be capable of detecting the contamination at 10-50% of the DCGLs.
- _____ Prepare area if necessary—clear and provide access to areas to be surveyed.
- _____ Establish reference coordinate systems (as appropriate).

SURVEY DESIGN

- _____ Enumerate DQOs: State objective of survey, state the null and alternative hypotheses, specify the acceptable decision error rates (Type I (α) and Type II (β)).
- _____ Specify sample collection and analysis procedures.
- _____ Determine numbers of data points for statistical tests, depending on whether or not the radionuclide is present in background.
 - _____ Specify the number of samples/measurements to be obtained based on the statistical tests.
 - _____ Evaluate the power of the statistical tests to determine that the number of samples is appropriate.
 - _____ Ensure that the sample size is sufficient for detecting areas of elevated activity.
 - _____ Add additional samples/measurements for QC and to allow for possible loss.
- _____ Specify sampling locations.
- _____ Provide information on survey instrumentation and techniques. The decision to use portable survey instrumentation or *in situ* techniques, and/or a combination of both, depends on whether or not the radiation levels are elevated compared to natural background, and whether or not the residual radioactivity is present at some fraction of background levels.
- _____ Specify methods of data reduction and comparison of survey units to reference areas.
- _____ Provide quality control procedures and QAPP for ensuring validity of survey data:
 - _____ properly calibrated instrumentation,
 - _____ necessary replicate, reference and blank measurements,
 - _____ comparison of field measurement results to laboratory sample analyses.
- _____ Document the survey plan (*e.g.*, QAPP, SOPs, *etc.*)

CONDUCTING SURVEYS

- _____ Perform reference (background) area measurements and sampling.
- _____ Conduct survey activities:
 - _____ Perform surface scans of the Class 1, Class 2, and Class 3 areas.
 - _____ Conduct surface activity measurements and sampling at previously selected sampling locations.
 - _____ Conduct additional direct measurements and sampling at locations based on professional judgment.
- _____ Perform and document any necessary investigation activities, including survey unit reclassification, remediation, and resurvey.
- _____ Document measurement and sample locations; provide information on measurement system MDC and measurement errors.
- _____ Document any observations, abnormalities, and deviations from the QAPP or SOPs

EVALUATING SURVEY RESULTS

- _____ Review DQOs.
- _____ Analyze samples.
- _____ Perform data reduction on survey results.
- _____ Verify assumptions of statistical tests.
- _____ Compare survey results with regulatory DCGLs:
 - _____ Conduct elevated measurement comparison.
 - _____ Determine area-weighted average, if appropriate.
 - _____ Conduct WRS or Sign tests.
- _____ Prepare final status survey report.
- _____ Obtain an independent review of the report.

6 FIELD MEASUREMENT METHODS AND INSTRUMENTATION

6.1 Introduction

Measurement is used in MARSSIM to mean 1) the act of using a detector to determine the level or quantity of radioactivity on a surface or in a sample of material removed from a media being evaluated, or 2) the quantity obtained by the act of measuring. Three methods are available for collecting radiation data while performing a survey—direct measurements, scanning, and sampling. This chapter discusses scanning and direct measurement methods and instrumentation. The collection and analysis of media samples are presented in Chapter 7. Information on the operation and use of individual field and laboratory instruments is provided in Appendix H. Quality assurance and quality control (QA/QC) are discussed in Chapter 9.

Total surface activities, removable surface activities, and radionuclide concentrations in various environmental media (*e.g.*, soil, water, air) are the radiological parameters typically determined using field measurements and laboratory analyses. Certain radionuclides or radionuclide mixtures may necessitate the measurement of alpha, beta, and gamma radiations. In addition to assessing each survey unit as a whole, any small areas of elevated activity should be identified and their extent and activities determined. Due to numerous detector requirements, no single instrument (detector and readout combination) is generally capable of adequately measuring all of the parameters required to satisfy the release criterion or meet all the objectives of a survey.

Selecting instrumentation requires evaluation of both site and radionuclide specific parameters and conditions. Instruments should be stable and reliable under the environmental and physical conditions where they are used, and their physical characteristics (size and weight) should be compatible with the intended application. The instrument and measurement method should be able to detect the type of radiation of interest, and should, in relation to the survey or analytical technique, be capable of measuring levels that are less than the derived concentration guideline level (DCGL). Numerous commercial firms offer a wide variety of instruments appropriate for the radiation measurements described in this manual. These firms can provide thorough information regarding capabilities, operating characteristics, limitations, *etc.*, for specific equipment.

If the field instruments and measurement methods cannot detect radiation levels below the DCGLs, laboratory methods discussed in Chapter 7 are typically used. A discussion of detection limits and detection levels for some typical instruments is presented in Section 6.7. There are certain radionuclides that will be essentially impossible to measure at the DCGLs *in situ* using current state-of-the-art instrumentation and techniques because of the types, energies, and abundances of their radiations. Examples of such radionuclides include very low energy, pure beta emitters such as ^3H and ^{63}Ni and low-energy photon emitters such as ^{55}Fe and ^{125}I . Pure alpha emitters dispersed in soil or covered with some absorbing layer may not be detectable because alpha radiation will not penetrate through the media or covering to reach the detector. A

common example of such a condition would be ^{230}Th surface contamination, covered by paint, dust, oil, or moisture. NRC report NUREG-1507 (NRC 1997a) provides information on the extent to which these surface conditions may affect detection sensitivity. In circumstances such as these, the survey design will usually rely on sampling and laboratory analysis to measure residual activity levels.

6.2 Data Quality Objectives

The third step of the Data Quality Objectives (DQO) Process involves identifying the data needs for a survey. One decision that can be made at this step is the selection of direct measurements for performing a survey or deciding that sampling methods followed by laboratory analysis are necessary.

6.2.1 Identifying Data Needs

The decision maker and the survey planning team need to identify the data needs for the survey being performed, including the:

- type of measurements to be performed (Chapter 5)
- radionuclide(s) of interest (Section 4.3)
- number of direct measurements to be performed (Section 5.5.2)
- area of survey coverage for surface scans based on survey unit classification (Section 5.5.3)
- type and frequency of field QC measurements to be performed (Section 4.9)
- measurement locations and frequencies (Section 5.5.2)
- standard operating procedures (SOPs) to be followed or developed (Chapter 6)
- analytical bias and precision (*e.g.*, quantitative or qualitative) (Appendix N, Section N.6)
- target detection limits for each radionuclide of interest (Section 6.4)
- cost of the methods being evaluated (cost per measurement as well as total cost) (Appendix H)
- necessary turnaround time
- specific background for the radionuclide(s) of interest (Section 4.5)
- derived concentration guideline level (DCGL) for each radionuclide of interest (Section 4.3)
- measurement documentation requirements
- measurement tracking requirements

Some of this information will be supplied by subsequent steps in the DQO process, and several iterations of the process may be needed to identify all of the data needs. Consulting with a health physicist or radiochemist may be necessary to properly evaluate the information before deciding

between direct measurements or sampling methods to perform the survey. Many surveys will involve a combination of direct measurements and sampling methods, along with scanning techniques, to demonstrate compliance with the release criterion.

6.2.2 Data Quality Indicators

The data quality indicators identified as DQOs in Section 2.3.1 and described in Appendix N should be considered when selecting a measurement method (*i.e.*, scanning, direct measurement, sampling) or a measurement system (*e.g.*, survey instrument, human operator, and procedure for performing measurements). In some instances, the data quality indicator requirements will help in the selection of a measurement system. In other cases, the requirements of the measurement system will assist in the selection of appropriate levels for the data quality indicators.

6.2.2.1 Precision

Precision is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions (ASQC 1995). Precision is determined quantitatively based on the results of replicate measurements (equations are provided in EPA 1990). The number of replicate analyses needed to determine a specified level of precision for a project is discussed in Section 4.9. Determining precision by replicating measurements with results at or near the detection limit of the measurement system is not recommended because the measurement uncertainty is usually greater than the desired level of precision. The types of replicate measurements applied to scanning and direct measurements are limited by the relatively uncomplicated measurement system (*i.e.*, the uncertainties associated with sample collection and preparation are eliminated). However, the uncertainties associated with applying a single calibration factor to a wide variety of site conditions mean these measurements are very useful for assessing data quality.

- Replicates to Measure Operator Precision. For scanning and direct measurements, replicates to measure operator precision provide an estimate of precision for the operator and the Standard Operating Procedure (SOP) or protocol used to perform the measurement. Replicates to measure operator precision are measurements performed using the same instrument at the same location, but with a different operator. Replicates to measure operator precision are usually non-blind or single-blind measurements.
- Replicates to Measure Instrument Precision. For scanning and direct measurements, replicates to measure instrument precision provide an estimate of precision for the type of instrument, the calibration, and the SOP or protocol used to perform the measurement. Replicates to measure instrument precision are measurements performed by the same operator at the same location, but with a different instrument. Replicates to measure instrument precision are usually non-blind or single-blind measurements.

For many surveys a combination of instrument and operator replicates are used to provide an estimate of overall precision for both scanning and direct measurements. Replicates of direct measurements can be compared with one another similar to the analytical results for samples. Results for scanning replicates may be obtained by stopping and recording instrument readings at specific intervals during the scanning survey (effectively performing direct measurements at specified locations). An alternative method for estimating the precision of scanning is to evaluate the effectiveness of the scanning survey for identifying areas of elevated activity. The results of scanning are usually locations that are identified for further investigation. A comparison of the areas identified by the replicate scanning surveys can be performed either quantitatively (using statistical methods) or qualitatively (using professional judgment). Because there is a necessity to evaluate whether the same number of locations were identified by both replicates as well as if the identified locations are the same, there is difficulty in developing precision as a DQO that can be evaluated.

6.2.2.2 Bias

Bias is the systematic or persistent distortion of a measurement process that causes error in one direction (EPA 1997a). Bias is determined quantitatively based on the measurement of materials with a known concentration. There are several types of materials with known concentrations that may be used to determine bias for scans and direct measurements.

- **Reference Material.** Reference material is a material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials (ISO 1993). A certified reference material is reference material for which each certified property value is accompanied by an uncertainty at a stated level of confidence. Radioactive reference materials may be available for certain radionuclides in soil (*e.g.*, uranium in soil), but reference building materials may not be available. Because reference materials are prepared and homogenized as part of the certification process, they are rarely available as double-blind samples. When appropriate reference materials are available (*i.e.*, proper matrix, proper radionuclide, proper concentration range) they are recommended for use in determining the overall bias for a measurement system. For scanning and direct measurements a known amount of reference material is sealed in a known geometry. This known material is measured in the field using a specified protocol (*e.g.*, specified measurement time at a specified distance from the reference material) to evaluate the performance of the instrument only.
- **Performance Evaluation (PE) Samples.** PE samples are used to evaluate the bias of the instrument and detect any error in the instrument calibration. These samples are usually prepared by a third party, using a quantity of analyte(s) which is known to the preparer but unknown to the operator, and always undergo certification analysis. The analyte(s)

used to prepare the PE sample is the same as the analyte(s) of interest (EPA 1991g). PE samples are recommended for use in determining bias for a measurement system when appropriate reference materials are not available. PE samples are equivalent to matrix spikes prepared by a third party that undergo certification analysis and can be non-blind or single-blind when used to measure bias for scanning and direct measurements.

- **Matrix Spike Samples.** Matrix spike samples are environmental samples that are spiked in the laboratory with a known concentration of a target analyte(s) to verify percent recoveries. They are primarily used to check sample matrix interferences but can also be used in the field to monitor instrument performance (EPA 1991g). Matrix Spike samples are often replicated to monitor a method's performance and evaluate bias and precision (when four or more pairs are analyzed). These replicates are often collectively referred to as a matrix spike/matrix spike duplicate (MS/MSD).
- **Calibration Checks.** Calibration checks are measurements performed to verify instrument performance each time an instrument is used (see Section 6.5.4). These checks may be qualitative or quantitative. Operators use qualitative checks to determine if an instrument is operating properly and can be used to perform measurements. Quantitative calibration checks require a specified protocol to measure a calibration source with a known instrument response, and the results are documented to provide a record of instrument precision and bias. The results of quantitative calibration checks are typically recorded on a control chart (see Section 6.2.2.7). Note that the calibration check source does not need to be traceable for qualitative or quantitative calibration checks as long as the instrument response has been adequately established (see Section 6.5.4). Because calibration checks are non-blind measurements they are only recommended when other types of QC measurements are not available.

Quality control measurements can also be used to estimate bias caused by contamination.

- **Background Measurement.** A background measurement is a measurement performed upgradient of the area of potential contamination (either onsite or offsite) where there is little or no chance of migration of the contaminants of concern (EPA 1991g). Background measurements are performed in the background reference area (Section 4.5), determine the natural composition and variability of the material of interest (especially important in areas with high concentrations of naturally occurring radionuclides), and are considered "clean." They provide a basis for comparison of contaminant concentration levels with measurements performed in the survey unit when the statistical tests described in Chapter 8 are performed.

- **Measurement Blanks.** Measurement blanks are samples prepared in the laboratory using certified clean sand or soil and brought to the field to monitor contamination for scanning and direct measurements. A measurement blank is used to evaluate contamination error associated with the instrument used to perform measurements in the field. Measurement blanks are recommended for determining bias resulting from contamination of instruments used for scanning and direct measurements.

6.2.2.3 Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point (ASQC 1995) or measurement location. Representativeness is a qualitative term that is reflected in the survey design through the selection of a measurement method (*e.g.*, direct measurement or sampling).

Sample collection and analysis is typically less representative of true radionuclide concentrations at a specific measurement location than performing a direct measurement. This is caused by the additional steps required in collecting and analyzing samples, such as sample collection, field sample preparation, laboratory sample preparation, and radiochemical analysis. However, direct measurement techniques with acceptable detection limits are not always available. The location of the direct measurement is determined in Section 5.5.2.5, where random and systematic survey designs are selected based on survey unit classification. The coverage for a survey unit using scanning techniques is discussed in Section 5.5.3 and is also based primarily on survey unit classification. Because scanning locations are often selected based on professional judgment for survey units with less than 100% coverage, representativeness of these locations may be a concern. For both scanning and direct measurements the measurement locations and method for performing the measurements should be compared to the modeling assumptions used to develop the DCGLs.

6.2.2.4 Comparability

Comparability is a qualitative term that expresses the confidence that two data sets can contribute to a common analysis and interpolation. Generally, comparability is provided by using the same measurement system for all analyses of a specific radionuclide. Comparability is usually not an issue except in cases where historical data has been collected and is being compared to current analytical results, or when multiple laboratories are used to provide results as part of a single survey design.

6.2.2.5 Completeness

Completeness is a measure of the amount of valid data obtained from the measurement system. This is expressed as a percentage of the number of valid measurements that should have been

collected. Completeness is of greater concern for laboratory analyses than for direct measurements because the consequences of incomplete data often require the collection of additional data. Completeness is a concern for scanning only if the scanning results are invalidated for some reason. Direct measurements and scans can usually be repeated fairly easily while the personnel performing the measurements are still in the field. For this reason MARSSIM strongly recommends that scanning and direct measurement results be evaluated as soon as possible. Direct measurements performed on a systematic grid to locate areas of elevated activity are also a concern for completeness. If one direct measurement result is not valid, the entire survey design for locating areas of elevated activity may be invalidated.

6.2.2.6 Other Data Quality Indicators

Several additional data quality indicators that influence the final status survey design are identified as DQOs in Section 2.3.1. Many of these (*e.g.*, selection and classification of survey units, decision error rates, variability in the contaminant concentration, lower bound of the gray region) are used to determine the number of measurements and are discussed in detail in Section 5.5.2. The method detection limit is directly related to the selection of a measurement method and a specific measurement system.

Scanning and direct measurement techniques should be capable of measuring levels below the established DCGLs—detection limits of 10-50% of the DCGL should be the target (see Section 6.7). Cost, time, best available technology, or other constraints may create situations where the above stated sensitivities are deemed impractical. Under these circumstances, higher detection sensitivities may be acceptable. Although service providers and instrument manufacturers will state detection limits, these sensitivities are usually based on ideal or optimistic situations and may not be achievable under site-specific measurement conditions. Detection limits are subject to variation from measurement to measurement, instrument to instrument, operator to operator, and procedure to procedure. This variation depends on geometry, background, instrument calibration, abundance of the radiations being measured, counting time, operator training, operator experience, self-absorption in the medium being measured, and interferences from radionuclides or other materials present in the medium. The detection limit that is achievable in practice should not exceed the DCGL.

6.2.2.7 Using Control Charts to Provide Control of Field Measurement Systems

Control charts are commonly used in radioanalytical laboratories to monitor the performance of laboratory instruments. Control charts are also useful for monitoring the performance of field instruments and can be used to help control field measurement systems.

A control chart is a graphical plot of measurement results with respect to time or sequence of measurement, together with limits within in which the measurement values are expected to lie

when the system is in a state of statistical control (DOE 1995). Calibration check results are typically plotted on control charts for field measurements. However, control charts may be developed for any measurements where the expected performance is established and documented. A separate set of control charts for monitoring each type of measurement (*e.g.*, calibration check, background, measurement of PE samples) should be developed for each instrument.

The control chart is constructed by preparing a graph showing the arithmetic mean and the control limits as horizontal lines. The recommended control limits are two standard deviations above and below the mean, and three standard deviations above and below the mean. The measurement results in the appropriate units are shown on the y-axis and time or sequence is plotted using the x-axis. Detailed guidance on the development and use of control charts is available in *Quality Assurance of Chemical Measurements* (Taylor 1987) and *Statistical Methods for Quality Improvement* (Kume 1985).

As the quality control or other measurements are performed, the results are entered on the control chart. If the results are outside the control limits or show a particular trend or tendency, then the process is not in control. The control chart documents the performance of the measurement system during the time period of interest.

Quality control measurements for field instruments may be difficult or expensive to obtain for some surveys. In these cases control charts documenting instrument performance may represent the only determination of precision and bias for the survey. Because control charts are non-blind measurements they are generally not appropriate for estimating precision and bias. However, the control chart documents the performance of the field instruments. Provided the checks for precision and bias fall within the control limits, the results obtained using that instrument should be acceptable for the survey.

6.3 Selecting a Service Provider to Perform Field Data Collection Activities

One of the first steps in designing a survey is to select a service provider to perform field data collection activities. MARSSIM recommends that this selection take place early in the planning process so that the service provider can provide information during survey planning and participate in the design of the survey. Service providers may include in-house experts in field measurements and sample collection, health physics companies, or environmental engineering firms among others.

When the service provider is not part of the organization responsible for the site, these services are obtained using some form of procurement mechanism. Examples of procurement mechanisms include purchase orders or contracts. A graded approach should be used in determining the appropriate method for procuring services.

Potential service providers should be evaluated to determine their ability to perform the necessary analyses. For large or complex sites, this evaluation may take the form of a pre-award audit. The results of this audit provide a written record of the decision to use a specific service provider. For less complex sites or facilities, a review of the potential service provider's qualifications is sufficient for the evaluation.

There are six criteria that should be reviewed during this evaluation:

- Does the service provider possess the validated Standard Operating Procedures (SOPs), appropriate instrumentation, and trained personnel necessary to perform the field data collection activities? Field data collection activities (e.g., scanning surveys, direct measurements, and sample collection) are defined by the data needs identified by the DQO process.
- Is the service provider experienced in performing the same or similar data collection activities?
- Does the service provider have satisfactory performance evaluation or technical review results? The service provider should be able to provide a summary of QA audits and QC measurement results to demonstrate proficiency. Equipment calibrations should be performed using National Institute of Standards and Technology (NIST) traceable reference radionuclide standards whenever possible.
- Is there an adequate capacity to perform all field data collection activities within the desired timeframe? This criterion considers the number of trained personnel and quantity of calibrated equipment available to perform the specified tasks.
- Does the service provider conduct an internal quality control review of all generated data that is independent of the data generators?
- Are there adequate protocols for method performance documentation, sample tracking and security (if necessary), and documentation of results?

Potential service providers should have an active and fully documented quality system in place.¹ This system should enable compliance with the objectives determined by the DQO process in Section 2.3 and Appendix D (see EPA 1994c). The elements of a quality management system are discussed in Section 9.1 (ASQC 1995, EPA 1994f).

¹ The quality management system is typically documented in one or more documents such as a Quality Management Plan (QMP) or Quality Assurance Manual (QAM). A description of quality systems is included in Section 9.1.

6.4 Measurement Methods

Measurement methods used to generate field data can be classified into two categories commonly known as scanning surveys and direct measurements. The decision to use a measurement method as part of the survey design is determined by the survey objectives and the survey unit classification. Scanning is performed to identify areas of elevated activity that may not be detected by other measurement methods. Direct measurements are analogous to collecting and analyzing samples to determine the average activity in a survey unit. Section 5.5.3 discusses combining scans and direct measurements in an integrated survey design.

6.4.1 Direct Measurements

To conduct direct measurements of alpha, beta, and photon surface activity, instruments and techniques providing the required detection sensitivity are selected. The type of instrument and method of performing the direct measurement are selected as dictated by the type of potential contamination present, the measurement sensitivity requirements, and the objectives of the radiological survey. Direct measurements are taken by placing the instrument at the appropriate distance² above the surface, taking a discrete measurement for a pre-determined time interval (*e.g.*, 10 s, 60 s, *etc.*), and recording the reading. A one minute integrated count technique is a practical field survey procedure for most equipment and provides detection sensitivities that are below most DCGLs. However, longer or shorter integrating times may be warranted (see Section 6.7.1 for information dealing with the calculation of direct measurement detection sensitivities).

Direct measurements may be collected at random locations in the survey unit. Alternatively, direct measurements may be collected at systematic locations and supplement scanning surveys for the identification of small areas of elevated activity (see Section 5.5.2.5). Direct measurements may also be collected at locations identified by scanning surveys as part of an investigation to determine the source of the elevated instrument response. Professional judgment may also be used to identify location for direct measurements to further define the areal extent of contamination and to determine maximum radiation levels within an area, although these types of direct measurements are usually associated with preliminary surveys (*i.e.*, scoping, characterization, remedial action support). All direct measurement locations and results should be documented.

² Measurements at several distances may be needed. Near-surface or surface measurements provide the best indication of the size of the contaminated region and are useful for model implementation. Gamma measurements at 1 m provide a good estimate of potential direct external exposure.

If the equipment and methodology used for scanning is capable of providing data of the same quality required for direct measurement (e.g., detection limit, location of measurements, ability to record and document results), then scanning may be used in place of direct measurements. Results should be documented for at least the number of locations required for the statistical tests. In addition, some direct measurement systems may be able to provide scanning data, provided they meet the objectives of the scanning survey.

The following sections briefly describe methods used to perform direct measurements in the field. The instruments used to perform these measurements are described in more detail in Section 6.5.3 and Appendix H.

6.4.1.1 Direct Measurements for Photon Emitting Radionuclides

There are a wide variety of instruments available for measuring photons in the field (see Appendix H) but all of them are used in essentially the same way. The detector is set up at a specified distance from the surface being measured and data are collected for a specified period of time. The distance from the surface to the detector is generally determined by the calibration of the instrument because photons do not interact appreciably with air. When measuring x-rays or low-energy gamma rays, the detector is often placed closer to the surface to increase the counting efficiency. The time required to perform a direct measurement may vary from very short (e.g., 10 seconds) to very long (e.g., several days or weeks) depending on the type of detector and the required detection limit. In general, the lower the required detection limit the longer the time required to perform the measurement. A collimator may be used in areas where activity from adjacent or nearby areas might interfere with the direct measurement. The collimator (usually lead, tungsten, or steel) shields the detector from extraneous photons but allows activity from a specified area of the surface to reach the detector.

Example:

The portable germanium detector, or *in situ* gamma spectrometer, can be used to estimate gamma-emitting radionuclide concentrations in the field. As with the laboratory-based germanium detector with multichannel analyzer, *in situ* gamma spectrometry can discriminate among various radionuclides on the basis of characteristic gamma and x-ray energies to provide a nuclide-specific measurement. A calibrated detector measures the fluence rate of primary photons at specific energies that are characteristic of a particular radionuclide (NRC 1995b). This fluence rate can then be converted to units of concentration. Under certain conditions the fluence rate may be converted directly to dose or risk for a direct comparison to the release criterion rather than to the DCGL_w. Although this conversion is generally made, the fluence rate should be considered the fundamental parameter for assessing the level of radiation at a specific location because it is a directly measurable physical quantity.

For outdoor measurements, where the contaminant is believed to be distributed within the surface soil, it may be appropriate to assume a uniform depth profile when converting the fluence rate to a concentration. At sites where the soil is plowed or overturned regularly, this assumption is quite realistic because of the effects of homogenization. At sites where the activity was initially deposited on the surface and has gradually penetrated deeper over time, the actual depth profile will have a higher activity at the surface and gradually diminish with depth. In this case, the assumption of a uniform depth profile will estimate a higher radionuclide concentration relative to the average concentration over that depth. In cases where there is an inverted depth profile (*i.e.*, low concentration at the surface that increase with depth), the assumption of a uniform depth profile will underestimate the average radionuclide concentration over that depth. For this reason, MARSSIM recommends that soil cores be collected to determine the actual depth profile for the site. These soil cores may be collected during the characterization or remedial action support survey to establish a depth profile for planning a final status survey. The cores may also be collected during the final status survey to verify the assumptions used to develop the fluence-to-concentration correction.

For indoor measurements, uncollimated *in situ* measurements can provide useful information on the low-level average activity across an entire room. The position of the measurement within the room is not critical if the radionuclide of interest is not present in the building materials. A measurement of peak count rate can be converted to fluence rate, which can in turn be related to the average surface activity. The absence of a discernible peak would mean that residual activity could not exceed a certain average level. However, this method will not easily locate small areas of elevated activity. For situations where the activity is not uniformly distributed on the surface, a series of collimated measurements using a systematic grid allows the operator to identify general areas of elevated contamination.

The NRC draft report *Measurement Methods for Radiological Surveys in Support of New Decommissioning Criteria* (NRC 1995b) provides a detailed description of the theory and implementation of *in situ* gamma spectrometry. *In situ* spectrometry is provided as one example of a useful tool for performing direct measurements for particular scenarios, but interpretation of the instrument output in terms of radionuclide distributions is dependent on the assumptions used to calibrate the method site-specifically. The depth of treatment of this technique in this example is not meant to imply that *in situ* gamma spectrometry is preferred *a priori* over other appropriate measurement techniques described in this manual.

6.4.1.2 Direct Measurements for Alpha Emitting Radionuclides

Direct measurements for alpha-emitting radionuclides are generally performed by placing the detector on or near the surface to be measured. The limited range of alpha particles (*e.g.*, about 1 cm or 0.4 in. in air, less in denser material) means that these measurements are generally restricted to relatively smooth, impermeable surfaces such as concrete, metal, or drywall where the activity is present as surface contamination. In most cases, direct measurements of porous (*e.g.*, wood) and volumetric (*e.g.*, soil, water) material cannot meet the objectives of the survey. However, special instruments such as the long range alpha detector (see Appendix H) have been developed to measure the concentration of alpha emitting radionuclides in soil under certain conditions. Because the detector is used in close proximity to the potentially contaminated surface, contamination of the detector or damage to the detector caused by irregular surfaces need to be considered before performing direct measurements for alpha emitters.

6.4.1.3 Direct Measurements for Beta Emitting Radionuclides

Direct measurements for beta emitting radionuclides are generally performed by placing the detector on or near the surface to be measured, similar to measurements for alpha emitting radionuclides. These measurements are typically restricted to relatively smooth, impermeable surfaces where the activity is present as surface contamination. In most cases, direct measurements of porous (*e.g.*, wood) and volumetric (*e.g.*, soil, water) material cannot meet the objectives of the survey. However, special instruments such as large area gas-flow proportional counters (see Appendix H) and arrays of beta scintillators have been developed to measure the concentration of beta emitting radionuclides in soil under certain conditions. Similar to direct measurements for alpha emitting radionuclides, contamination of the detector and damage to the detector need to be considered before performing direct measurements for beta emitters.

6.4.2 Scanning Surveys

Scanning is the process by which the operator uses portable radiation detection instruments to detect the presence of radionuclides on a specific surface (*i.e.*, ground, wall, floor, equipment). The term scanning survey is used to describe the process of moving portable radiation detectors across a suspect surface with the intent of locating radionuclide contamination. Investigation levels for scanning surveys are determined during survey planning to identify areas of elevated activity. Scanning surveys are performed to locate radiation anomalies indicating residual gross activity that may require further investigation or action. These investigation levels may be based on the $DCGL_w$, the $DCGL_{EMC}$, or some other level as discussed in Section 5.5.2.6.

Small areas of elevated activity typically represent a small portion of the site or survey unit. Thus, random or systematic direct measurements or sampling on the commonly used grid spacing may have a low probability of identifying such small areas. Scanning surveys are often relatively quick and inexpensive to perform. For these reasons, scanning surveys are typically performed before direct measurements or sampling. This way time is not spent fully evaluating an area that may quickly prove to be contaminated above the investigation level during the scanning process. Scans are conducted which would be indicative of all radionuclides potentially present, based on the Historical Site Assessment, surfaces to be surveyed, and survey design objectives. Surrogate measurements may be utilized where appropriate (see Section 4.3.2). Documenting scanning results and observations from the field is very important. For example, a scan that identified relatively sharp increases in instrument response or identified the boundary of an area of increased instrument response should be documented. This information is useful when interpreting survey results.

The following sections briefly describe techniques used to perform scanning surveys for different types of radiation. The instruments used to perform these measurements are described in more detail in Section 6.5.3 and Appendix H.

6.4.2.1 Scanning for Photon Emitting Radionuclides

Sodium iodide survey meters (NaI(Tl) detectors) are normally used for scanning areas for gamma emitters because they are very sensitive to gamma radiation, easily portable and relatively inexpensive. The detector is held close to the ground surface (~6 cm or 2.5 in.) and moved in a serpentine (*i.e.*, snake like, "S" shaped) pattern while walking at a speed that allows the investigator to detect the desired investigation level. A scan rate of approximately 0.5 m/s is typically used for distributed gamma emitting contaminants in soil; however, this rate must be adjusted depending on the expected detector response and the desired investigation level. Discussion of scanning rates versus detection sensitivity for gamma emitters is provided in Section 6.7.2.1.

Sodium iodide survey meters are also used for scanning to detect areas with elevated areas of low-energy gamma and x-ray emitting radionuclides such as ^{241}Am and ^{239}Pu . Specially designed detectors, such as the FIDLER (field instrument for the detection of low energy radiation) probe with survey meter, are typically used to detect these types of radionuclides.

6.4.2.2 Scanning for Alpha Emitting Radionuclides

Alpha scintillation survey meters and thin window gas-flow proportional counters are typically used for performing alpha surveys. Alpha radiation has a very limited range and, therefore, instrumentation must be kept close to the surface—usually less than 1 cm (0.4 in.). For this reason, alpha scans are generally performed on relatively smooth, impermeable surfaces (*e.g.*,

concrete, metal, drywall) and not on porous material (e.g., wood) or for volumetric contamination (e.g., soil, water). In most cases, porous and volumetric contamination cannot be detected by scanning for alpha activity and meet the objectives of the survey because of high detection sensitivities. Under these circumstances, samples of the material are usually collected and analyzed as discussed in Chapter 7. Determining scan rates when surveying for alpha emitters is discussed in Section 6.7.2.2 and Appendix J.

6.4.2.3 Scanning for Beta Emitting Radionuclides

Thin window gas-flow proportional counters are normally used when surveying for beta emitters, although solid scintillators designed for this purpose are also available. Typically, the beta detector is held less than 2 cm from the surface and moved at a rate such that the desired investigation level can be detected. Low-energy (<100 keV) beta emitters are subject to the same interferences and self-absorption problems found with alpha emitting radionuclides, and scans for these radionuclides are performed under similar circumstances. Determination of scan rates when surveying for beta emitters is discussed in Section 6.7.2.1.

6.5 Radiation Detection Instrumentation

Traditional radiation instruments consist of two components: 1) a radiation detector, and 2) electronic equipment to provide power to the detector and to display or record radiation events. This section identifies and very briefly describes the types of radiation detectors and associated display or recording equipment that are applicable to survey activities in support of environmental assessment or remedial action. Each survey usually requires performing direct field measurements using portable instrumentation and collection of samples for laboratory analysis. The selection and proper use of appropriate instruments for both direct measurements and laboratory analyses will likely be the most critical factors in assuring that the survey accurately determines the radiological status of a site and meets the survey objectives. Chapter 7 provides specific information on laboratory analysis of collected samples. Appendix H contains instrument specific information for various types of field survey and laboratory analysis equipment currently in use.

6.5.1 Radiation Detectors

The particular capabilities of a radiation detector will establish its potential applications in conducting a specific type of survey. Radiation detectors can be divided into four general classes based on the detector material or the application. These categories are: 1) gas-filled detectors, 2) scintillation detectors, 3) solid-state detectors, and 4) passive integrating detectors.

6.5.1.1 Gas-Filled Detectors

Radiation interacts with the fill gas, producing ion-pairs that are collected by charged electrodes. Commonly used gas-filled detectors are categorized as ionization, proportional, or Geiger-Mueller (GM), referring to the region of gas amplification in which they are operated. The fill gas varies, but the most common are: 1) air, 2) argon with a small amount of organic methane (usually 10% methane by mass, referred to as P-10 gas), and 3) argon or helium with a small amount of a halogen such as chlorine or bromine added as a quenching agent.

6.5.1.2 Scintillation Detectors

Radiation interacts with a solid or liquid medium causing electronic transitions to excited states in a luminescent material. The excited states decay rapidly, emitting photons that in turn are captured by a photomultiplier tube. The ensuing electrical signal is proportional to the scintillator light output, which, under the right conditions, is proportional to the energy loss that produced the scintillation. The most common scintillant materials are NaI(Tl), ZnS(Ag), Cd(Te), and CsI(Tl) which are used in traditional radiation survey instruments such as the NaI(Tl) detector used for gamma surveys and the ZnS(Ag) detector for alpha surveys.

6.5.1.3 Solid-State Detectors

Radiation interacting with a semiconductor material creates electron-hole pairs that are collected by a charged electrode. The design and operating conditions of a specific solid-state detector determines the types of radiations (alpha, beta, and/or gamma) that can be measured, the detection level of the measurements, and the ability of the detector to resolve the energies of the interacting radiations. The semiconductor materials currently being used are germanium and silicon which are available in both n and p types in various configurations.

Spectrometric techniques using these detectors provide a marked increase in sensitivity in many situations. When a particular radionuclide contributes only a fraction of the total particle or photon fluence, or both, from all sources (natural or manmade background), gross measurements are inadequate and nuclide-specific measurements are necessary. Spectrometry provides the means to discriminate among various radionuclides on the basis of characteristic energies. *In-situ* gamma spectrometry is particularly effective in field measurements since the penetrating nature of the radiation allows one to "see" beyond immediate surface contamination. The availability of large, high efficiency germanium detectors permits measurement of low abundance gamma emitters such as ^{238}U as well as low energy emitters such as ^{241}Am and ^{239}Pu .

6.5.1.4 Passive Integrating Detectors

There is an additional class of instruments that consists of passive, integrating detectors and associated reading/analyzing instruments. The integrated ionization is read using a laboratory or hand-held reader. This class includes thermoluminescence dosimeters (TLDs) and electret ion chambers (EICs). Because these detectors are passive and can be exposed for relatively long periods of time, they can provide better sensitivity for measuring low activity levels such as free release limits or for continuing surveillance. The ability to read and present data onsite is a useful feature and such systems are comparable to direct reading instruments.

The scintillation materials in Section 6.5.1.2 are selected for their prompt fluorescence characteristics. In another class of inorganic crystals, called TLDs, the crystal material and impurities are chosen so that the free electrons and holes created following the absorption of energy from the radiation are trapped by impurities in the crystalline lattice thus locking the excitation energy in the crystal. Such materials are used as passive, integrating detectors. After removal from the exposure area, the TLDs are heated in a reader which measures the total amount of light produced when the energy is released. The total amount of light is proportional to the number of trapped, excited electrons, which in turn is proportional to the amount of energy absorbed from the radiation. The intensity of the light emitted from the thermoluminescent crystals is thus directly proportional to the radiation dose. TLDs come in a large number of materials, the most common of which are LiF, $\text{CaF}_2\text{:Mn}$, $\text{CaF}_2\text{:Dy}$, $\text{CaSO}_4\text{:Mn}$, $\text{CaSO}_4\text{:Dy}$, $\text{Al}_2\text{O}_3\text{:C}$.

The electret ion chamber consists of a very stable electret (a charged Teflon® disk) mounted inside a small chamber made of electrically charged plastic. The ions produced inside this air filled chamber are collected onto the electret, causing a reduction of its surface charge. The reduction in charge is a function of the total ionization during a specific monitoring period and the specific chamber volume. This change in voltage is measured with a surface potential voltmeter.

6.5.2 Display and Recording Equipment

Radiation detectors are connected to electronic devices to 1) provide a source of power for detector operation, and 2) enable measurement of the quantity and/or quality of the radiation interactions that are occurring in the detector. The quality of the radiation interaction refers to the amount of energy transferred to the detector. In many cases, radiation interacts with other material (e.g., air) prior to interacting with the detector, or only partially interacts with the detector (e.g., Compton scattering for photons). Because the energy recorded by the detector is affected, there is an increased probability of incorrectly identifying the radionuclide.

The most common recording or display device used for portable radiation measurement systems is a ratemeter. This device provides a display on an analog meter representing the number of events occurring over some time period (e.g., counts per minute). Digital ratemeters are also commercially available. The number of events can also be accumulated over a preset time period using a digital scaling device. The resulting information from a scaling device is the total number of events that occurred over a fixed period of time, where a ratemeter display varies with time and represents a short term average of the event rate. Determining the average level on a ratemeter will require judgment by the user, especially when a low frequency of events results in significant variations in the meter reading.

Pulse height analyzers are specialized electronic devices designed to measure and record the number of pulses or events that occur at different pulse height levels. These types of devices are used with detectors which produce output pulses that are proportional in height to the energy deposited within them by the interacting radiation. They can be used to record only those events occurring in a detector within a single band of energy or can simultaneously record the events in multiple energy ranges. In the former case, the equipment is known as a single-channel analyzer; the latter application is referred to as a multichannel analyzer.

6.5.3 Instrument Selection

Radiation survey parameters that might be needed for site release purposes include surface activities, exposure rates, and radionuclide concentrations in soil. To determine these parameters, field measurements and laboratory analyses may be necessary. For certain radionuclides or radionuclide mixtures, both alpha and beta radiations may have to be measured. In addition to assessing average radiological conditions, the survey objectives should address identifying small areas of elevated activity and determining the extent and level of residual radioactivity.

Additionally, the potential uses of radiation instruments can vary significantly depending on the specific design and operating criteria of a given detector type. For example, a NaI(Tl) scintillator can be designed to be very thin with a low atomic number entrance window (e.g., beryllium) such that the effective detection capability for low energy photons is optimized. Conversely, the same scintillant material can be fabricated as a thick cylinder in order to optimize the detection probability for higher energy photons. On the recording end of a detection system, the output could be a ratemeter, scaler, or multichannel analyzer as described in Section 6.5.2. Operator variables such as training and level of experience with specific instruments should also be considered.

With so many variables, it is highly unlikely that any single instrument (detector and readout combination) will be capable of adequately measuring all of the radiological parameters necessary to demonstrate that criteria for release have been satisfied. It is usually necessary to select multiple instruments to perform the variety of measurements required.

Selection of instruments will require an evaluation of a number of situations and conditions. Instruments must be stable and reliable under the environmental and physical conditions where they will be used, and their physical characteristics (size and weight) should be compatible with the intended application. The instrument must be able to detect the type of radiation of interest, and the measurement system should be capable of measuring levels that are less than the DCGL (see Section 6.7).

For gamma radiation scanning, a scintillation detector/ratemeter combination is the usual instrument of choice. A large-area proportional detector with a ratemeter is recommended for scanning for alpha and beta radiations where surface conditions and locations permit; otherwise, an alpha scintillation or thin-window GM detector (for beta surveys) may be used.

For direct gamma measurements, a pressurized ionization chamber or *in-situ* gamma spectroscopy system is recommended. As an option, a NaI(Tl) scintillation detector may be used if cross-calibrated to a pressurized ion chamber or calibrated for the specific energy of interest. The same alpha and beta detectors identified above for scanning surveys are also recommended for use in direct measurements.

There are certain radionuclides that, because of the types, energies, and abundances of their radiations, will be essentially impossible to measure at the guideline levels, under field conditions, using state-of-the-art instrumentation and techniques. Examples of such radionuclides include very low energy pure beta emitters, such as ^3H and ^{63}Ni , and low energy photon emitters, such as ^{55}Fe and ^{125}I . Pure alpha emitters dispersed in soil or covered with some absorbing layer will not be detectable because the alpha radiation will not penetrate through the media or covering to reach the detector. A common example of such a condition would be ^{230}Th surface contamination covered by paint, dust, oil, or moisture. In such circumstances, sampling and laboratory analysis would be required to measure the residual activity levels unless surrogate radionuclides are present as discussed in Section 4.3.2.

The number of possible design and operating schemes for each of the different types of detectors is too large to discuss in detail within the context of this document. For a general overview, lists of common radiation detectors along with their usual applications during surveys are provided in Tables 6.1 through 6.3. Appendix H contains specific information for various types of field survey and laboratory analysis equipment currently in use. Continual development of new technologies will result in changes to these listings.

Table 6.1 Radiation Detectors with Applications to Alpha Surveys

| Detector Type | Detector Description | Application | Remarks |
|---|---|---|---|
| Gas Proportional | <1 mg/cm ² window; probe area 50 to 1000 cm ² | Surface scanning; surface contamination measurement | Requires a supply of appropriate fill gas |
| | <0.1 mg/cm ² window; probe area 10 to 20 cm ² | Laboratory measurement of water, air, and smear samples | |
| | No window (internal proportional) | Laboratory measurement of water, air, and smear samples | |
| Air Proportional | <1 mg/cm ² window; probe area ~50 cm ² | Useful in low humidity conditions | |
| Scintillation | ZnS(Ag) scintillator; probe area 50 to 100 cm ² | Surface contamination measurements, smears | |
| | ZnS(Ag) scintillator; probe area 10 to 20 cm ² | Laboratory measurement of water, air, and smear samples | |
| | Liquid scintillation cocktail containing sample | Laboratory analysis, spectrometry capabilities | |
| Solid State | Silicon surface barrier detector | Laboratory analysis by alpha spectrometry | |
| Passive, integrating electret ion chamber | <0.8 mg/cm ² window, also window-less, window area 50-180 cm ² , chamber volume 50-1,000 ml | Contamination on surfaces, in pipes and in soils | Useable in high humidity and temperature |

6.5.4 Instrument Calibration

Calibration refers to the determination and adjustment of the instrument response in a particular radiation field of known intensity. Proper calibration procedures are an essential requisite toward providing confidence in measurements made to demonstrate compliance with cleanup criteria. Certain factors, such as energy dependence and environmental conditions, require consideration in the calibration process, depending on the conditions of use of the instrument in the field. Routine calibration of radiation detection instruments refers to calibration for normal use under typical field conditions. Considerations for the use and calibration of instruments include:

Table 6.2 Radiation Detectors with Applications to Beta Surveys

| Detector Type | Detector Description | Application | Remarks |
|---|--|--|---|
| Gas Proportional | <1 mg/cm ² window; probe area 50 to 1,000 cm ² | Surface scanning; surface contamination measurement | Requires a supply of appropriate fill gas |
| | <0.1 mg/cm ² window; probe area 10 to 20 cm ² | Laboratory measurement of water, air, smear, and other samples | Can be used for measuring very low-energy betas |
| | No window (internal proportional) | Laboratory measurement of water, air, smear, and other samples | |
| Ionization (non-pressurized) | 1-7 mg/cm ² window | Contamination measurements; skin dose rate estimates | |
| Geiger-Mueller | <2 mg/cm ² window; probe area 10 to 100 cm ² | Surface scanning; contamination measurements; laboratory analyses | |
| | Various window thickness; few cm ² probe face | Special scanning applications | |
| Scintillation | Liquid scintillation cocktail containing sample | Laboratory analysis; spectrometry capabilities | |
| | Plastic scintillator | Contamination measurements | |
| Passive, integrating electret ion chamber | 7 mg/cm ² window, also window-less, window area 50-180 cm ² , chamber volume 50-1,000 ml | Low energy beta including H-3 contamination on surfaces and in pipes | Useable in high humidity and temperature |

- use of the instrument for radiation of the type for which the instrument is designed
- use of the instrument for radiation energies within the range of energies for which the instrument is designed
- use under environmental conditions for which the instrument is designed
- use under influencing factors, such as magnetic and electrostatic fields, for which the instrument is designed
- use of the instrument in an orientation such that geotropic effects are not a concern
- use of the instrument in a manner that will not subject the instrument to mechanical or thermal stress beyond that for which it is designed

Table 6.3 Radiation Detectors with Applications to Gamma Surveys

| Detector Type | Detector Description | Application | Remarks |
|---|--|--|---|
| Gas Ionization | Pressurized ionization chamber; Non-pressurized ionization chamber | Exposure rate measurements | |
| Geiger-Mueller | Pancake (<2 mg/cm ² window) or side window (~30 mg/cm ²) | Surface scanning; exposure rate correlation (side window in closed position) | Low relative sensitivity to gamma radiation |
| Scintillation | Nal(Tl) scintillator; up to 5 cm by 5 cm | Surface scanning; exposure rate correlation | High sensitivity; Cross calibrate with PIC (or equivalent) or for specific site gamma energy mixture for exposure rate measurements. Detection of low-energy radiation |
| | Nal(Tl) scintillator; large volume and "well" configurations | Laboratory gamma spectrometry | |
| | CsI or Nal(Tl) scintillator; thin crystal | Scanning; low-energy gamma and x-rays | |
| | Organic tissue equivalent (plastics) | Dose equivalent rate measurements | |
| Solid State | Germanium semi-conductor | Laboratory and field gamma spectrometry and spectroscopy | |
| Passive, integrating electret ion chamber | 7 mg/cm ² window, also window-less, window area 50-180 cm ² , chamber volume 50-1,000 ml | | Useable in high humidity and temperature |

Routine calibration commonly involves the use of one or more sources of a specific radiation type and energy, and of sufficient activity to provide adequate field intensities for calibration on all ranges of concern.

Actual field conditions under which the radiation detection instrument will be used may differ significantly from those present during routine calibration. Factors which may affect calibration validity include:

- the energies of radioactive sources used for routine calibration may differ significantly from those of radionuclides in the field
- the source-detector geometry (*e.g.*, point source or large area distributed source) used for routine calibration may be different than that found in the field
- the source-to-detector distance typically used for routine calibration may not always be achievable in the field
- the condition and composition of the surface being monitored (*e.g.*, sealed concrete, scabbled concrete, carbon steel, stainless steel, and wood) and the presence of overlaying material (*e.g.*, water, dust, oil, paint) may result in a decreased instrument response relative to that observed during routine calibration

If the actual field conditions differ significantly from the calibration assumptions, a special calibration for specific field conditions may be required. Such an extensive calibration need only be done once to determine the effects of the range of field conditions that may be encountered at the site. If responses under routine calibration conditions and proposed use conditions are significantly different, a correction factor or chart should be supplied with the instrument for use under the proposed conditions.

As a minimum, each measurement system (detector/readout combination) should be calibrated annually and response checked with a source following calibration (ANSI 1996). Instruments may require more frequent calibration if recommended by the manufacturer. Re-calibration of field instruments is also required if an instrument fails a performance check or if it has undergone repair or any modification that could affect its response.

The user may decide to perform calibrations following industry recognized procedures (ANSI 1996b, DOE Order 5484.1, NCRP 1978, NCRP 1985, NCRP 1991, ISO 1988, HPS 1994a, HPS 1994b), or the user can choose to obtain calibration by an outside service, such as a major instrument manufacturer or a health physics services organization.

Calibration sources should be traceable to the National Institute of Standards and Technology (NIST). Where NIST traceable standards are not available, standards obtained from an industry recognized organization (*e.g.*, the New Brunswick Laboratory for various uranium standards) may be used.

Calibration of instruments for measurement of surface contamination should be performed such that a direct instrument response can be accurately converted to the 4π (total) emission rate from the source. An accurate determination of activity from a measurement of count rate above a surface in most cases is an extremely complex task because of the need to determine appropriate characteristics of the source including decay scheme, geometry, energy, scatter, and self-absorption. For the purpose of release of contaminated areas from radiological control, measurements must provide sufficient accuracy to ensure that cleanup standards have been achieved. Inaccuracies in

measurements should be controlled in a manner that minimizes the consequences of decision errors. The variables that affect instrument response should be understood well enough to ensure that the consequences of decision errors are minimized. Therefore, the calibration should account for the following factors (where necessary):

- Calibrations for point and large area source geometries may differ, and both may be necessary if areas of activity smaller than the probe area and regions of activity larger than the probe area are present.
- Calibration should either be performed with the radionuclide of concern, or with appropriate correction factors developed for the radionuclide(s) present based on calibrations with nuclides emitting radiations similar to the radionuclide of concern.
- For portable instrumentation, calibrations should account for the substrate of concern (*i.e.*, concrete, steel) or appropriate correction factors developed for the substrates relative to the actual calibration standard substrate. This is especially important for beta emitters because backscatter is significant and varies with the composition of the substrate. Conversion factors developed during the calibration process should be for the same counting geometry to be used during the actual use of the detector.

For cleanup standards for building surfaces, the contamination level is typically expressed in terms of the particle emission rate per unit time per unit area, normally Bq/m² or disintegrations per minute (dpm) per 100 cm². In many facilities, surface contamination is assessed by converting the instrument response (in counts per minute) to surface activity using one overall total efficiency. The total efficiency may be considered to represent the product of two factors, the instrument (detector) efficiency, and the source efficiency. Use of the total efficiency is not a problem provided that the calibration source exhibits characteristics similar to the surface contamination (*i.e.*, radiation energy, backscatter effects, source geometry, self-absorption). In practice, this is hardly the case; more likely, instrument efficiencies are determined with a clean, stainless steel source, and then those efficiencies are used to determine the level of contamination on a dust-covered concrete surface. By separating the efficiency into two components, the surveyor has a greater ability to consider the actual characteristics of the surface contamination.

The instrument efficiency is defined as the ratio of the net count rate of the instrument and the surface emission rate of a source for a specified geometry. The surface emission rate is defined as the number of particles of a given type above a given energy emerging from the front face of the source per unit time. The surface emission rate is the 2π particle fluence that embodies both the absorption and scattering processes that effect the radiation emitted from the source. Thus, the instrument efficiency is determined by the ratio of the net count rate and the surface emission rate.

The instrument efficiency is determined during calibration by obtaining a static count with the detector over a calibration source that has a traceable activity or surface emission rate. In many cases, a source emission rate is measured by the manufacturer and certified as NIST traceable. The source activity is then calculated from the surface emission rate based on assumed backscatter and self-absorption properties of the source. The maximum value of instrument efficiency is 1.

The source efficiency is defined as the ratio of the number of particles of a given type emerging from the front face of a source and the number of particles of the same type created or released within the source per unit time. The source efficiency takes into account the increased particle emission due to backscatter effects, as well as the decreased particle emission due to self-absorption losses. For an ideal source (*i.e.*, no backscatter or self-absorption), the value of the source efficiency is 0.5. Many real sources will exhibit values less than 0.5, although values greater than 0.5 are possible, depending on the relative importance of the absorption and backscatter processes.

Source efficiencies may be determined experimentally. Alternatively, ISO-7503-1 (ISO 1988) makes recommendations for default source efficiencies. A source efficiency of 0.5 is recommended for beta emitters with maximum energies above 0.4 MeV. Alpha emitters and beta emitters with maximum beta energies between 0.15 and 0.4 MeV have a recommended source efficiency of 0.25. Source efficiencies for some common surface materials and overlaying material are provided in NUREG-1507 (NRC 1997b).

Instrument efficiency may be affected by detector-related factors such as detector size (probe surface area), window density thickness, geotropism, instrument response time, counting time (in static mode), scan rate (in scan mode), and ambient conditions such as temperature, pressure, and humidity. Instrument efficiency also depends on solid angle effects, which include source-to-detector distance and source geometry.

Source efficiency may be affected by source-related factors such as the type of radiation and its energy, source uniformity, surface roughness and coverings, and surface composition (*e.g.*, wood, metal, concrete).

The calibration of gamma detectors for the measurement of photon radiation fields should also provide reasonable assurance of acceptable accuracy in field measurements. Use of these instruments for demonstration of compliance with cleanup standards is complicated by the fact that most cleanup levels produce exposure rates of at most a few $\mu\text{R/h}$. Several of the portable survey instruments currently available in the United States for exposure rate measurements of $\sim 1 \mu\text{R/h}$ (often referred to as micro-R meters) have full scale intensities of ~ 3 to $5 \mu\text{R/h}$ on the first range. This is below the ambient background for most low radiation areas and most calibration laboratories. (A typical background dose equivalent rate of 100 mrem/y gives a

background exposure rate of about $10 \mu\text{R/h.}$) Even on the second range, the ambient background in the calibration laboratory is normally a significant part of the range and must be taken into consideration during calibration. The instruments commonly are not energy-compensated and are very sensitive to the scattered radiation that may be produced by the walls and floor of the room or additional shielding required to lower the ambient background.

Low intensity sources and large distances between the source and detector can be used for low-level calibrations if the appropriate precautions are taken. Field characterization of low-level sources with traceable transfer standards is difficult because of the poor signal-to-noise ratio in the standard chamber. In order to achieve adequate ionization current, the distance between the standard chamber and the source generally will be as small as possible while still maintaining good geometry (5 to 7 detector diameters). Generally it is not possible to use a standard ionization chamber to characterize the field at the distance necessary to reduce the field to the level required for calibration. A high quality GM detector, calibrated as a transfer standard, may be useful at low levels.

Corrections for scatter can be made using a shadow-shield technique in which a shield of sufficient density and thickness to eliminate virtually all the primary radiation is placed about midway between the source and the detector. The dimensions of the shield should be the minimum required to reduce the primary radiation intensity at the detector location to less than 2% of its unshielded value. The change in reading caused by the shield being removed is attributed to the primary field from the source at the detector position.

In some instruments that produce pulses (GM counters or scintillation counters), the detector can be separated electronically from the readout electronics and the detector output can be simulated with a suitable pulser. Caution must be exercised to ensure that either the high voltage is properly blocked or that the pulser is designed for this application. If this can be accomplished, the instrument can first be calibrated on a higher range that is not affected by the ambient background and in a geometry where scatter is not a problem and, after disconnecting the detector, to provide the pulse-rate from the pulser which will give the same instrument response. The pulse rate can then be related to field strength and reduced to give readings on lower ranges (with the detector disconnected) even below the ambient background. This technique does not take account of any inherent detector background independent of the external background.

Ionization chambers are commonly used to measure radiation fields at very low levels. In order to obtain the sensitivity necessary to measure these radiation levels, the instruments are frequently very large and often pressurized. These instruments have the same calibration problems as the more portable micro-R meters described above. The same precautions (shadow shield) must be taken to separate the response of the instrument to the source and to scattered radiation. Generally, it is not possible to substitute an electronic pulser for the radiation field in these instruments.

For energy-dependent gamma scintillation instruments, such as NaI(Tl) detectors, calibration for the gamma energy spectrum at a specific site may be accomplished by comparing the instrument response to that of a pressurized ionization chamber, or equivalent detector, at different locations on the site. Multiple radionuclides with various photon energies may also be used to calibrate the system for the specific energy of interest.

In the interval between calibrations, the instrument should receive a performance check prior to use. In some cases, a performance check following use may also provide valuable information. This calibration check is merely intended to establish whether or not the instrument is operating within certain specified, rather large, uncertainty limits. The initial performance check should be conducted following the calibration by placing the source in a fixed, reproducible location and recording the instrument reading. The source should be identified along with the instrument, and the same check source should be used in the same fashion to demonstrate the instrument's operability on a daily basis when the instrument is in use. For analog readout (count rate) instruments, a variation of $\pm 20\%$ is usually considered acceptable. Optionally, instruments that integrate events and display the total on a digital readout typically provide an acceptable average response range of 2 or 3 standard deviations. This is achieved by performing a series of repetitive measurements (10 or more is suggested) of background and check source response and determining the average and standard deviation of those measurements. From a practical standpoint, a maximum deviation of $\pm 20\%$ is usually adequate when compared with other uncertainties associated with the use of the equipment. The amount of uncertainty allowed in the response checks should be consistent with the level of uncertainty allowed in the final data. Ultimately the decision maker determines what level of uncertainty is acceptable.

Instrument response, including both the background and check source response of the instrument, should be tested and recorded at a frequency that ensures the data collected with the equipment is reliable. For most portable radiation survey equipment, MARSSIM recommends that a response check be performed twice daily when in use—typically prior to beginning the day's measurements and again following the conclusion of measurements on that same day. Additional checks can be performed if warranted by the instrument and the conditions under which it is used. If the instrument response does not fall within the established range, the instrument is removed from use until the reason for the deviation can be resolved and acceptable response again demonstrated. If the instrument fails the post-survey source check, all data collected during that time period with the instrument must be carefully reviewed and possibly adjusted or discarded, depending on the cause of the failure. Ultimately, the frequency of response checks must be balanced with the stability of the equipment being used under field conditions and the quantity of data being collected. For example, if the instrument experiences a sudden failure during the course of the day's work due to physical harm, such as a punctured probe, then the data collected up until that point is probably acceptable even though a post-use performance check cannot be performed. Likewise, if no obvious failure occurred but the instrument failed the post-use response check, then the data collected with that instrument since the last response check should be viewed with

great skepticism and possibly re-collected or randomly checked with a different instrument. Additional corrective action alternatives are presented in Section 9.3. If re-calibration is necessary, acceptable response ranges must be reestablished and documented.

Record requirements vary considerably and depend heavily on the needs of the user. While Federal and State regulatory agencies all specify requirements, the following records should be considered a minimum.

Laboratory Quality Control

- records documenting the traceability of radiological standards
- records documenting the traceability of electronic test equipment

Records for Instruments to be Calibrated

- date received in the calibration laboratory
- initial condition of the instrument, including mechanical condition (*e.g.*, loose or broken parts, dents, punctures), electrical condition (*e.g.*, switches, meter movement, batteries), and radiological condition (presence or absence of contamination)
- calibrator's records including training records and signature on calibration records
- calibration data including model and serial number of instrument, date of calibration, recommended recalibration date, identification of source(s) used, "as found" calibration results, and final calibration results—"as returned" for use.

In addition, records of instrument problems, failures, and maintenance can be included and are useful in assessing performance and identifying possible needs for altered calibration frequencies for some instruments. Calibration records should be maintained at the facility where the instruments are used as permanent records, and should be available either as hard copies or in safe computer storage.

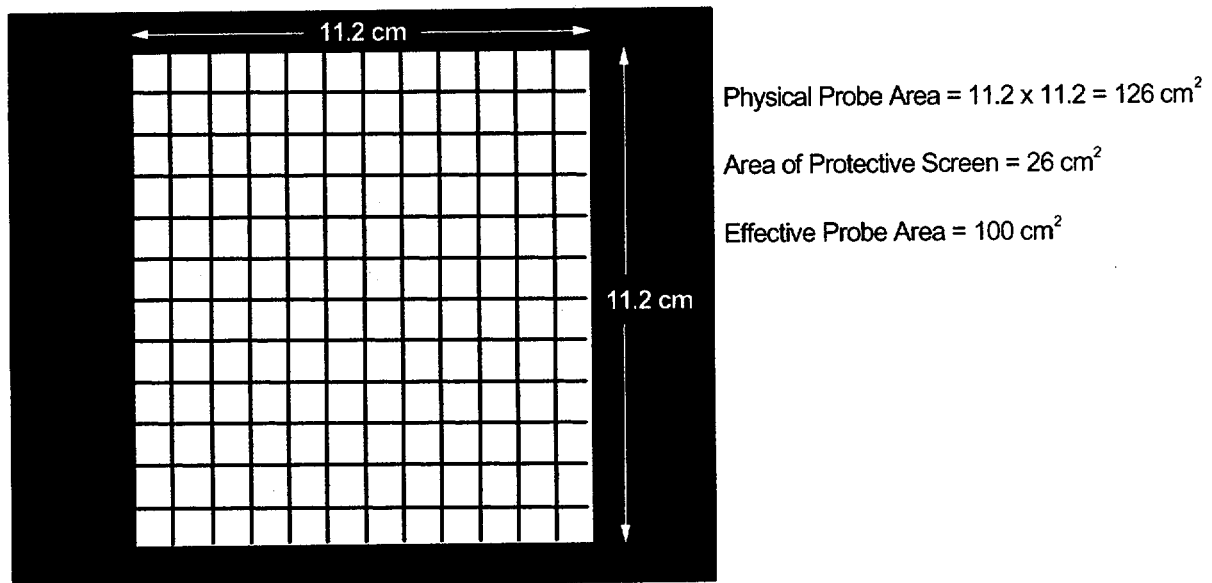
6.6 Data Conversion

This section describes methods for converting survey data to appropriate units for comparison to radiological criteria. As stated in Chapter 4, conditions applicable to satisfying decommissioning requirements include determining that any residual contamination will not result in individuals being exposed to unacceptable levels of radiation and/or radioactive materials.

Radiation survey data are usually obtained in units, such as the number of counts per unit time, that have no intrinsic meaning relative to DCGLs. For comparison of survey data to DCGLs, the survey data from field and laboratory measurements should be converted to DCGL units.

6.6.1 Surface Activity

When measuring surface activity, it is important to account for the physical surface area assessed by the detector in order to make probe area corrections and report data in the proper units (*i.e.*, Bq/m², dpm/100 cm²). This is termed the *physical probe area*. A common misuse is to make probe area corrections using the *effective probe area* which accounts for the amount of the physical probe area covered by a protective screen. Figure 6.1 illustrates the difference between the physical probe area and the effective probe area. The physical probe area is used because the reduced detector response due to the screen is accounted for during instrument calibration.



Gas Flow Proportional Detector with Physical Probe Area of 126 cm²

Figure 6.1 The Physical Probe Area of a Detector

The conversion of instrument display in counts to surface activity units is obtained using the following equation.

$$\text{Bq/m}^2 = \frac{\frac{C_s}{T_s}}{(\epsilon_T \times A)} \quad (6-1)$$

where

| | | |
|--------------|---|---|
| C_s | = | integrated counts recorded by the instrument |
| T_s | = | time period over which the counts were recorded in seconds |
| ϵ_T | = | total efficiency of the instrument in counts per disintegration, effectively the product of the instrument efficiency (ϵ_i) and the source efficiency (ϵ_s) |
| A | = | physical probe area in m^2 |

To convert instrument counts to conventional surface activity units, Equation 6-1 can be modified as shown in Equation 6-2.

$$\frac{dpm}{100 \text{ cm}^2} = \frac{\frac{C_s}{T_s}}{(\epsilon_T) \times (A/100)} \quad (6-2)$$

where T_s is recorded in minutes instead of seconds, and A is recorded in cm^2 instead of m^2 .

Some instruments have background counts associated with the operation of the instrument. A correction for instrument background can be included in the data conversion calculation as shown in Equation 6-3. Note that the instrument background is not the same as the measurements in the background reference area used to perform the statistical tests described in Chapter 8.

$$Bq/m^2 = \frac{\frac{C_s}{T_s} - \frac{C_b}{T_b}}{(\epsilon_T \times A)} \quad (6-3)$$

where

| | | |
|-------|---|---|
| C_b | = | background counts recorded by the instrument |
| T_b | = | time period over which the background counts were recorded in seconds |

Equation 6-3 can be modified to provide conventional surface activity units as shown in Equation 6-4.

$$\frac{dpm}{100 \text{ cm}^2} = \frac{\frac{C_s}{T_s} - \frac{C_b}{T_b}}{(\hat{\epsilon}_T) \times (A/100)} \quad (6-4)$$

where T_s and T_b are recorded in minutes instead of seconds and A is recorded in cm^2 instead of m^2 .

The presence of multiple radionuclides at a site requires additional considerations for demonstrating compliance with a dose- or risk-based regulation. As demonstrated in Section 4.3.2, a gross activity DCGL should be determined. For example, consider a site contaminated with ^{60}Co and ^{63}Ni , with ^{60}Co representing 60% of the total activity. The relative fractions are 0.6 for ^{60}Co and 0.4 for ^{63}Ni . If the DCGL for ^{60}Co is $8,300 \text{ Bq/m}^2$ ($5,000 \text{ dpm/100 cm}^2$) and the DCGL for ^{63}Ni is $12,000 \text{ Bq/m}^2$ ($7,200 \text{ dpm/100 cm}^2$), the gross activity DCGL is $9,500 \text{ Bq/m}^2$ ($5,700 \text{ dpm/100 cm}^2$) calculated using Equation 4-4.

When using the gross activity DCGL, it is important to use an appropriately weighted total efficiency to convert from instrument counts to surface activity units using Equations 6-1 through 6-4. In this example, the individual efficiencies for ^{60}Co and ^{63}Ni should be independently evaluated. The overall efficiency is then determined by weighting each individual efficiency by the relative fraction of each radionuclide.

6.6.2 Soil Radionuclide Concentration and Exposure Rates

Analytical procedures, such as alpha and gamma spectrometry, are typically used to determine the radionuclide concentration in soil in units of Bq/kg . Net counts are converted to soil DCGL units by dividing by the time, detector or counter efficiency, mass or volume of the sample, and by the fractional recovery or yield of the chemistry procedure (if applicable). Refer to Chapter 7 for examples of analytical procedures.

Instruments, such as a PIC or micro-R meter, used to measure exposure rate typically read directly in mSv/h . A gamma scintillation detector (e.g., NaI(Tl)) provides data in counts per minute and conversion to mSv/h is accomplished by using site-specific calibration factors developed for the specific instrument (Section 6.5.4).

In situ gamma spectrometry data may require special analysis routines before the spectral data can be converted to soil concentration units or exposure rates.

6.7 Detection Sensitivity

The detection sensitivity of a measurement system refers to a radiation level or quantity of radioactive material that can be measured or detected with some known or estimated level of confidence. This quantity is a factor of both the instrumentation and the technique or procedure being used.

The primary parameters that affect the detection capability of a radiation detector are the background count rate, the detection efficiency of the detector and the counting time interval. It is important to use actual background count rate values and detection efficiencies when determining counting and scanning parameters, particularly during final status and verification surveys. When making field measurements, the detection sensitivity will usually be less than what can be achieved in a laboratory due to increased background and, often times, a significantly lower detection efficiency. It is often impossible to guarantee that pure alpha emitters can be detected *in situ* since the weathering of aged surfaces will often completely absorb the alpha emissions. NRC report NUREG-1507 (NRC 1997b) contains data on many of the parameters that affect detection efficiencies *in situ*, such as absorption, surface smoothness, and particulate radiation energy.

6.7.1 Direct Measurement Sensitivity

Prior to performing field measurements, an investigator must evaluate the detection sensitivity of the equipment proposed for use to ensure that levels below the DCGL can be detected (see Section 4.3). After a direct measurement has been made, it is then necessary to determine whether or not the result can be distinguished from the instrument background response of the measurement system. The terms that are used in this manual to define detection sensitivity for fixed point counts and sample analyses are:

- Critical level (L_C)
- Detection limit (L_D)
- Minimum detectable concentration (MDC)

The critical level (L_C) is the level, in counts, at which there is a statistical probability (with a predetermined confidence) of incorrectly identifying a measurement system background value as "greater than background." Any response above this level is considered to be greater than background. The detection limit (L_D) is an *a priori* estimate of the detection capability of a measurement system, and is also reported in units of counts. The minimum detectable concentration (MDC) is the detection limit (counts) multiplied by an appropriate conversion factor to give units consistent with a site guideline, such as Bq/kg.

The following discussion provides an overview of the derivation contained in the well known publication by Currie (Currie 1968) followed by a description of how the resulting formulae should be used. Publications by Currie (Currie 1968, NRC 1984) and Altshuler and Pasternack (Altshuler and Pasternack 1963) provide details of the derivations involved.

The two parameters of interest for a detector system with a background response greater than zero are:

- L_C the net response level, in counts, at which the detector output can be considered "above background"
- L_D the net response level, in counts, that can be expected to be seen with a detector with a fixed level of certainty

Assuming that a system has a background response and that random uncertainties and systematic uncertainties are accounted for separately, these parameters can be calculated using Poisson statistics. For these calculations, two types of decision errors should be considered. A Type I error (or "false positive") occurs when a detector response is considered to be above background when, in fact, only background radiation is present. A Type II error (or "false negative") occurs when a detector response is considered to be background when in fact radiation is present at levels above background. The probability of a Type I error is referred to as α (alpha) and is associated with L_C ; the probability of a Type II error is referred to as β (beta) and is associated with L_D . Figure 6.2 graphically illustrates the relationship of these terms with respect to each other and to a normal background distribution.

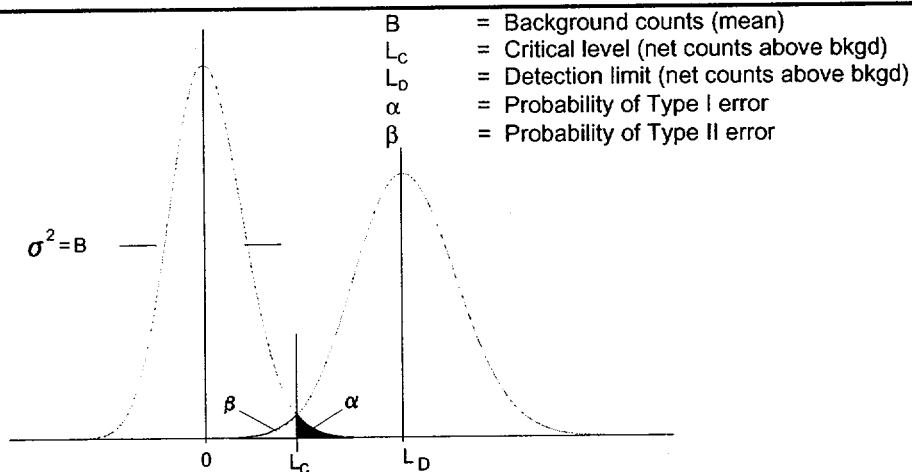


Figure 6.2 Graphically Represented Probabilities for Type I and Type II Errors in Detection Sensitivity for Instrumentation with a Background Response

If α and β are assumed to be equal, the variance (σ^2) of all measurement values is assumed to be equal to the values themselves. If the background of the detection system is not well known, then the critical detection level and the detection limit can be calculated by using the following formulae:

$$\begin{aligned}
 L_C &= k\sqrt{2B} \\
 L_D &= k^2 + 2k\sqrt{2B}
 \end{aligned}
 \tag{6-5}$$

where

| | | |
|-------|---|---|
| L_C | = | critical level (counts) |
| L_D | = | detection limit (counts) |
| k | = | Poisson probability sum for α and β (assuming α and β are equal) |
| B | = | number of background counts that are expected to occur while performing an actual measurement |

The curve to the left in the diagram is the background distribution minus the mean of the background distribution. The result is a Poisson distribution with a mean equal to zero and a variance, σ^2 , equal to B . Note that the distribution accounts only for the expected statistical variation due to the stochastic nature of radioactive decay. Currie assumed "paired blanks" when deriving the above stated relationships (Currie 1968), which is interpreted to mean that the sample and background count times are the same.

If values of 0.05 for both α and β are selected as acceptable, then $k = 1.645$ (from Appendix I, Table I.1) and Equation 6-5 can be written as:

$$\begin{aligned}
 L_C &= 2.33\sqrt{B} \\
 L_D &= 3 + 4.65\sqrt{B}
 \end{aligned}
 \tag{6-6}$$

Note: In Currie's derivation, the constant factor of 3 in the L_D formula was stated as being 2.71, but since that time it has been shown (Brodsky 1992) and generally accepted that a constant factor of 3 is more appropriate. If the sample count times and background count times are different, a slightly different formulation is used.

For an integrated measurement over a preset time, the MDC can be obtained from Equation 6-6 by multiplying by the factor, C . This factor is used to convert from counts to concentration as shown in Equation 6-7:

$$MDC = C \times (3 + 4.65\sqrt{B}) \tag{6-7}$$

The total detection efficiency and other constants or factors represented by the variable C are usually not truly constants as shown in Equation 6-7. It is likely that at least one of these factors will have a certain amount of variability associated with it which may or may not be significant. These varying factors are gathered together into the single constant, C , by which the net count result will be multiplied when converting the final data. If C varies significantly between measurements, then it might be best to select a value, C' , from the observed distribution of C values that represents a conservative estimate. For example, a value of C might be selected to ensure that at least 95% of the possible values of C are less than the chosen value, C' . The MDC calculated in this way helps assure that the survey results will meet the Data Quality Objectives. This approach for including uncertainties into the MDC calculation is recommended in both NUREG/CR-4007 (NRC 1984) and Appendix A to ANSI N13.30 (ANSI 1996a). Underestimating an MDC can have adverse consequences, especially if activity is later detected at a level above the stated MDC.

Summary of Direct Measurement Sensitivity Terms

- The MDC is the *a priori* net activity level above the critical level that an instrument can be expected to detect 95% of the time. This value should be used when stating the detection capability of an instrument. The MDC is the detection limit, L_D , multiplied by an appropriate conversion factor to give units of activity. Again, this value is used before any measurements are made and is used to estimate the level of activity that can be detected using a given protocol.
- The critical level, L_C , is the lower bound on the 95% detection interval defined for L_D and is the level at which there is a 5% chance of calling a background value "greater than background." This value should be used when actually counting samples or making direct radiation measurements. Any response above this level should be considered as above background (*i.e.*, a net positive result). This will ensure 95% detection capability for L_D .
- From a conservative point of view, it is better to overestimate the MDC for a measurement method. Therefore, when calculating MDC and L_C values, a measurement system background value should be selected that represents the high end of what is expected for a particular measurement method. For direct measurements, probes will be moved from point to point and, as a result, it is expected that the background will most likely vary significantly due to variations in background, source materials, and changes in geometry and shielding. Ideally, the MDC values should be calculated for each type of area, but it may be more economical to simply select a background value from the highest distribution expected and use this for all calculations. For the same reasons, realistic values of detection efficiencies and other process parameters should be used when possible and should be reflective of the actual conditions. To a great degree, the selection of these parameters will be based on judgment and will require evaluation of site-specific conditions.

MDC values for other counting conditions may be derived from Equation 6-7 depending on the detector and contaminants of concern. For example, it may be required to determine what level of contamination, distributed over 100 cm², can be detected with a 500 cm² probe or what contamination level can be detected with any probe when the contamination area is smaller than the probe active area. Table 6.4 lists several common field survey detectors with estimates of MDC values for ²³⁸U on a smooth, flat plane. As such, these represent minimum MDC values and may not be applicable at all sites. Appropriate site-specific MDC values should be determined using the DQO Process.

Table 6.4 Examples of Estimated Detection Sensitivities for Alpha and Beta Survey Instrumentation

(Static one minute counts for ²³⁸U calculated using Equations 6-6 and 6-7)

| Detector | Probe area (cm ²) | Background (cpm) | Efficiency (cpm/dpm) | Approximate Sensitivity | | |
|---------------------|----------------------------------|---------------------|-------------------------|----------------------------|----------------------------|--|
| | | | | L _C (counts) | L _D (counts) | MDC (Bq/m ²) ^a |
| Alpha proportional | 50 | 1 | 0.15 | 2 | 7 | 150 |
| Alpha proportional | 100 | 1 | 0.15 | 2 | 7 | 83 |
| Alpha proportional | 600 | 5 | 0.15 | 5 | 13 | 25 |
| Alpha scintillation | 50 | 1 | 0.15 | 2 | 7 | 150 |
| Beta proportional | 100 | 300 | 0.20 | 40 | 83 | 700 |
| Beta proportional | 600 | 1500 | 0.20 | 90 | 183 | 250 |
| Beta GM pancake | 15 | 40 | 0.20 | 15 | 32 | 1800 |

^a Assumes that the size of the contamination area is at least as large as the probe area.

Sample Calculation 1:

The following example illustrates the calculation of an MDC in Bq/m² for an instrument with a 15 cm² probe area when the measurement and background counting times are each one minute:

$$\begin{aligned}
 B &= 40 \text{ counts} \\
 C &= (5 \text{ dpm/count})(\text{Bq}/60 \text{ dpm})(1/15 \text{ cm}^2 \text{ probe area})(10,000 \text{ cm}^2/\text{m}^2) \\
 &= 55.6 \text{ Bq/m}^2\text{-counts}
 \end{aligned}$$

The MDC is calculated using Equation 6-7:

$$MDC = 55.6 \times (3 + 4.65 \sqrt{40}) = 5,000 \text{ Bq/m}^2 \text{ (3,000 dpm/100 cm}^2\text{)}$$

The critical level, L_c , for this example is calculated from Equation 6-6:

$$L_c = 2.33\sqrt{B} = 15 \text{ counts}$$

Given the above scenario, if a person asked what level of contamination could be detected 95% of the time using this method, the answer would be 5,000 Bq/m² (3,000 dpm/100 cm²). When actually performing measurements using this method, any count yielding greater than 55 total counts, or greater than 15 net counts (55-40=15) during a period of one minute, would be regarded as greater than background.

6.7.2 Scanning Sensitivity

The ability to identify a small area of elevated radioactivity during surface scanning is dependent upon the surveyor's skill in recognizing an increase in the audible or display output of an instrument. For notation purposes, the term "scanning sensitivity" is used throughout this section to describe the ability of a surveyor to detect a pre-determined level of contamination with a detector. The greater the sensitivity, the lower the level of contamination that can be detected.

Many of the radiological instruments and monitoring techniques typically used for occupational health physics activities may not provide the detection sensitivities necessary to demonstrate compliance with the DCGLs. The detection sensitivity for a given application can be improved (*i.e.*, lower the MDC) by: 1) selecting an instrument with a higher detection efficiency or a lower background, 2) decreasing the scanning speed, or 3) increasing the size of the effective probe area without significantly increasing the background response.

Scanning is usually performed during radiological surveys in support of decommissioning to identify the presence of any areas of elevated activity. The probability of detecting residual contamination in the field depends not only on the sensitivity of the survey instrumentation when used in the scanning mode of operation, but is also affected by the surveyor's ability—*i.e.*, human factors. The surveyor must make a decision whether the signals represent only the background

activity, or residual contamination in excess of background. The greater the sensitivity, the lower the level of contamination that may be detected by scanning. Accounting for these human factors represents a significant change from the traditionally accepted methods of estimating scanning sensitivities.

An empirical method for evaluating the detection sensitivity for contamination surveys is by actual experimentation or, since it is certainly feasible, by simulating an experimental setup using computer software. The following steps provide a simple example of how one can perform this empirical evaluation:

- 1) A desired nuclide contamination level is selected.
- 2) The response of the detector to be used is determined for the selected nuclide contamination level.
- 3) A test source is constructed which will give a detector count rate equivalent to what was determined in step 2. The count rate is equivalent to what would be expected from the detector when placed on an actual contamination area equal in value to that selected in step 1.
- 4) The detector of choice is then moved over the source at different scan rates until an acceptable speed is determined.

The most useful aspect of this approach is that the source can then be used to show surveyors what level of contamination is expected to be targeted with the scan. They, in turn, can gain experience with what the expected response of the detector will be and how fast they can survey and still feel comfortable about detecting the target contamination level. The person responsible for the survey can then use this information when developing a fixed point measurement and sampling plan.

The remainder of this section is dedicated to providing the reader with information pertaining to the underlying processes involved when performing scanning surveys for alpha, beta, and gamma emitting radionuclides. The purpose is to provide relevant information that can be used for estimating realistic scanning sensitivities for survey activities.

6.7.2.1 Scanning for Beta and Gamma Emitters

The minimum detectable concentration of a scan survey (scan MDC) depends on the intrinsic characteristics of the detector (efficiency, physical probe area, *etc.*), the nature (type and energy of emissions) and relative distribution of the potential contamination (point versus distributed source and depth of contamination), scan rate, and other characteristics of the surveyor. Some factors that may affect the surveyor's performance include the costs associated with various outcomes—*e.g.*, fatigue, noise, level of training, experience—and the survey's *a priori* expectation of the likelihood of contamination present. For example, if the surveyor believes that

the potential for contamination is very low, as in a Class 3 area, a relatively large signal may be required for the surveyor to conclude that contamination is present. NRC draft report NUREG/CR-6364 (NRC 1997d) provides a complete discussion of the human factors as they relate to the performance of scan surveys.

Signal Detection Theory. Personnel conducting radiological surveys for residual contamination at decommissioning sites must interpret the audible output of a portable survey instrument to determine when the signal ("clicks") exceeds the background level by a margin sufficient to conclude that contamination is present. It is difficult to detect low levels of contamination because both the signal and the background vary widely. Signal detection theory provides a framework for the task of deciding whether the audible output of the survey meter during scanning is due to background or signal plus background levels. An index of sensitivity (d') that represents the distance between the means of the background and background plus signal (refer to Figure 6.2 for determining L_D), in units of their common standard deviation, can be calculated for various decision errors (correct detection and false positive rate). As an example, for a correct detection rate of 95% (complement of a false negative rate of 5%) and a false positive rate of 5%, d' is 3.29 (similar to the static MDC for the same decision error rates). The index of sensitivity is independent of human factors, and therefore, the ability of an ideal observer (theoretical construct), may be used to determine the minimum d' that can be achieved for particular decision errors. The ideal observer makes optimal use of the available information to maximize the percent correct responses, providing an effective upper bound against which to compare actual surveyors. Table 6.5 lists selected values of d' .

Two Stages of Scanning. The framework for determining the scan MDC is based on the premise that there are two stages of scanning. That is, surveyors do not make decisions on the basis of a single indication, rather, upon noting an increased number of counts, they pause briefly and then decide whether to move on or take further measurements. Thus, scanning consists of two components: continuous monitoring and stationary sampling. In the first component, characterized by continuous movement of the probe, the surveyor has only a brief "look" at potential sources, determined by the scan speed. The surveyor's willingness to decide that a signal is present at this stage is likely to be liberal, in that the surveyor should respond positively on scant evidence, since the only "cost" of a false positive is a little time. The second component occurs only after a positive response was made at the first stage. This response is marked by the surveyor interrupting his scanning and holding the probe stationary for a period of time, while comparing the instrument output signal during that time to the background counting rate. Owing to the longer observation interval, sensitivity is relatively high. For this decision, the criterion should be more strict, since the cost of a "yes" decision is to spend considerably more time taking a static measurement or a sample.

Table 6.5 Values of d' for Selected True Positive and False Positive Proportions

| False Positive Proportion | True Positive Proportion | | | | | | | |
|---------------------------|--------------------------|------|------|------|------|------|------|------|
| | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 | 0.85 | 0.90 | 0.95 |
| 0.05 | 1.90 | 2.02 | 2.16 | 2.32 | 2.48 | 2.68 | 2.92 | 3.28 |
| 0.10 | 1.54 | 1.66 | 1.80 | 1.96 | 2.12 | 2.32 | 2.56 | 2.92 |
| 0.15 | 1.30 | 1.42 | 1.56 | 1.72 | 1.88 | 2.08 | 2.32 | 2.68 |
| 0.20 | 1.10 | 1.22 | 1.36 | 1.52 | 1.68 | 1.88 | 2.12 | 2.48 |
| 0.25 | 0.93 | 1.06 | 1.20 | 1.35 | 1.52 | 1.72 | 1.96 | 2.32 |
| 0.30 | 0.78 | 0.91 | 1.05 | 1.20 | 1.36 | 1.56 | 1.80 | 2.16 |
| 0.35 | 0.64 | 0.77 | 0.91 | 1.06 | 1.22 | 1.42 | 1.66 | 2.02 |
| 0.40 | 0.51 | 0.64 | 0.78 | 0.93 | 1.10 | 1.30 | 1.54 | 1.90 |
| 0.45 | 0.38 | 0.52 | 0.66 | 0.80 | 0.97 | 1.17 | 1.41 | 1.77 |
| 0.50 | 0.26 | 0.38 | 0.52 | 0.68 | 0.84 | 1.04 | 1.28 | 1.64 |
| 0.55 | 0.12 | 0.26 | 0.40 | 0.54 | 0.71 | 0.91 | 1.15 | 1.51 |
| 0.60 | 0.00 | 0.13 | 0.27 | 0.42 | 0.58 | 0.82 | 1.02 | 1.38 |

Since scanning can be divided into two stages, it is necessary to consider the survey's scan sensitivity for each of the stages. Typically, the minimum detectable count rate (MDCR) associated with the first scanning stage will be greater due to the brief observation intervals of continuous monitoring—provided that the length of the pause during the second stage is significantly longer. Typically, observation intervals during the first stage are on the order of 1 or 2 seconds, while the second stage pause may be several seconds long. The greater value of MDCR from each of the scan stages is used to determine the scan sensitivity for the surveyor.

Determination of MDCR and Use of Surveyor Efficiency. The minimum detectable number of net source counts in the interval is given by s_i . Therefore, for an ideal observer, the number of source counts required for a specified level of performance can be arrived at by multiplying the square root of the number of background counts by the detectability value associated with the desired performance (as reflected in d') as shown in Equation 6-8:

$$s_i = d' \sqrt{b_i} \quad (6-8)$$

where the value of d' is selected from Table 6.5 based on the required true positive and false positive rates and b_i is the number of background counts in the interval.

For example, suppose that one wished to estimate the minimum count rate that is detectable by scanning in an area with a background of 1,500 cpm. Note that the minimum detectable count rate must be considered for both scan stages—and the more conservative value is selected as the minimum count rate that is detectable. It will be assumed that a typical source remains under the probe for 1 second during the first stage, therefore, the average number of background counts in the observation interval is 25 ($b_i = 1500 \times (1/60)$). Furthermore, as explained earlier, it can be assumed that at the first scanning stage a high rate (e.g., 95%) of correct detections is required, and that a correspondingly high rate of false positives (e.g., 60%) will be tolerated. From Table 6.5, the value of d' , representing this performance goal, is 1.38. The net source counts needed to support the specified level of performance (assuming an ideal observer) will be estimated by multiplying 5 (the square root of 25) by 1.38. Thus, the net source counts per interval, s_i , needed to yield better than 95% detections with about 60% false positives is 6.9. The minimum detectable source count rate, in cpm, may be calculated by:

$$MDCR = s_i \times (60/i) \quad (6-9)$$

For this example, MDCR is equivalent to 414 cpm (1,914 cpm gross). Table 6.6 provides the scan sensitivity for the ideal observer (MDCR) at the first scanning stage for various background levels, based on an index of sensitivity (d') of 1.38 and a 2-second observation interval.

Table 6.6 Scanning Sensitivity (MDCR) of the Ideal Observer for Various Background Levels^a

| Background (cpm) | MDCR (net cpm) | Scan Sensitivity (gross cpm) |
|------------------|----------------|------------------------------|
| 45 | 50 | 95 |
| 60 | 60 | 120 |
| 260 | 120 | 380 |
| 300 | 130 | 430 |
| 350 | 140 | 490 |
| 400 | 150 | 550 |
| 1,000 | 240 | 1,240 |
| 3,000 | 410 | 3,410 |
| 4,000 | 480 | 4,480 |

^aThe sensitivity of the ideal observer during the first scanning stage is based on an index of sensitivity (d') of 1.38 and a 2-second observation interval.

The minimum number of source counts required to support a given level of performance for the final detection decision (second scan stage) can be estimated using the same method. As explained earlier, the performance goal at this stage will be more demanding. The required rate of true positives remains high (e.g., 95%), but fewer false positives (e.g., 20%) can be tolerated, such that d' (from Table 6.5) is now 2.48. One will assume that the surveyor typically stops the probe over a suspect location for about 4 seconds before making a decision, so that the average number of background counts in an observation interval is 100 ($b_i = 1,500 \times (4/60)$). Therefore, the minimum detectable number of net source counts, s_i , needed will be estimated by multiplying 10 (the square root of 100) by 2.48 (the d' value); so s_i equals 24.8. The MDCR is calculated by $2.48 \times (60/4)$ and equals 372 cpm. The value associated with the first scanning stage (this example, 414 cpm) will typically be greater, owing to the relatively brief intervals assumed.

Laboratory studies using simulated sources and backgrounds were performed to assess the abilities of surveyors under controlled conditions. The methodology and analysis of results for these studies are described in draft NUREG/CR-6364 (NRC 1997d) and NUREG-1507 (NRC 1997b). The surveyor's actual performance as compared with that which is ideally possible (using the ideal observer construct) provided an indication of the efficiency of the surveyors. Based on the results of the confidence rating experiment, this surveyor efficiency (p) was estimated to be between 0.5 and 0.75.

MARSSIM recommends assuming an efficiency value at the lower end of the observed range (i.e., 0.5) when making MDC estimates. Thus, the required number of net source counts for the surveyor, $MDCR_{\text{surveyor}}$, is determined by dividing the MDCR by the square root of p . Continuing with this example, the surveyor MDCR is calculated by $414 \text{ cpm}/0.707$, or 585 cpm (2,085 cpm gross).

Scan MDCs for Structure Surfaces and Land Areas. The survey design for determining the number of data points for areas of elevated activity (see Section 5.5.2.4) depends on the scan MDC for the selected instrumentation. In general, alpha or beta scans are performed on structure surfaces to satisfy the elevated activity measurements survey design, while gamma scans are performed for land areas. Because of low background levels for alpha emitters, the approach described here is not generally applied to determining scan MDCs for alpha contaminants—rather, the reader is referred to Section 6.7.2.2 for an appropriate method for determining alpha scan MDCs for building surfaces. In any case, the data requirements for assessing potential elevated areas of direct radiation depend on the scan MDC of the survey instrument (e.g., floor monitor, GM detector, NaI scintillation detector).

Scan MDCs for Building/Structure Surfaces. The scan MDC is determined from the minimum detectable count rate (MDCR) by applying conversion factors that account for detector and surface characteristics and surveyor efficiency. As discussed above, the MDCR accounts for the background level, performance criteria (d'), and observation interval. The observation interval

during scanning is the actual time that the detector can respond to the contamination source—this interval depends on the scan speed, detector size in the direction of the scan, and area of elevated activity. Because the actual dimensions of potential areas of elevated activity in the field cannot be known *a priori*, MARSSIM recommends postulating a certain area (*e.g.*, perhaps 50 to 200 cm²), and then selecting a scan rate that provides a reasonable observation interval.

Finally, the scan MDC for structure surfaces may be calculated:

$$\text{Scan MDC} = \frac{\text{MDCR}}{\sqrt{p} \epsilon_i \epsilon_s \frac{\text{probe area}}{100 \text{ cm}^2}} \quad (6-10)$$

where

| | | |
|--------------|---|-------------------------------|
| MDCR | = | minimum detectable count rate |
| ϵ_i | = | instrument efficiency |
| ϵ_s | = | surface efficiency |
| p | = | surveyor efficiency |

As an example, the scan MDC (in dpm/100 cm²) for ⁹⁹Tc on a concrete surface may be determined for a background level of 300 cpm and a 2-second observation interval using a hand-held gas proportional detector (126 cm² probe area). For a specified level of performance at the first scanning stage of 95% true positive rate and 60% false positive rate (and assuming the second stage pause is sufficiently long to ensure that the first stage is more limiting), d' equals 1.38 (Table 6.5) and the MDCR is 130 cpm (Table 6.6). Using a surveyor efficiency of 0.5, and assuming instrument and surface efficiencies of 0.36 and 0.54, respectively, the scan MDC is calculated using Equation 6-10:

$$\text{Scan MDC} = \frac{130}{\sqrt{0.5} (0.36) (0.54) (1.26)} = 750 \text{ dpm/100 cm}^2$$

Additional examples for calculating the scan MDC may be found in NUREG-1507 (NRC 1997b).

Scan MDCs for Land Areas. In addition to the MDCR and detector characteristics, the scan MDC (in pCi/g) for land areas is based on the area of elevated activity, depth of contamination, and the radionuclide (*i.e.*, energy and yield of gamma emissions). If one assumes constant parameters for each of the above variables, with the exception of the specific radionuclide in question, the scan MDC may be reduced to a function of the radionuclide alone. NaI scintillation detectors are generally used for scanning land areas.

An overview of the approach used to determine scan MDCs for land areas follows. The NaI(Tl) scintillation detector background level and scan rate (observation interval) are postulated, and the MDCR for the ideal observer, for a given level of performance, is obtained. After a surveyor efficiency is selected, the relationship between the surveyor MDCR ($MDCR_{\text{surveyor}}$) and the radionuclide concentration in soil (in Bq/kg or pCi/g) is determined. This correlation requires two steps—first, the relationship between the detector's net count rate to net exposure rate (cpm per $\mu\text{R/h}$) is established, and second, the relationship between the radionuclide contamination and exposure rate is determined.

For a particular gamma energy, the relationship of NaI(Tl) scintillation detector count rate and exposure rate may be determined analytically (in cpm per $\mu\text{R/h}$). The approach used to determine the gamma fluence rate necessary to yield a fixed exposure rate ($1 \mu\text{R/h}$)—as a function of gamma energy—is provided in NUREG-1507 (NRC 1997b). The NaI(Tl) scintillation detector response (cpm) is related to the fluence rate at specific energies, considering the detector's efficiency (probability of interaction) at each energy. From this, the NaI(Tl) scintillation detector versus exposure rates for varying gamma energies are determined. Once the relationship between the NaI(Tl) scintillation detector response (cpm) and the exposure rate is established, the $MDCR_{\text{surveyor}}$ (in cpm) of the NaI(Tl) scintillation detector can be related to the minimum detectable net exposure rate. The minimum detectable exposure rate is used to determine the minimum detectable radionuclide concentration (*i.e.*, the scan MDC) by modeling a specified small area of elevated activity.

Modeling (using MicroshieldTM) of the small area of elevated activity (soil concentration) is used to determine the net exposure rate produced by a radionuclide concentration at a distance 10 cm above the source. This position is selected because it relates to the average height of the NaI(Tl) scintillation detector above the ground during scanning.

The factors considered in the modeling include:

- radionuclide of interest (considering all gamma emitters for decay chains)
- expected concentration of the radionuclide of interest
- areal dimensions of the area of elevated activity
- depth of the area of elevated activity
- location of dose point (NaI(Tl) scintillation detector height above the surface)
- density of soil

Modeling analyses are conducted by selecting a radionuclide (or radioactive material decay series) and then varying the concentration of the contamination. The other factors are held constant—the areal dimension of a cylindrical area of elevated activity is 0.25 m^2 (radius of 28 cm), the depth of the area of elevated activity is 15 cm, the dose point is 10 cm above the surface, and the density of soil is 1.6 g/cm^3 . The objective is to determine the radionuclide concentration that is correlated to the minimum detectable net exposure rate.

As an example, the scan MDC for ^{137}Cs using a 1.5 in. by 1.25 in. NaI(Tl) scintillation detector is considered in detail. Assume that the background level is 4,000 cpm and that the desired level of performance, 95% correct detections and 60% false positive rate, results in a d' of 1.38. The scan rate of 0.5m/s provides an observation interval of 1-second (based on a diameter of about 56 cm for the area of elevated activity). The $\text{MDCR}_{\text{surveyor}}$ may be calculated assuming a surveyor efficiency (p) of 0.5 as follows:

- 1) $b_i = (4,000 \text{ cpm}) \times (1 \text{ sec}) \times (1 \text{ min}/60 \text{ sec}) = 66.7 \text{ counts}$
- 2) $\text{MDCR} = (1.38) \times (\sqrt{66.7}) \times (60 \text{ sec}/1 \text{ min}) = 680 \text{ cpm}$
- 3) $\text{MDCR}_{\text{surveyor}} = 680/\sqrt{0.5} = 960 \text{ cpm}$

The corresponding minimum detectable exposure rate is determined for this detector and radionuclide. The manufacturer of this particular 1.5 in. by 1.25 in. NaI(Tl) scintillation detector quotes a count rate to exposure rate ratio for ^{137}Cs of 350 cpm per $\mu\text{R/h}$. The minimum detectable exposure rate is calculated by dividing the count rate (960 cpm) by the count rate to exposure rate ratio for the radionuclide of interest (350 cpm per $\mu\text{R/h}$). The minimum detectable exposure rate for this example is 2.73 $\mu\text{R/h}$.

Both ^{137}Cs and its short-lived progeny, $^{137\text{m}}\text{Ba}$, were chosen from the MicroshieldTM library. The source activity and other modeling parameters were entered into the modeling code. The source activity was selected based on an arbitrary concentration of 5 pCi/g. The modeling code performed the appropriate calculations and determined an exposure rate of 1.307 $\mu\text{R/h}$ (which accounts for buildup). Finally, the radionuclide concentrations of ^{137}Cs and $^{137\text{m}}\text{Ba}$ (scan MDC) necessary to yield the minimum detectable exposure rate (2.73 $\mu\text{R/h}$) may be calculated using the following formula.

$$\text{scan MDC} = \frac{(5 \text{ pCi/g})(2.73 \mu\text{R/h})}{1.307 \mu\text{R/h}} = 10.4 \text{ pCi/g} \quad (6-11)$$

It must be emphasized that while a single scan MDC value can be calculated for a given radionuclide—other scan MDC values may be equally justifiable depending on the values chosen for the various factors, including the MDCR (background level, acceptable performance criteria, observation interval), surveyor efficiency, detector parameters and the modeling conditions of the contamination. It should also be noted that determination of the scan MDC for radioactive materials—like uranium and thorium—must consider the gamma radiation emitted from the entire decay series. NUREG-1507 (NRC 1997b) provides a detailed example of how the scan MDC can be determined for enriched uranium.

Table 6.7 provides scan MDCs for common radionuclides and radioactive materials in soil. It is important to note that the variables used in the above examples to determine the scan MDCs for the 1.25 in. by 1.5 in. NaI(Tl) scintillation detector—*i.e.*, the $MDCR_{\text{surveyor}}$ detector parameters (*e.g.*, cpm per $\mu\text{R/h}$), and the characteristics of the area of elevated activity—have all been held constant to facilitate the calculation of scan MDCs provided in Table 6.7. The benefit of this approach is that generally applicable scan MDCs are provided for different radioactive contaminants. Additionally, the relative detectability of different contaminants is evident because the only variable in Table 6.7 is the nature of the contaminant.

As noted above, the scan MDCs calculated using the approach in this section are dependent on several factors. One way to validate the appropriateness of the scan MDC is by tracking the residual radioactivity (both surface activity and soil concentrations) levels identified during investigations performed as a result of scanning surveys. The measurements performed during these investigations may provide an *a posteriori* estimate of the scan MDC that can be used to validate the *a priori* scan MDC used to design the survey.

6.7.2.2 Scanning for Alpha Emitters

Scanning for alpha emitters differs significantly from scanning for beta and gamma emitters in that the expected background response of most alpha detectors is very close to zero. The following discussion covers scanning for alpha emitters and assumes that the surface being surveyed is similar in nature to the material on which the detector was calibrated. In this respect, the approach is purely theoretical. Surveying surfaces that are dirty, non-planar, or weathered can significantly affect the detection efficiency and therefore bias the expected MDC for the scan. The use of reasonable detection efficiency values instead of optimistic values is highly recommended. Appendix J contains a complete derivation of the alpha scanning equations used in this section.

Since the time a contaminated area is under the probe varies and the background count rate of some alpha instruments is less than 1 cpm, it is not practical to determine a fixed MDC for scanning. Instead, it is more useful to determine the probability of detecting an area of contamination at a predetermined DCGL for given scan rates.

For alpha survey instrumentation with backgrounds ranging from <1 to 3 cpm, a single count provides a surveyor sufficient cause to stop and investigate further. Assuming this to be true, the probability of detecting given levels of alpha surface contamination can be calculated by use of Poisson summation statistics.

**Table 6.7 NaI(Tl) Scintillation Detector Scan MDCs
for Common Radiological Contaminants^a**

| Radionuclide/Radioactive Material | 1.25 in. by 1.5 in. NaI Detector | | 2 in. by 2 in. NaI Detector | |
|---|----------------------------------|-------------------------|-----------------------------|-------------------------|
| | Scan MDC (Bq/kg) | Weighted cpm/ μ R/h | Scan MDC (Bq/kg) | Weighted cpm/ μ R/h |
| Am-241 | 1,650 | 5,830 | 1,170 | 13,000 |
| Co-60 | 215 | 160 | 126 | 430 |
| Cs-137 | 385 | 350 | 237 | 900 |
| Th-230 | 111,000 | 4,300 | 78,400 | 9,580 |
| Ra-226 (in equilibrium with progeny) | 167 | 300 | 104 | 760 |
| Th-232 decay series (Sum of all radionuclides in the thorium decay series) | 1,050 | 340 | 677 | 830 |
| Th-232 (In equilibrium with progeny in decay series) | 104 | 340 | 66.6 | 830 |
| Depleted Uranium ^b (0.34% U-235) | 2,980 | 1,680 | 2,070 | 3,790 |
| Natural Uranium ^b | 4,260 | 1,770 | 2,960 | 3,990 |
| 3% Enriched Uranium ^b | 5,070 | 2,010 | 3,540 | 4,520 |
| 20% Enriched Uranium ^b | 5,620 | 2,210 | 3,960 | 4,940 |
| 50% Enriched Uranium ^b | 6,220 | 2,240 | 4,370 | 5,010 |
| 75% Enriched Uranium ^b | 6,960 | 2,250 | 4,880 | 5,030 |

^a Refer to text for complete explanation of factors used to calculate scan MDCs. For example, the background level for the 1.25 in. by 1.5 in. NaI detector was assumed to be 4,000 cpm, and 10,000 cpm for the 2 in. by 2 in. NaI detector. The observation interval was 1-sec and the level of performance was selected to yield d' of 1.38.

^b Scan MDC for uranium includes sum of ²³⁸U, ²³⁵U, and ²³⁴U.

Given a known scan rate and a surface contamination DCGL, the probability of detecting a single count while passing over the contaminated area is

$$P(n \geq 1) = 1 - e^{-\frac{GE d}{60v}} \quad (6-12)$$

where

| | | |
|---------------|---|---|
| $P(n \geq 1)$ | = | probability of observing a single count |
| G | = | contamination activity (dpm) |
| E | = | detector efficiency (4π) |
| d | = | width of detector in direction of scan (cm) |
| v | = | scan speed (cm/s) |

Note: Refer to Appendix J for a complete derivation of these formulas.

Once a count is recorded and the guideline level of contamination is present the surveyor should stop and wait until the probability of getting another count is at least 90%. This time interval can be calculated by

$$t = \frac{13,800}{CAE} \quad (6-13)$$

where

| | | |
|-----|---|--|
| t | = | time period for static count (s) |
| C | = | contamination guideline (dpm/100 cm ²) |
| A | = | physical probe area (cm ²) |
| E | = | detector efficiency (4π) |

Many portable proportional counters have background count rates on the order of 5 to 10 cpm, and a single count should not cause a surveyor to investigate further. A counting period long enough to establish that a single count indicates an elevated contamination level would be prohibitively inefficient. For these types of instruments, the surveyor usually will need to get at least 2 counts while passing over the source area before stopping for further investigation.

Assuming this to be a valid assumption, the probability of getting two or more counts can be calculated by:

$$\begin{aligned}
 P(n \geq 2) &= 1 - P(n=0) - P(n=1) \\
 &= 1 - \left(1 + \frac{(GE + B)t}{60} \right) \left(e^{-\frac{(GE + B)t}{60}} \right) \quad (6-14)
 \end{aligned}$$

where

| | | |
|---------------|---|--|
| $P(n \geq 2)$ | = | probability of getting 2 or more counts during the time interval t |
| $P(n=0)$ | = | probability of not getting any counts during the time interval t |
| $P(n=1)$ | = | probability of getting 1 count during the time interval t |
| B | = | background count rate (cpm) |

All other variables are the same as for Equation 6-12.

Appendix J provides a complete derivation of Equations 6-12 through 6-14 and a detailed discussion of the probability of detecting alpha surface contamination for several different variables. Several probability charts are included at the end of Appendix J for common detector sizes. Table 6.8 provides estimates of the probability of detecting 300 dpm/100 cm² for some commonly used alpha detectors.

Table 6.8 Probability of Detecting 300 dpm/100 cm² of Alpha Activity While Scanning with Alpha Detectors Using an Audible Output (calculated using Equation 6-12)

| Detector Type | Detection Efficiency cpm/dpm | Probe Dimension in Direction of Scan (cm) | Scan Rate (cm/s) | Probability of detecting 300 dpm/100 cm ² |
|---------------|---------------------------------|---|---------------------|--|
| Proportional | 0.20 | 5 | 3 | 80% |
| Proportional | 0.15 | 15 | 5 | 90% |
| Scintillation | 0.15 | 5 | 3 | 70% |
| Scintillation | 0.15 | 10 | 3 | 90% |

6.8 Measurement Uncertainty (Error)

The quality of measurement data will be directly impacted by the magnitude of the measurement uncertainty associated with it. Some uncertainties, such as statistical counting uncertainties, can be easily calculated from the count results using mathematical procedures. Evaluation of other

sources of uncertainty require more effort and in some cases is not possible. For example, if an alpha measurement is made on a porous concrete surface, the observed instrument response when converted to units of activity will probably not exactly equal the true activity under the probe. Variations in the absorption properties of the surface for particulate radiation will vary from point to point and therefore will create some level of variation in the expected detection efficiency. This variability in the expected detector efficiency results in uncertainty in the final reported result. In addition, QC measurement results provide an estimate of random and systematic uncertainties associated with the measurement process.

The measurement uncertainty for every analytical result or series of results, such as for a measurement system, should be reported. This uncertainty, while not directly used for demonstrating compliance with the release criterion, is used for survey planning and data assessment throughout the Radiation Survey and Site Investigation (RSSI) process. In addition, the uncertainty is used for evaluating the performance of measurement systems using QC measurement results. Uncertainty can also be used for comparing individual measurements to the DCGL. This is especially important in the early stages of decommissioning (*i.e.*, scoping, characterization, remedial action support) when decisions are made based on a limited number of measurements.

For most sites, evaluations of uncertainty associated with field measurements is important only for data being used as part of the final status survey documentation. The final status survey data, which is used to document the final radiological status of a site, should state the uncertainties associated with the measurements. Conversely, detailing the uncertainties associated with measurements made during scoping or characterization surveys may or may not be of value depending on what the data will be used for—*i.e.* the data quality objectives (DQOs). From a practical standpoint, if the observed data are obviously greater than the DCGL and will be eventually cleaned up, then the uncertainty may be relatively unimportant. Conversely, data collected during early phases of a site investigation that may eventually be used to show that the area is below the DCGL—and therefore does not require any clean-up action—will need the same uncertainty evaluation as the final status survey data. In summary, the level of effort needs to match the intended use of the data.

6.8.1 Systematic and Random Uncertainties

Measurement uncertainties are often broken into two sub-classes of uncertainty termed systematic (*e.g.*, methodical) uncertainty and random (*e.g.*, stochastic) uncertainty. Systematic uncertainties derive from a lack of knowledge about the true distribution of values associated with a numerical parameter and result in data that is consistently higher (or lower) than the true value. An example of a systematic uncertainty would be the use of a fixed counting efficiency value even though it is known that the efficiency varies from measurement to measurement but without knowledge of the frequency. If the fixed counting efficiency value is higher than the true but unknown

efficiency—as would be the case for an unrealistically optimistic value—then every measurement result calculated using that efficiency would be biased low. Random uncertainties refer to fluctuations associated with a known distribution of values. An example of a random uncertainty would be a well documented chemical separation efficiency that is known to fluctuate with a regular pattern about a mean. A constant recovery value is used during calculations, but the true value is known to fluctuate from sample to sample with a fixed and known degree of variation.

To minimize the need for estimating potential sources of uncertainty, the sources of uncertainty themselves should be reduced to a minimal level by using practices such as:

- The detector used should minimize the potential uncertainty. For example, when making field surface activity measurements for ^{238}U on concrete, a beta detector such as a thin-window Geiger-Mueller “pancake” may provide better quality data than an alpha detector depending on the circumstances. Less random uncertainty would be expected between measurements with a beta detector such as a pancake since beta emissions from the uranium will be affected much less by thin absorbent layers than will the alpha emissions.
- Calibration factors should accurately reflect the efficiency of a detector being used on the surface material being measured for the contaminant radionuclide or mixture of radionuclides (see Section 6.5.4). For most field measurements, variations in the counting efficiency on different types of materials will introduce the largest amount of uncertainty in the final result.
- Uncertainties should be reduced or eliminated by use of standardized measurement protocols (e.g., SOPs) when possible. Special effort should be made to reduce or eliminate systematic uncertainties, or uncertainties that are the same for every measurement simply due to an error in the process. If the systematic uncertainties are reduced to a negligible level, then the random uncertainties, or those uncertainties that occur on a somewhat statistical basis, can be dealt with more easily.
- Instrument operators should be trained and experienced with the instruments used to perform the measurements.
- QA/QC should be conducted as described in Chapter 9.

Uncertainties that cannot be eliminated need to be evaluated such that the effect can be understood and properly propagated into the final data and uncertainty estimates. As previously stated, non-statistical uncertainties should be minimized as much as possible through the use of good work practices.

Overall random uncertainty can be evaluated using the methods described in the following sections. Section 6.8.2 describes a method for calculating random counting uncertainty. Section 6.8.3 discusses how to combine this counting uncertainty with other uncertainties from the measurement process using uncertainty propagation.

Systematic uncertainty is derived from calibration errors, incorrect yields and efficiencies, non-representative survey designs, and “blunders.” It is difficult—and sometimes impossible—to evaluate the systematic uncertainty for a measurement process, but bounds should always be estimated and made small compared to the random uncertainty, if possible. If no other information on systematic uncertainty is available, Currie (NRC 1984) recommends using 16% as an estimate for systematic uncertainties (1% for blanks, 5% for baseline, and 10% for calibration factors).

6.8.2 Statistical Counting Uncertainty

When performing an analysis with a radiation detector, the result will have an uncertainty associated with it due to the statistical nature of radioactive decay. To calculate the total uncertainty associated with the counting process, both the background measurement uncertainty and the sample measurement uncertainty must be accounted for. The standard deviation of the net count rate, or the statistical counting uncertainty, can be calculated by

$$\sigma_n = \sqrt{\frac{C_{s+b}}{T_{s+b}^2} + \frac{C_b}{T_b^2}} \quad (6-15)$$

where

| | | |
|------------|---|---|
| σ_n | = | standard deviation of the net count rate result |
| C_{s+b} | = | number of gross counts (sample) |
| T_{s+b} | = | gross count time |
| C_b | = | number of background counts |
| T_b | = | background count time |

6.8.3 Uncertainty Propagation

Most measurement data will be converted to different units or otherwise included in a calculation to determine a final result. The standard deviation associated with the final result, or the total uncertainty, can then be calculated. Assuming that the individual uncertainties are relatively small, symmetric about zero, and independent of one another, then the total uncertainty for the final calculated result can be determined by solving the following partial differential equation:

$$\sigma_u = \sqrt{\left(\frac{\partial u}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial u}{\partial z}\right)^2 \sigma_z^2 + \dots} \quad (6-16)$$

where

| | | |
|-----------------------------|---|--|
| u | = | function, or formula, that defines the calculation of a final result as a function of the collected data. All variables in this equation, <i>i.e.</i> , x, y, z, \dots , are assumed to have a measurement uncertainty associated with them and do not include numerical constants |
| σ_u | = | standard deviation, or uncertainty, associated with the final result |
| $\sigma_x, \sigma_y, \dots$ | = | standard deviation, or uncertainty, associated with the parameters x, y, z, \dots |

Equation 6-16, generally known as the error propagation formula, can be solved to determine the standard deviation of a final result from calculations involving measurement data and their associated uncertainties. The solutions for common calculations along with their uncertainty propagation formulas are included below.

| <u>Data Calculation</u> | <u>Uncertainty Propagation</u> |
|--|---|
| $u = x + y$, or $u = x - y$: | $\sigma_u = \sqrt{\sigma_x^2 + \sigma_y^2}$ |
| $u = x \div y$, or $u = x \times y$: | $\sigma_u = u \sqrt{\left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2}$ |
| $u = c \times x$, where c is a positive constant: | $\sigma_u = c \sigma_x$ |
| $u = x \div c$, where c is a positive constant: | $\sigma_u = \frac{\sigma_x}{c}$ |

Note: In the above examples, x and y are measurement values with associated standard deviations, or uncertainties, equal to σ_x and σ_y , respectively. The symbol “ c ” is used to represent a numerical constant which has no associated uncertainty. The symbol σ_u is used to denote the standard deviation, or uncertainty, of the final calculated value u .

6.8.4 Reporting Confidence Intervals

Throughout Section 6.8, the term “measurement uncertainty” is used interchangeably with the term “standard deviation.” In this respect, the uncertainty is qualified as numerically identical to

the standard deviation associated with a normally distributed range of values. When reporting a confidence interval for a value, one provides the range of values that represent a pre-determined level of confidence (*i.e.*, 95%). To make this calculation, the final standard deviation, or total uncertainty σ_u as shown in Equation 6-16, is multiplied by a constant factor k representing the area under a normal curve as a function of the standard deviation. The values of k representing various intervals about a mean of normal distributions as a function of the standard deviation is given in Table 6.9. The following example illustrates the use of this factor in context with the propagation and reporting of uncertainty values.

Table 6.9 Areas Under Various Intervals About the Mean of a Normal Distribution

| Interval ($\bar{\mu} \pm k\sigma$) | Area |
|---|-------|
| $\bar{\mu} \pm 0.674\sigma$ | 0.500 |
| $\bar{\mu} \pm 1.00\sigma$ | 0.683 |
| $\bar{\mu} \pm 1.65\sigma$ | 0.900 |
| $\bar{\mu} \pm 1.96\sigma$ | 0.950 |
| $\bar{\mu} \pm 2.00\sigma$ | 0.954 |
| $\bar{\mu} \pm 2.58\sigma$ | 0.990 |
| $\bar{\mu} \pm 3.00\sigma$ | 0.997 |

Example:

Uncertainty Propagation and Confidence Interval: A measurement process with a zero background yields a count result of 28 ± 5 counts in 5 minutes, where the ± 5 counts represents one standard deviation about a mean value of 28 counts. The detection efficiency is 0.1 counts per disintegration ± 0.01 counts per disintegration, again representing one standard deviation about the mean.

Calculate the activity of the sample, in dpm, total measurement uncertainty, and the 95% confidence interval for the result.

- 1) The total number of disintegrations is:

$$\frac{28 \text{ counts}}{0.1 \text{ c/d}} = 280$$

- 2) Using the equation for error propagation for division, total uncertainty is:

$$280 \sqrt{\left(\frac{5}{28}\right)^2 + \left(\frac{0.01}{0.1}\right)^2} = 57 \text{ disintegrations}$$

- 3) The activity will then be $280 \div 5 \text{ minutes} = 56 \text{ dpm}$ and the total uncertainty will be $57 \div 5 \text{ minutes} = 11 \text{ dpm}$. (Since the count time is considered to have trivial variance, this is assumed to be a constant.)

Referring to Table 6.9, a k value of ± 1.96 represents a confidence interval equal to 95% about the mean of a normal distribution. Therefore, the 95% confidence interval would be $1.96 \times 11 \text{ dpm} = 22 \text{ dpm}$. The final result would be $56 \pm 22 \text{ dpm}$.

6.9 Radon Measurements

There are three radon isotopes in nature: ^{222}Rn (radon) in the ^{238}U decay chain, ^{220}Rn (thoron) in the ^{232}Th chain, and ^{219}Rn (actinon) in the ^{235}U chain. ^{219}Rn is the least abundant of these three isotopes, and because of its short half-life of 4 seconds it has the least probability of emanating into the atmosphere before decaying. ^{220}Rn with a 55 second half-life is somewhat more mobile. ^{222}Rn with a 3.8 d half-life is capable of migrating through several decimeters of soil or building material and reaching the atmosphere. Therefore, in most situations, ^{222}Rn should be the predominant airborne radon isotope.

Many techniques have been developed over the years for measuring radon (Jenkins 1986) and radon progeny in air. In addition, considerable attention is given by EPA to measurement of radon and radon progeny in homes (EPA 1992d). Radon and radon progeny emit alpha and beta particles and gamma rays. Therefore, numerous techniques can and have been developed for measuring these radionuclides based on detecting alpha particles, beta particles, or gamma rays, independently or in some combination. It is even difficult to categorize the various techniques that are presently in use. This section contains an overview of information dealing with the measurement of radon and radon progeny. The information is focused on the measurement of ^{222}Rn , however the information may be adapted for the measurement of ^{219}Rn and ^{220}Rn .

Radon concentrations within a fixed structure can vary significantly from one section of the building to another and can fluctuate over time. If a home has a basement, for instance, it is usually expected that a higher radon concentration will be found there. Likewise, a relatively small increase in the relative pressure between the soil and the inside of a structure can cause a significant increase in the radon emanation rate from the soil into the structure. Many factors play a role in these variations, but from a practical standpoint it is only necessary to recognize that fluctuations are expected and that they should be accounted for. Long term measurement periods

are required to determine a true mean concentration inside a structure and to account for the fluctuations.

Two analytical end points are of interest when performing radon measurements. The first and most commonly used is radon concentration, which is stated in terms of activity per unit volume (Bq/m³ or pCi/L). Although this terminology is consistent with most federal guidance values, it only infers the potential dose equivalent associated with radon. The second analytical end point is the radon progeny working level. Radon progeny usually attach very quickly to charged aerosols in the air following creation. The fraction that remains unattached is usually quite small (*i.e.*, 5-10%). Since most aerosol particles carry an electrical charge and are relatively massive ($\geq 0.1 \mu\text{m}$), they are capable of attaching to the surfaces of the lung. Essentially all dose or risk from radon is associated with alpha decays from radon progeny attached to tissues of the respiratory system. If an investigator is interested in accurately determining the potential dose or risk associated with radon in the air of a room, the radon progeny concentration must be known.

Radon progeny concentrations are usually reported in units of working levels (WL), where one working level is equal to the potential alpha energy associated with the radon progeny in secular equilibrium with 100 pCi/L of radon. One working level is equivalent to 1.28×10^5 MeV/L of potential alpha energy. Given a known breathing rate and lung attachment probability, the expected mean lung dose from exposure to a known working level of radon progeny can be calculated.

Radon progeny are not usually found in secular equilibrium with radon indoors due to plating out of the charged aerosols onto walls, furniture, *etc.* The ratio of ²²²Rn progeny activity to ²²²Rn activity usually ranges from 0.2 to as high as 0.8 indoors (NCRP 1988). If only the ²²²Rn concentration is measured and it is not practical to measure the progeny concentrations, then general practice is to assume a progeny to ²²²Rn equilibrium ratio of 0.5 for indoor areas. This allows one to estimate the expected dose or risk associated with a given radon concentration.

In general, the following generic guidelines should be followed when performing radon measurements during site investigations:

- The radon measurement method used should be well understood and documented.
- Long term measurements are used to determine the true mean radon concentration.
- The impact of variable environmental conditions (*e.g.*, humidity, temperature, dust loading, and atmospheric pressure) on the measurement process should be accounted for when necessary. Consideration should be given to effects on both the air collection process and the counting system.

- The background response of the detection system should be accounted for.
- If the quantity of interest is the working level, then the radon progeny concentrations should be evaluated. If this is not practical, then the progeny activities can be estimated by assuming they are 50% of the measured radon activity (NCRP 1988).

For a general overview, a list of common radiation detectors with their usual applications during radon surveys is provided in Table 6.10. Descriptions and costs for specific equipment used for the measurement of radon are contained in Appendix H.

Table 6.10 Radiation Detectors with Applications to Radon Surveys

| System | Description | Application | Remarks |
|---|---|---|---|
| Large area activated charcoal collector | A canister containing activated charcoal is twisted into the surface and left for 24 hours. | Short term radon flux measurements | The LLD is $0.007 \text{ Bq m}^{-2}\text{s}^{-1}$ ($0.2 \text{ pCi m}^{-2}\text{s}^{-1}$). |
| Continuous radon monitor | Air pump and scintillation cell or ionization chamber. | Track the real time concentration of radon | Takes 1 to 4 hours for system to equilibrate before starting. The LLD is $0.004\text{--}0.04 \text{ Bq/L}$ ($0.1\text{--}1.0 \text{ pCi/L}$). |
| Activated charcoal adsorption | Activated charcoal is opened to the ambient air, then gamma counted on a gamma scintillator or in a liquid scintillation counter. | Measure radon concentration in indoor air | Detector is deployed for 2 to 7 days. The LLD is $0.007\text{--}0.04 \text{ Bq/L}$ (0.2 to 1.0 pCi/L). |
| Electret ion chamber | This is a charged plastic vessel that can be opened for air to pass through. | Measure short-term or long-term radon concentration in indoor air | Must correct reading for gamma background concentration. Electret is sensitive to extremes of temperature and humidity. LLD is $0.007\text{--}0.02 \text{ Bq/L}$ ($0.2\text{--}0.5 \text{ pCi/L}$). |
| Alpha track detection | A small piece of special plastic or film inside a small container. Damage tracks from alpha particles are chemically etched and tracks counted. | Measure indoor or outdoor radon concentration in air | LLD is $0.04 \text{ Bq L}^{-1}\text{d}^{-1}$ ($1 \text{ pCi L}^{-1}\text{d}^{-1}$). |

The following provides a general overview of radon sampling and measurement concepts. The intent of this section is to provide an overview of common methods and terminology.

6.9.1 Direct Radon Measurements

Direct radon measurements are performed by gathering radon into a chamber and measuring the ionizations produced. A variety of methods have been developed, each making use of the same fundamental mechanics but employing different measurement processes. The first step is to get the radon into a chamber without collecting any radon progeny from the ambient air. A filter is normally used to capture charged aerosols while allowing the radon gas to pass through. Most passive monitors rely on diffusion of the ambient radon in the air into the chamber to establish an equilibrium between the concentrations of radon in the air and in the chamber. Active monitors use some type of air pump system for the air exchange method.

Once inside the chamber, the radon decays by alpha emission to form ^{218}Po which usually takes on a positive charge within thousandths of a second following formation. Some monitor types collect these ionic molecules and subsequently measure the alpha particles emitted by the radon progeny. Other monitor types, such as the electret ion chamber, measure the ionization produced by the decay of radon in the air within the chamber by directly collecting the ions produced inside the chamber. Simple systems measure the cumulative radon during the exposure period based on the total alpha decays that occur. More complicated systems actually measure the individual pulse height distributions of the alpha and/or beta radiation emissions and derive the radon plus progeny isotopic concentration in the air volume.

Care must be taken to accurately calibrate a system and to understand the effects of humidity, temperature, dust loading, and atmospheric pressure on the system. These conditions create a small adverse effect on some systems and a large influence on others.

6.9.1.1 Integrating Methods for Radon Measurement

With integrating methods, measurements are made over a period of days, weeks, or months and the device is subsequently read by an appropriate device for the detector media used. The most common detectors used are activated charcoal adsorbers, electret ion chamber (EIC), and alpha track plastics. Short term fluctuations are averaged out, thus making the measurement representative of average concentration. Results in the form of an average value provide no way to determine the fluctuations of the radon concentration over the measurement interval. Successive short term measurements can be used in place of single long term measurements to gain better insight into the time dependence of the radon concentration.

6.9.1.2 Continuous Methods for Radon Measurement

Devices that measure direct radon concentrations over successive time increments are generally called continuous radon monitors. These systems are more complex than integrating devices in that they measure the radon concentration and log the results to a data recording device on a real time basis. Continuous radon measurement devices normally allow the noble gas radon to pass

through a filter into a detection chamber where the radon decays and the radon and/or the resulting progeny are measured. The most common detectors used for real time measurements are ion chambers, solid state surface barrier detectors, and ZnS(Ag) scintillation detectors.

Continuous methods offer the advantage of providing successive, short-term results over long periods of time. This allows the investigator not only to determine the average radon concentration, but also to analyze the fluctuations in the values over time. More complicated systems are available that measure the relative humidity and temperature at the measurement location and log the values along with the radon concentrations to the data logging device. This allows the investigator to make adjustments, if necessary, to the resulting data prior to reporting the results.

6.9.2 Radon Progeny Measurements

Radon progeny measurements are performed by collecting charged aerosols onto filter paper and subsequently counting the filter for attached progeny. Some systems pump air through a filter and then automatically count the filter for alpha and/or beta emissions. An equivalent but more labor intensive method is to collect a sample using an air sampling pump and then count the filter in stand alone alpha and/or beta counting systems. The measurement system may make use of any number of different techniques ranging from full alpha and beta spectrometric analysis of the filters to simply counting the filter for total alpha and or beta emissions.

When performing total (gross) counting analyses, the assumption is usually made that the only radioisotopes in the air are due to ^{222}Rn and its progeny. This uncertainty, which is usually very small, can be essentially eliminated when performing manual sampling and analysis by performing a follow up measurement of the filter after the radon progeny have decayed to a negligible level. This value can then be used as a background value for the air. Of course, such a simple approach is only applicable when ^{222}Rn is the isotope of concern. For ^{219}Rn or ^{220}Rn , other methods would have to be used.

Time is a significant element in radon progeny measurements. Given any initial equilibrium condition for the progeny isotopes, an investigator must be able to correlate the sampling and measurement technique back to the true concentration values. When collecting radon progeny, the buildup of total activity on the filter increases asymptotically until the activity on the filter becomes constant. At this point, the decay rate of the progeny atoms on the filter is equal to the collection rate of progeny atoms. This is an important parameter to consider when designing a radon sampling procedure.

Note that the number of charged aerosol particles in the air can affect the results for radon progeny measurements. If the number of particles is few, as is possible when humidity is low and a room is very clean, then most of the progeny will not be attached and can plate out on room surfaces prior to reaching the sample filter. This is not a problem if the same conditions always

exist in the room, however the calculated dose would underestimate the dose that would be received in a higher humidity or dust concentration state with the same radon progeny concentration.

6.9.3 Radon Flux Measurements

Sometimes it is desirable to characterize the source of radon in terms of the rate at which radon is emanating from a surface—that is, soil, uranium mill tailings, or concrete. One method used for measuring radon flux is briefly described here.

The measurement of radon flux can be achieved by adsorption onto charcoal using a variety of methods such as a charcoal canister or a large area collector (*e.g.*, 25 cm PVC end cap). The collector is deployed by firmly twisting the end cap into the surface of the material to be measured. After 24 hours of exposure, the activated charcoal is removed and transferred to plastic containers. The amount of radon adsorbed on the activated charcoal is determined by gamma spectroscopy. Since the area of the surface is well defined and the deployment period is known, the radon flux (in units of Bq/m²-s or pCi/m²-s) can be calculated.

This method is reliable for measuring radon flux in normal environmental situations. However, care should be taken if an extremely large source of radon is measured with this method. The collection time should be chosen carefully to avoid saturating the canister with radon. If saturation is approached, the charcoal loses its ability to absorb radon and the collection rate decreases. Even transporting and handling of a canister that is saturated with radon can be a problem due to the dose rate from the gamma rays being emitted. One would rarely encounter a source of radon that is so large that this would become a problem; however, it should be recognized as a potential problem. Charcoal can also become saturated with water, which will affect the absorption of radon. This can occur in areas with high humidity.

An alternative method for making passive radon flux measurements has been developed recently using electret ionization chambers (EICs). EIC technology has been widely used for indoor radon measurements. The passive EIC procedure is similar to the procedures used with large area activated charcoal canisters. In order to provide the data for the background corrections, an additional passive monitor is located side by side on a radon impermeable membrane. These data are used to calculate the net radon flux. The Florida State Bureau of Radiation Protection has compared the results from measurements of several phosphogypsum flux beds using the charcoal canisters and EICs and has shown that the two methods give comparable results. The passive method seems to have overcome some of the limitations encountered in the use of charcoal. The measurement periods can be extended from hours to several days in order to obtain a better average, if needed. EIC flux measurements are not affected by environmental conditions such as temperature, humidity, and air flow. The measured sensitivities are comparable to the charcoal method but, unlike charcoal, EICs do not become saturated by humidity. Intermediate readings

can be made if needed.. In view of the low cost of the EIC reading/analyzing equipment, the cost per measurement can be as much as 50% lower than the charcoal method with additional savings in time.

6.10 Special Equipment

Various specialized systems have been developed which can be used during the performance of radiation surveys and site investigations. These range from specially designed quick radiation scanning systems to commercial global positioning systems (GPSs). The equipment may be designed to detect radiation directly, detect and locate materials associated with the contamination (*e.g.*, metal containers), or locate the position where a particular measurement is performed (*e.g.*, GPS). Because these specialized systems are continuously being modified and developed for site-specific applications, it is not possible to provide detailed descriptions of every system. The following sections provide examples of specialized equipment that have been applied to radiation surveys and site investigations.

6.10.1 Positioning Systems

As stated in Section 4.8.5, documenting the location of measurements is important for demonstrating the reproducibility of the results. There are a variety of positioning systems available that provide a range of accuracy and precision that can be evaluated during survey planning to determine their applicability to a particular site. These positioning systems can be used to establish a reproducible reference coordinate system or to locate individual measurements using an established reference coordinate system (*e.g.*, longitude and latitude).

6.10.1.1 Differential Global Positioning Systems

A variety of practical and versatile GPSs based on radio signals tracked from satellite beacons are available (*e.g.*, Trimble™, Novatel™, Garmin™). These systems are generally used to aid in recording and retrieving location data with precision on the order of tens of meters. With a stationary base station and a separate moving locator, the system is deployed in the “differential global positioning system” (DGPS) mode. DGPSs can record and retrieve location data with a precision in the centimeter range.

DGPS can be used to provide position information on surface features in areas being surveyed, linking the survey results to previously published maps and aerial photographs. In addition, survey results may be positioned using the DGPS readings to accurately and precisely locate the results as well as the results of any subsequent analyses to these same maps or photographs. A process called waypointing uses the DGPS to locate specific points and allows the user to find

predetermined locations and set up gridded locations for measurements based on location data that are tied into local or state coordinate systems.

Limitations on the use of DGPS are related to the number of satellite beacons available to the system. When three or fewer satellites are available the accuracy and precision of the location data will be reduced. There are short periods of time (usually less than one hour even on the worst days) when a limited number of satellites are overhead in the continental United States. Satellites may also be blocked by excess tree cover or tall buildings. Distance between the moving locator and the stationary base station may be several kilometers or may be limited to line-of-sight. This limitation can be mitigated through the strategic use of repeater stations to re-transmit the signal between the moving locator and the base station.

6.10.1.2 Local Microwave and Sonar Positioning Systems

Local microwave or sonar beacons and receivers may provide useful location data in small areas and tree-covered locales. One example of a sonar-based system is the ultrasonic ranging and data system (USRADS). With a number of fixed beacons in place, a roving unit can be oriented and provide location data with similar accuracy and precision as the DGPS. If the beacons are located at known points, the resulting positions can be determined using simple calculations based on the known reference locations of the beacons.

The logistics of deploying the necessary number of beacons properly and the short range of the signals are the major limitations of the system. In addition, multipathing of signals within wooded areas can cause jumps in the positioning data.

6.10.2 Mobile Systems with Integrated Positioning Systems

In recent years, the advent of new technologies has introduced mobile sensor systems for acquiring data that include fully-integrated positioning systems. Portable and vehicle-based versions of these systems record survey data while moving over surfaces to be surveyed and simultaneously recording the location data from either a roving DGPS receiver or local microwave/sonar receiver. All measurement data are automatically stored and processed with the measurement location for later posting (see Section 8.2.2.2 for a discussion of posting plots) or for mapping the results. These systems are designed with a variety of detectors for different applications. For example, alpha or beta detectors have been mounted on a robot a fixed distance over a smooth surface. The robot moves at a predetermined speed over the surface to provide scanning results, and also records individual direct measurements at predetermined intervals. This type of system not only provides the necessary measurement data, but also reduces the uncertainty associated with human factors. Other systems are equipped with several types of radiation detectors, magnetometers, electromagnetic sensors, or various combinations of multiple sensors. The limitations of each system should be evaluated on a site-specific basis to determine if the

positioning system, the detector, the transport system, or some combination based on site-specific characteristics will represent the limits of the system.

6.10.3 Radar, Magnetometer, and Electromagnetic Sensors

The number of sensors and sensor systems applicable to the detection and location of buried waste have increased in use and reliability in recent years. These systems are typically applicable to scoping and characterization surveys where the identification of subsurface contamination is a primary concern. However, the results of these surveys may be used during final status survey planning to demonstrate that subsurface contamination is not a concern for a particular site or survey unit. Some of the major technologies are briefly described in the following sections.

6.10.3.1 Ground Penetrating Radar

For most sites, ground penetrating radar (GPR) is the only instrument capable of collecting images of buried objects *in situ*, as compared to magnetometers (Section 6.10.3.2) and electromagnetic sensors (Section 6.10.3.3) which detect the strength of signals as measured at the ground surface. Additionally, GPR is unique in its ability to detect both metallic and non-metallic (e.g., plastic, glass) containers.

Subsurface radar detection systems have been the focus of study for locating and identifying buried or submerged objects that otherwise could not be detected. There are two major categories of radar signals: 1) time domain, and 2) frequency domain. Time-domain radar uses short impulses of radar-frequency energy directed into the ground being investigated. Reflections of this energy, based on changes in dielectric properties, are then received by the radar. Frequency-domain radar, on the other hand, uses a continuous transmission where the frequency of the transmission can be varied either stepwise or continuously. The changes in the frequency characteristics due to effects from the ground are recorded. Signal processing, in both cases, converts this signal to represent the location of radar reflectors against the travel time of the return signal. Greater travel time corresponds to a greater distance beneath the surface. Table 6.11 lists the typical penetration depth for various geologic materials (fresh water is included as a baseline for comparison).

Examples of existing GPR technologies currently being applied to subsurface investigations include:

- narrow-band radar
- ultra-wideband radar
- synthetic aperture radar
- frequency modulated continuous radar
- polarized radar waves

Table 6.11 Typical Radar Penetration Depths for Various Geologic Materials

| Material | Penetration Depth m (ft) |
|------------------|-------------------------------------|
| Fresh Water | 100 (330) |
| Sand (desert) | 5 (16) |
| Sandy Soil | 3 (10) |
| Loam Soil | 3 (10) |
| Clay Soil | 2 (6) |
| Salt Flats (dry) | 1 (3) |
| Coal | 20 (66) |
| Rocks | 20 (66) |
| Walls | 0.3 (1) |

The major limitation to GPR is the difficulty in interpreting the data, which is often provided in the form of hazy, “waterfall-patterned” data images requiring an experienced professional to interpret. Also, GPR can vary depending on the soil type as shown in Table 6.10. Highly conductive clay soils often absorb a large amount of the radar energy, and may even reflect the energy. GPR can be deployed using ground-based or airborne systems.

6.10.3.2 Magnetometers

Although contaminated soil and most radioactive waste possess no ferromagnetic properties, the containers commonly used to hold radioactive waste (*e.g.*, 55-gallon drums) are made from steel. These containers possess significant magnetic susceptibility making the containers detectable using magnetometry.

Magnetometers sense the pervasive magnetic field of the Earth. This field, when encountering an object with magnetic susceptibility, induces a secondary magnetic field in that object. This secondary field creates an increase or decrease in Earth’s ambient magnetic field. Magnetometers measure these changes in the expected strength of the ambient magnetic field. Some magnetometers, called “vector magnetometers,” can sense the direction as well as the magnitude of these changes. However, for subsurface investigations only the magnitude of the changes are used.

The ambient magnetic field on Earth averages 55,000 gamma in strength. The variations caused by the secondary magnetic fields typically range from 10 to 1,000 gamma, and average around 100 gamma. Most magnetometers currently in use have a sensitivity in the 0.1 to 0.01 gamma range and are capable of detecting these secondary fields.

An alternate magnetometer survey can be performed using two magnetometers in a gradiometric configuration. This means that the first magnetometer is placed at the ground surface, while the second is mounted approximately 0.5 meters above the first. Data is recorded from both sensors and compared. When the readings from both detectors are nearly the same, it implies that there is no significant disturbance in the Earth's ambient magnetic field or that such disturbances are broad and far away from the gradiometer. When a secondary magnetic field is induced in an object, it affects one sensor more strongly than the other, producing a difference in the readings from the two magnetometers. This approach is similar to the use of a guard detector in anti-coincidence mode in a low-background gas-flow proportional counter in a laboratory (see Appendix H for a description of gas-flow proportional counters). The gradiometric configuration filters out the Earth's ambient magnetic field, large scale variations, and objects located far from the sensor to measure the effects of nearby objects, all without additional data processing.

Fifty-five gallon drums buried 5 to 7 meters below the surface may be detectable using a magnetometer. At many sites, multiple drums have been buried in trenches or pits and detection is straightforward. A single operator carrying a magnetometer with the necessary electronics in a backpack can cover large areas in a relatively small amount of time.

The limitations on the system are related to the size of the objects and their depth below the surface. Objects that are too small or buried too deep will not provide a secondary magnetic field that can be detected at the ground surface.

6.10.3.3 Electromagnetic Sensors

Electromagnetic sensors emit an electromagnetic wave, in either a pulsed or continuous wave mode, and then receive the result of that transmission. The result of the transmission is two signals; quadrature and in-phase. As the wave passes through some material other than air, it is slowed down by a resistive medium or sped up by a conductor through dielectric effects. This produces the quadrature signal. If the electromagnetic wave encounters a highly conductive object it induces a magnetic field in the object. This induced electromagnetic field returns to the sensor as a reflection of the original electromagnetic wave and forms the in-phase signal.

The in-phase signal is indicative of the presence, size, and conductivity of nearby objects (*e.g.*, 55-gallon drums), while the quadrature signal is a measure of the dielectric properties of the nearby objects such as soil. This means that electromagnetic sensors can detect all metallic objects (including steel, brass, and aluminum), such as the metal in waste containers, and also sample the soil for changes in properties, such as those caused by leaks of contaminants.

Depths of interest are largely determined by the spacing between the coil used to transmit the primary electromagnetic wave, and the receiver used to receive that transmission. The rule of thumb is that the depth of interest is on the order of the distance between the transmitter and the receiver. A system designed with the transmitter and receiver placed tens of meters apart can detect signals from tens of meters below the surface. A system with the transmitter and receiver collocated can only detect signals from depths on the order of the size of the coil, which is typically about one meter. The limitations of electromagnetic sensors include a lack of clearly defined signals, and decreasing resolution of the signal as the distance below the surface increases.

6.10.4 Aerial Radiological Surveys

Low-altitude aerial radiological surveys are designed to encompass large areas and may be useful in:

- providing data to assist in the identification of radioactive contaminants and their corresponding concentrations and spatial distributions
- characterizing the nature, extent, and impact of contamination

The measurement sensitivity and data processing procedures provide total area coverage and a detailed definition of the extent of gamma-producing isotopes for a specific area. The gamma radiation spectral data are processed to provide a qualitative and quantitative analysis of the radionuclides in the survey area. Helicopter flights establish a grid pattern (*e.g.*, east-west) of parallel lines approximately 61 m (200 ft) above the ground surface.

The survey consists of airborne measurements of natural and man-made gamma radiation from the terrain surface. These measurements allow for the determination of terrestrial spatial distribution of isotopic concentrations and equivalent gamma exposure rates (*e.g.*, ^{60}Co , $^{234\text{m}}\text{Pa}$, and ^{137}Cs). The results are reported as isopleths for the isotopes and are usually superimposed on scale maps of the area.

7 SAMPLING AND PREPARATION FOR LABORATORY MEASUREMENTS

7.1 Introduction

There are three methods for collecting radiation data while performing a survey. A direct measurement is obtained by placing the detector near or against the surface or in the media being surveyed and reading the radioactivity level directly. Scanning is an evaluation technique performed by moving a portable radiation detection instrument at a constant speed and distance above the surface to semi-quantitatively detect elevated areas of radiation. These measurement techniques are discussed in Chapter 6. Sampling is the process of collecting a portion of an environmental medium as representative of the locally remaining medium. The collected portion of the medium is then analyzed to determine the radionuclide concentration. This chapter discusses issues involved in collecting and preparing samples in the field for analysis, and in evaluating the results of these analyses. In addition, a general discussion on laboratory sample preparation and analysis is provided to assist in communications with the laboratory during survey planning.

Samples should be collected and analyzed by qualified individuals using the appropriate equipment and procedures. This manual assumes that the samples taken during the survey will be submitted to a qualified laboratory for analysis. The laboratory should have written procedures that document its analytical capabilities for the radionuclides of interest and a Quality Assurance/Quality Control (QA/QC) program that documents the compliance of the analytical process with established criteria. The method used to assay for the radionuclides of concern should be recognized as a factor affecting analysis time.

Commonly used radiation detection and measuring equipment for radiological survey field applications is described in Chapter 6 and Appendix H. Many of these equipment types are also used for laboratory analyses, usually under more controlled conditions that provide for lower detection limits and greater delineation between radionuclides. Laboratory methods often involve combinations of both chemical and instrument techniques to quantify the low levels expected in the samples. This chapter provides guidance to assist the MARSSIM user in selecting appropriate procedures for collecting and handling samples for laboratory analysis. More detailed information is available in documents listed in the reference section of this manual.

7.2 Data Quality Objectives

The survey design is developed and documented using the Data Quality Objectives (DQO) Process (see Appendix D). The third step of the DQO Process involves identifying the data needs for a survey. One decision that can be made at this step is the selection of direct measurements

for performing a survey or deciding that sampling methods followed by laboratory analysis are necessary.

7.2.1 Identifying Data Needs

The decision maker and the survey planning team need to identify the data needs for the survey being performed, including the:

- type of samples to be collected or measurements to be performed (Chapter 5)
- radionuclide(s) of interest (Section 4.3)
- number of samples to be collected (Section 5.5.2)
- type and frequency of field QC samples to be collected (Section 4.9)
- amount of material to be collected for each sample (Section 4.7.3 and Section 7.5)
- sampling locations and frequencies (Section 5.5.2)
- standard operating procedures (SOPs) to be followed or developed (Chapter 7)
- analytical bias and precision (*e.g.*, quantitative or qualitative) (Appendix N)
- target detection limits for each radionuclide of interest (Section 6.4 and Table 7.2)
- cost of the methods being evaluated (cost per analysis as well as total cost) (Appendix H)
- necessary turnaround time
- sample preservation and shipping requirements (Section 7.6 and Section 7.9)
- specific background for the radionuclide(s) of interest (Section 4.5)
- derived concentration guideline level (DCGL) for each radionuclide of interest (Section 4.3)
- measurement documentation requirements (Section 9.4.2.2)
- sample tracking requirements (Section 7.8)

Some of this information will be supplied by subsequent steps in the DQO process, and several iterations of the process may be needed to identify all of the data needs. Consulting with a radiochemist or health physicist may be necessary to properly evaluate the information before deciding between direct measurements or sampling methods to perform the survey. Surveys may require data from all three collection methods (*i.e.*, sample analysis, direct measurements, and scans) in order to demonstrate compliance with the regulation.

7.2.2 Data Quality Indicators

The data quality indicators identified as DQOs in Section 2.3.1 and described in Appendix N, Section N.6, should be considered when selecting a measurement method (*i.e.*, scanning, direct measurement, sampling) or an analytical technique (*e.g.*, radionuclide-specific analytical procedure). In some instances, the data quality indicator requirements will help in the selection of an analytical technique. In other cases, the analytical requirements will assist in the selection of appropriate levels for the data quality indicators.

7.2.2.1 Precision

Precision is a measure of agreement among replicate measurements of the same property under prescribed similar conditions (ASQC 1995). Precision is determined quantitatively based on the results of replicate measurements (equations are provided in EPA 1990). The number of replicate analyses needed to determine a specified level of precision for a project is discussed in Section 4.9. There are several types of replicate analyses available to determine the level of precision, and these replicates are typically distinguished by the point in the sample collection and analysis process where the sample is divided. Determining precision by replicating measurements with results at or near the detection limit of the measurement system is not recommended because the measurement uncertainty is usually greater than the desired level of precision.

- **Collocated Samples.** Collocated samples are samples collected adjacent to the routine field sample to determine local variability of the radionuclide concentration. Typically, collocated samples are collected about one-half to three feet away from the selected sample location. Analytical results from collocated samples can be used to assess site variation, but only in the immediate sampling area. Collocated samples should not be used to assess variability across a site and are not recommended for assessing error (EPA 1991g). Collocated samples can be non-blind, single-blind, or double-blind.
- **Field Replicates.** Field replicates are samples obtained from one location, homogenized, divided into separate containers and treated as separate samples throughout the remaining sample handling and analytical processes. These samples are used to assess error associated with sample heterogeneity, sample methodology and analytical procedures. Field replicates are used when determining total error for critical samples with contamination concentrations near the action level. For statistical analysis to be valid in such a case, a minimum of eight replicate samples would be required (EPA 1991g). Field replicates (or field split samples) can be non-blind, single-blind, or double-blind and are recommended for determining the level of precision for a radiation survey or site investigation.
- **Analytical Laboratory Replicate.** An analytical laboratory replicate is a subsample of a routine sample that is homogenized, divided into separate containers, and analyzed using the same analytical method. It is used to determine method precision, but because it is a non-blind sample, or known to the analyst, it can only be used by the analyst as an internal control tool and not as an unbiased estimate of analytical precision (EPA 1990).
- **Laboratory Instrument Replicate.** A laboratory instrument replicate is the repeated measurement of a sample that has been prepared for counting (*i.e.*, laboratory sample preparation and radiochemical procedures have been completed). It is used to determine

precision for the instrument (repeated measurements using same instrument) and the instrument calibration (repeated measurements using different instruments, such as two different germanium detectors with multichannel analyzers). A laboratory instrument replicate is generally performed as part of the laboratory QC program and is a non-blind sample. It is typically used as an internal control tool and not as an unbiased estimate of analytical precision.

7.2.2.2 Bias

Bias is the systematic or persistent distortion of a measurement process that causes error in one direction (ASQC 1995). Bias is determined quantitatively based on the analysis of samples with a known concentration. There are several types of samples with known concentrations. QC samples used to determine bias should be included as early in the analytical process as possible.

- **Reference Material.** A material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials (ISO 1993). A certified reference material is reference material for which each certified property value is accompanied by an uncertainty at a stated level of confidence. Radioactive reference materials may be available for certain radionuclides in soil (*e.g.*, uranium in soil), but reference building materials may not be available. Because reference materials are prepared and homogenized as part of the certification process, they are rarely available as double-blind samples. When appropriate reference materials are available (*i.e.*, proper matrix, proper radionuclide, proper concentration range), they are recommended for use in determining the overall bias for a measurement system.
- **Performance Evaluation (PE) Samples.** PE sample are samples that evaluate the overall bias of the analytical laboratory and detect any error in the analytical method used. These samples are usually prepared by a third party, using a quantity of analyte(s) which is known to the preparer but unknown to the laboratory, and always undergo certification analysis. The analyte(s) used to prepare the PE sample is the same as the analyte(s) of interest. Laboratory procedural error is evaluated by the percentage of analyte identified in the PE sample (EPA 1991g). PE samples are recommended for use in determining overall bias for a measurement system when appropriate reference material are not available. PE samples are equivalent to matrix spikes prepared by a third party that undergo certification analysis and can be non-blind, single-blind, or double-blind.
- **Matrix Spike Samples.** Matrix spike samples are environmental samples that are spiked in the laboratory with a known concentration of a target analyte(s) to verify percent recoveries. They are used primarily to check sample matrix interferences but can also be used to monitor laboratory performance. However, a data set of at least three or more

results is necessary to distinguish between laboratory performance and matrix interference (EPA 1991g). Matrix Spike samples are often replicated to monitor method performance and evaluate error due to laboratory bias and precision (when four or more pairs are analyzed). These replicates are often collectively referred to as a matrix spike/matrix spike duplicate (MS/MSD).

There are several additional terms applied to samples prepared by adding a known amount of the radionuclide of interest to the sample. The majority of these samples are designed to isolate individual sources of bias within a measurement system by preparing pre- and post-operation spikes. For example, the bias from the digestion phase of the measurement system can be determined by comparing the result from a pre-digest spike to the result from a post-digest spike.

There are also several types of samples used to estimate bias caused by contamination.

- **Background Sample.** A background sample is a sample collected upgradient of the area of potential contamination (either onsite or offsite) where there is little or no chance of migration of the contaminants of concern (EPA 1991g). Background samples are collected from the background reference area (Section 4.5), determine the natural composition and variability of the soil (especially important in areas with high concentrations of naturally occurring radionuclides), and are considered “clean” samples. They provide a basis for comparison of contaminant concentration levels with samples collected from the survey unit when the statistical tests described in Chapter 8 are performed.
- **Field Blanks.** Field blanks are samples prepared in the field using certified clean sand or soil and then submitted to the laboratory for analysis (EPA 1991g). A field blank is used to evaluate contamination error associated with sampling methodology and laboratory procedures. It also provides information about contaminants that may be introduced during sample collection, storage, and, transport. Field blanks are recommended for determining bias resulting from contamination for a radiation survey or site investigation.
- **Method Blank.** A method blank is an analytical control sample used to demonstrate that reported analytical results are not the result of laboratory contamination (ATSDR 1992). It contains distilled or deionized water and reagents, and is carried through the entire analytical procedure (laboratory sample preparation, digestion, and analysis). The method blank is also referred to as a reagent blank. The method blank is generally used as an internal control tool by the laboratory because it is a non-blind sample.

7.2.2.3 Representativeness

Representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point (ASQC 1995). Representativeness is a qualitative term that is reflected in the survey design through the selection of a measurement method (*e.g.*, direct measurement or sampling) and the size of a sample collected for analysis.

Sample collection and analysis is typically less representative of true radionuclide concentrations at a specific measurement location than performing a direct measurement. This is caused by the additional steps required in collecting and analyzing samples, such as sample collection, field sample preparation, laboratory sample preparation, and radiochemical analysis. However, direct measurement techniques with acceptable detection limits are not always available. When sampling is required as part of a survey design, it is critical that the sample collection procedures consider representativeness. The location of the sample is determined in Section 5.5.2.5, but the size and content of the sample are usually determined as the sample is collected. Sample size and content are discussed in Section 4.7.3 and Section 7.5. Sample collection procedures also need to consider the development of the DCGLs when determining the representativeness of the samples.

7.2.2.4 Comparability

Comparability is a qualitative term that expresses the confidence that two data sets can contribute to a common analysis and interpolation. Generally, comparability is provided by using the same measurement system for all analyses of a specific radionuclide. In many cases, equivalent procedures used within a measurement system are acceptable. For example, using a liquid-liquid extraction purification step to determine the concentration of ^{238}Pu using alpha spectrometry may be equivalent to using an ion-exchange column purification step. However, using a gross alpha measurement on a gas proportional counting system would not be considered equivalent. Comparability is usually not an issue except in cases where historical data have been collected and are being compared to current analytical results, or when multiple laboratories are used to provide results as part of a single survey design.

7.2.2.5 Completeness

Completeness is a measure of the amount of valid data obtained from the measurement system, expressed as a percentage of the number of valid measurements that should have been collected. Completeness is of greater concern for laboratory analyses than for direct measurements because the consequences of incomplete data often require the collection of additional samples. Direct measurements can usually be repeated fairly easily. The collection of additional samples generally requires a remobilization of sample collection personnel which can be expensive. Conditions at the site may have changed making it difficult or impossible to collect representative and

comparable samples without repeating the entire survey. On the other hand, if it is simply an analytical problem and sufficient sample was originally collected, the analysis can be repeated using archived sample material. Samples collected on a grid to locate areas of elevated activity are also a concern for completeness. If one sample analysis is not valid, the entire survey design for locating areas of elevated activity may be invalidated.

7.2.2.6 Other Data Quality Indicators

Several additional data quality indicators that influence the final status survey design are identified as DQOs in Section 2.3.1. Many of these (*e.g.*, selection and classification of survey units, decision error rates, variability in the contaminant concentration, lower bound of the gray region) are used to determine the number of measurements and are discussed in detail in Section 5.5. The method detection limit is directly related to the selection of a measurement method and a radionuclide-specific analytical technique.

Analytical methods should be capable of measuring levels below the established DCGLs, detection limits of 10-50% of the DCGL should be the target (see Section 6.7). Cost, time, best available technology, or other constraints may create situations where the above stated sensitivities are deemed impracticable. Under these circumstances, higher detection sensitivities may be acceptable. Although laboratories will state detection limits, these sensitivities are usually based on ideal or optimistic situations and may not be achievable under actual measurement conditions. Detection limits are subject to variation from sample to sample, instrument to instrument, and procedure to procedure, depending on sample size, geometry, background, instrument efficiency, chemical recovery, abundance of the radiations being measured, counting time, self-absorption in the prepared sample, and interferences from radionuclides or other materials present in the sample. The detection limit that is achievable in practice should not exceed the DCGL.

7.3 Communications with the Laboratory

Laboratory analyses of samples are generally performed by personnel not directly involved in the collection of the samples being analyzed. Samples are typically collected by one group working in the field, and analyzed by a second group located in a laboratory. This separation of tasks can potentially lead to problems based on the lack of communication between the two groups. For this reason, communications between the Project Manager, field personnel, and laboratory personnel are vital to ensuring the success of a project.

7.3.1 Communications During Survey Planning

The radioanalytical laboratory is a valuable resource during survey planning. Information on available analytical techniques, analytical bias and precision, method detection limits, analytical costs, and turnaround times can easily be provided by the laboratory. All of this information is used to make the decision to perform direct measurements or collect samples for laboratory measurements. Additional information, such as required sample size/volume, type of sample container, preservative requirements, and shipping requirements, including the availability of the laboratory for receipt of samples on weekends or holidays, can be obtained and factored into the survey plan.

Involving the radioanalytical laboratory during survey planning also provides the laboratory with site-specific information about the project. Information on the radionuclides of interest, possible chemical and physical form of the contamination, and mechanism for release of the contamination to the environment is used to modify or develop the analytical method for site-specific conditions if required. The laboratory should also be provided with the site-specific action levels (i.e., DCGLs, investigation levels) early in the survey planning process.

In some cases, it is not practical to select a radioanalytical laboratory early in the survey process to participate in the survey planning activities. For example, Federal procurement procedures require that a statement of work (SOW) identifying the tasks to be performed by the laboratory be developed prior to selecting a laboratory. Unfortunately, the details of the tasks for the laboratory to perform are developed during survey planning. This means that the information provided by the laboratory and used during survey planning will be obtained from another source, usually a radiochemist or health physicist trained in radiochemistry. The uncertainty associated with this information and subsequent decisions made based on this information increases. This may lead to increased costs caused by specifying an unnecessarily expensive analytical method in the SOW or repeated sampling and analysis of samples that did not meet the target detection limits because the specified analytical method was not sensitive enough. In addition, unnecessary or inappropriate analytical methods may be selected by the laboratory because site-specific information concerning the samples was not provided.

The laboratory should be consulted when planning the schedule for the survey to insure that the expected turnaround times can be met based on the projected laboratory workload.

7.3.2 Communications Before and During Sample Collection

In most situations, the sample collection and shipping containers are supplied by the laboratory; therefore, the laboratory should be notified well in advance of the sampling trip so that these items will be available to the sampling team during the survey.

The main purpose of communications with the laboratory during sample collection is to inform the laboratory of modifications to the survey design specified in the planning documents (*e.g.*, QAPP and SOPs). The laboratory should have a copy of the survey design in their possession prior to samples being collected.

Modifications to the survey design are often minor deviations from the SOPs caused by site-specific conditions and usually affect a small number of samples. For example, a rock outcropping covered by a thin layer of soil may restrict the depth of the surface soil sample to 5 cm (2 in.) instead of the 10 cm (4 in.) specified in the SOP. The mass of the samples collected from this area of the site is one-half the expected sample mass, and the laboratory needs to be informed of this deviation from the SOP.

In other situations, there may be an extensive modification to the number or types of samples collected at the site that will affect the analytical methods, detection capabilities, analytical costs, or even the assumptions used to develop the DCGL. For example, a large portion of the site may have been converted to a parking lot. A large pile of material that may represent the former surface soil will be sampled as well as soil collected from beneath the parking lot surface. The number of samples to be analyzed has doubled compared to the original SOW.

If the expected timing of receipt of samples at the laboratory changes due to sample collection schedule deviations, the laboratory should be notified. Most laboratories require prior notification for samples to be received on weekends.

7.3.3 Communications During Sample Analysis

The laboratory should communicate with the Project Manager and field personnel during sample analysis. The laboratory should provide a list of missing or damaged samples as soon after the samples are received as practical. This allows the Project Manager to determine if resampling is required to replace the missing or damaged samples. The Project Manager may also request notification from the laboratory when samples are spilled or lost during analysis. Preliminary reports of analytical results may be useful to help direct sampling activities and provide early indications of whether the survey objectives defined by the DQOs are being met. However, if preliminary results have not been verified or validated, their usefulness is limited.

7.3.4 Communications Following Sample Analysis

Following sample analysis, the laboratory will provide documentation of the analytical results as specified in the survey design. Laboratory personnel should be available to assist with data verification and validation.

7.4 Selecting a Radioanalytical Laboratory

Once the decision to perform sampling activities is made, the next step is to select the analytical methods and determine the data needs for these methods. It is advisable to select a radiochemical laboratory early in the survey planning process in order that it may be consulted on the analytical methodology¹ and the sampling activities. In addition, mobile laboratories can provide on-site analytical capability. Obtaining laboratory or other services may involve a specific procurement process. Federal procurement procedures may require additional considerations beyond the method described here.

The procurement of laboratory services usually starts with the development of a request for proposal that includes a statement-of-work describing the analytical services to be procured. The careful preparation of the statement-of-work is essential to the selection of a laboratory capable of performing the required services in a technically competent and timely manner.

The technical proposals received in response to the procurement request for proposal must be reviewed by personnel familiar with radioanalytical laboratory operations in order to select the most qualified offerer. For complicated sites with a large number of laboratory analyses, it is recommended that a portion of this evaluation take the form of a pre-award audit. The provision for this audit must be in the request for proposal. The results of this audit provide a written record of the decision to use a specific laboratory. Smaller sites or facilities may decide that a review of the laboratory's qualifications is sufficient for the evaluation.

There are six criteria that should be reviewed during this evaluation:

- Does the laboratory possess the appropriate well-documented procedures, instrumentation, and trained personnel to perform the necessary analyses? Necessary analyses are defined by the data needs (radionuclide(s) of interest and target detection limits) identified by the DQO process.
- Is the laboratory experienced in performing the same or similar analyses?
- Does the laboratory have satisfactory performance evaluation results from formal monitoring or accreditation programs? The laboratory should be able to provide a summary of QA audits and proof of participation in interlaboratory cross-check programs. Equipment calibrations should be performed using National Institute of Standards and Technology (NIST) traceable reference radionuclide standards whenever possible.

¹ The laboratory provides information on personnel, capabilities, and current workload that are necessary inputs to the decision-making process.

- Is there an adequate capacity to perform all analyses within the desired timeframe? This criterion considers whether or not the laboratory possesses a radioactive materials handling license or permit for the samples to be analyzed. Very large survey designs may indicate that more than one analytical laboratory is necessary to meet the survey objectives.²
- Does the laboratory provide an internal quality control review of all generated data that is independent of the data generators?
- Are there adequate protocols for method performance documentation and sample security?

Providers of radioanalytical services should have an active and fully documented QA program in place.³ This program should comply with the objectives determined by the DQO process in Section 2.3. The QA program should include:

- laboratory organizational structure
- personnel qualifications
- written standard operating procedures and instructions
- inter- and intralaboratory performance analyses
- design control to define the flow of samples through the laboratory
- a corrective action plan
- an internal audit program

Chain-of-Custody requirements and numbers of samples are also specified. The analytical procedures as well as the documentation and reporting requirements should be specified and agreed upon. These topics are discussed in detail in the following sections of this chapter.

7.5 Sampling

This section provides guidance on developing appropriate sample collection procedures for surveys designed to demonstrate compliance with a dose- or risk-based regulation. Sample collection procedures are concerned mainly with ensuring that a sample is representative of the sample media, is large enough to provide sufficient material to achieve the desired detection limit, and is consistent with assumptions used to develop the conceptual site model and the DCGLs. Additional considerations for sample collection activities are discussed in Section 4.7.3.

² If several laboratories are performing analyses as part of the survey, the analytical methods used to perform the analyses should be similar to ensure comparability of results (see Appendix N, Section N.6.5).

³ The QA program is typically documented in one or more documents such as a Quality Management Plan, Quality Assurance Manual, or Quality Assurance Project Plan.

The presence of radioactive and hazardous chemical wastes (mixed wastes) at a site can influence the survey design. The external exposure rates or radioactivity concentration of a specific sample may limit the time that workers will be permitted to remain in intimate contact with the samples, or may dictate that smaller samples be taken and special holding areas be provided for collected samples prior to shipment. These special handling considerations may conflict with the size specifications for the analytical method, normal sampling procedures, or equipment. There is a potential for biasing sampling programs by selecting samples that can be safely handled or legally shipped to support laboratories. Because final status surveys are performed to demonstrate that a site can be safely released, issues associated with high levels of radioactivity are not expected to be a concern.

7.5.1 Surface Soil

The purpose of surface soil sampling is to collect samples that accurately and precisely represent the radionuclides and their concentrations at the location being sampled. In order to do this and plan for sampling, a decision must be made as to the survey design. The selection of a survey design is based on the Historical Site Assessment, results from preliminary surveys (*i.e.*, scoping characterization, remedial action support), and the objectives of the survey developed using the Data Quality Objectives (DQO) Process. The selection between judgmental, random, and systematic survey designs is discussed in Section 5.5.3.

7.5.1.1 Sample Volume

The volume of soil collected should be specified in the sample collection procedure. In general, large volumes of soil are more representative than small volumes of soil. In addition, large samples provide sufficient sample to ensure that required detection limits can be achieved and that sample reanalysis can be done if there is a problem. However, large samples may cause problems with shipping, storage, and disposal. All of these issues should be discussed with the sample collection team and the analytical laboratory during development of sample collection procedures. In general, surface soil samples range in size from 100 g up to several kilograms.

The sample collection procedure should also make clear if it is more important to meet the volume requirement of the survey design or the surface area the sample represents. Constant volume is related to comparability of the results while surface area is more closely related to the representativeness of the results. Maintaining a constant surface area and depth for samples collected for a particular survey can eliminate problems associated with different depth profiles. The actual surface area included as part of the sample may be important for estimating the probability of locating areas of elevated concentration.

7.5.1.2 Sample Content

The material present in the field at the sample location may or may not provide a representative sample. Vegetative cover, soil particle size distribution, inaccessibility, or lack of sample material are examples of problems that may be identified during sample collection. All deviations from the survey design as documented in the Standard Operating Procedures (SOPs) should be recorded as part of the field sample documentation.

Sample content is generally defined by the assumptions used to develop the conceptual site model and the DCGLs. A typical agricultural scenario assumes that the top few centimeters of soil are available for resuspension in air, that the top 15 cm (6 in.) are homogenized by agricultural activities (e.g., plowing), that roots can extend down several meters to obtain water and nutrients depending on the plant, and that external exposure is based on an assumed thickness of contaminated soil (usually at the surface). Depending on the dominant exposure pathways for each radionuclide, this can result in a complicated set of instructions for collecting representative samples. This situation can be further complicated by the fact that the site is not currently being used for agricultural purposes. For this situation it is necessary to look at the analytical results from the preliminary surveys (i.e., scoping, characterization, remedial action support) to determine the expected depth of contamination.

In most situations the vegetative cover is not considered part of the surface soil sample and is removed in the field. For agricultural scenarios where external exposure is not the primary concern, soil particles greater than 2 mm (0.08 in.) are generally not considered as part of the sample (EPA 1990). Foreign material (e.g., plant roots, glass, metal, or concrete) is also generally not considered part of the sample, but should be reviewed on a site-specific basis. It is important that the sample collection procedure clearly indicate what is and what is not considered part of the sample.

7.5.1.3 Sampling Equipment

The selection of proper sampling equipment is important to ensure that samples are collected effectively and efficiently. Sampling equipment generally consists of a tool to collect the sample and a container to place the collected sample in. Sample tracking begins as soon as the sample is collected, so it may be necessary to consider security of collected samples required by the objectives of the survey.

Sampling tools are selected based on the type of soil, sample depth, number of samples required, and training of available personnel. The selection of a sampling tool may also be based on the expected use of the results. For example, if a soil sample is collected to verify the depth profile used to develop the calibration for *in situ* gamma spectrometry, it is important to preserve the soil core. Table 7.1 lists several examples of tools used for collecting soil samples, situations where they are applicable, and some advantages and disadvantages involved in their use.

Table 7.1 Soil Sampling Equipment*

| Equipment | Application | Advantages/Disadvantages |
|----------------------------|---|--|
| Tier | Soft surface soil | Inexpensive; easy to use and decontaminate; difficult to use in stone or dry soil. |
| Scoop or trowel | Soft surface soil | Inexpensive; easy to use and decontaminate; trowels with painted surfaces should be avoided |
| Bulb Planter | Soft Soil, 0-15 cm (0-6 in.) | Easy to use and decontaminate; uniform diameter and sample volume; preserves soil core; limited depth capability; can be difficult to decontaminate |
| Soil Coring Device | Soft soil, 0-60 cm (0-24 in.) | Relatively easy to use; preserves soil core; limited depth capability; can be difficult to decontaminate |
| Thin-wall tube sampler | Soft soil, 0-3 m (0-10 ft) | easy to use; preserves soil core; easy to decontaminate; can be difficult to remove cores |
| Split spoon sampler | Soil, to bedrock | Excellent depth range; preserves soil core; useful for hard soils; often used in conjunction with drill rig for obtaining deep cores |
| Shelby tube sampler | Soft soil, to bedrock | Excellent depth range; preserves soil core; tube may be used for shipping core to lab.; may be used in conjunction with drill rig for obtaining deep cores |
| Bucket auger | Soft soil, 7.5 cm - 3 m (3 in. - 10 ft) | Easy to use; good depth range; uniform diameter and sample volume; may disrupt and mix soil horizons greater than 15 cm |
| Hand -operated power auger | Soil, 15 cm - 4.5 m (6 in. -15 ft) | Good depth range; generally used in conjunction with bucket auger; destroys soil core; requires two or more operators; can be difficult to decontaminate |

* Reproduced from EPA 1991g

Sample containers are generally not a major concern for collecting surface soil samples. Polyethylene bottles with screw caps and wide mouths are recommended. These containers are fairly economical, provide easy access for adding and removing samples, and resist chemicals, breaking, and temperature extremes. Glass containers are also acceptable, but they are fragile and tend to break during shipment. Metal containers are sometimes used, but sealing the container can present a problem and corrosion can be an issue if the samples are stored for a significant length of time.

7.5.2 Building Surfaces

Because building surfaces tend to be relatively smooth and the radioactivity is assumed to be on or near the surface, direct measurements are typically used to provide information on contaminant concentrations. Sometimes, however, it is necessary to collect actual samples of the building material surface for analysis in a laboratory.

7.5.2.1 Sample Volume

The sample volume collected from building surfaces is usually a less significant DQO concern than the area from which the sample was collected. This is because building surface DCGLs are usually expressed in terms of activity per unit area. It is still necessary to consider the sample volume to account for sample matrix effects that may reduce the chemical recovery, which in turn has an affect on the detection limit.

7.5.2.2 Sample Content

If residual activity is covered by paint or some other treatment, the underlying surface and the coating itself may be contaminated. If the activity is a pure alpha or low-energy beta emitter, measurements at the surface will probably not be representative of the actual residual activity level. In this case the surface layer is removed from the known area, such as by using a commercial stripping agent or by physically abrading the surface. The removed coating material is analyzed for activity content and the level converted to appropriate units (*i.e.*, Bq/m², dpm/100 cm²) for comparison with surface activity DCGLs. Direct measurements can be performed on the underlying surface after removal of the coating.

Residual radioactivity may be incorporated into building materials, such as pieces of concrete or other unusual matrices. Development of SOPs for collecting these types of samples may involve consultation with the analytical laboratory to help ensure that the objectives of the survey are achieved.

The thickness of the layer of building surface to be removed as a sample should be consistent with the development of the conceptual site model and the DCGLs. For most sites the surface layer will only be the first few millimeters of the material being sampled.

7.5.2.3 Sampling Equipment

Tools used to provide samples of building surfaces depend on the material to be sampled. Concrete may require chisels, hammers, drills, or other tools specifically designed to remove a thin layer of the surface. Wood surfaces may require using a sander or a saw to collect a sample. Paint may be chemically or physically stripped from the surface.

Sample containers for these samples are generally the same as those recommended for soil samples. If chemicals are used to strip paint or other surface materials, the chemical resistance of the container should be considered.

7.5.3 Other Media

Surface soil and building surfaces are the media addressed in MARSSIM during the final status survey design. Other media may be involved and may have been remediated. Data collection activities during preliminary surveys (*i.e.*, scoping, characterization, remedial action support) may involve collecting samples of other media to support the final status survey design. Examples of other media that may be sampled include:

- subsurface soil
- ground water
- surface water
- sediments
- sewers and septic systems
- flora and fauna (plants and animals)
- airborne particulates
- air (gas)

Appendix M provides a list of resources that can be used to develop sample collection procedures for other media that may be required by preliminary surveys to support the development of a final status survey design.

7.6 Field Sample Preparation and Preservation

Proper sample preparation and preservation are essential parts of any radioactivity sampling program. The sampling objectives should be specified before sampling activities begin. Precise records of sample collection and handling are necessary to ensure that data obtained from different locations or time frames are correctly compared.

The appropriateness of sample preparation techniques is a function of the analysis to be performed (EPA 1992a, 1992b). Field sample preparation procedures are a function of the specified analysis and the objectives of the survey. It is essential that these objectives be clearly established and agreed upon in the early stages of survey planning (see Section 2.3).

7.6.1 Surface Soil

Soil and sediment samples, in most protocols, require no field preparation and are not preserved. In some protocols, cooling of soil samples to 4 °C is required during shipping and storage of soil samples. This is not a practice normally followed for the radiochemical analysis of soil samples.

When replicate samples are prepared in the field, it is necessary to homogenize the sample prior to separation into replicates. There are standard procedures for homogenizing soil in the laboratory (ASTM 1995), but the equipment required for these procedures may not be available in the field. Simple field techniques, such as cone and quarter, or using a riffle splitter to divide the sample may be appropriate if the sample can be dried (ASTM 1993, EPA 1991g). If the sample contains significant amounts of residual water (*e.g.*, forms clumps of soil) and there are no facilities for drying the sample, it is recommended that the homogenization and separation into replicates be performed in a laboratory. It is preferable to use non-blind replicates where the same laboratory prepares and analyzes the replicates rather than use poorly homogenized or heterogeneous samples to prepare replicates samples.

7.6.2 Building Surfaces

Field preparation and preservation of building and associated materials, including smear samples, is not generally required. Homogenization of samples to prepare replicates is the same for building surface material and soil.

7.6.3 Other Media

Other media may have significant requirements related to field sample preparation and preservation. For example, water samples may need filtering and acidification. Storage at reduced temperatures (*i.e.*, cooling or freezing) to reduce biological activity may be necessary for some samples. Addition of chemical preservatives for specific radionuclides or media may also be required.

7.7 Analytical Procedures

The selection of the appropriate radioanalytical methods is normally made prior to the procurement of analytical services and is included in the statement-of-work of the request for proposal. The statement-of-work may dictate the use of specific methods or be performance based. Unless there is a regulatory requirement, such as conformance to the EPA drinking water methods (EPA 1980a), the specification of performance based methodology is encouraged. One reason for this is that a laboratory will usually perform better using the methods routinely employed in its laboratory as contrasted to using other methods with which it has less experience.

The laboratory is also likely to have historical data on performance for methods routinely used by that laboratory. However, the methods employed in a laboratory should be derived from a reliable source, such as those listed in Table 7.2.

Table 7.2 Examples of References for Routine Analytical Methods

- *Methods of Air Sampling and Analysis* (Lodge 1988)
- *Annual Book of ASTM Standards, Water and Environmental technology. Volume 11.04, Environmental Assessment; Hazardous Substances and Oil Spill Responses; Waste Management; Environmental Risk Assessment* (ASTM 1997)
- *Standard Methods for the Examination of Water and Wastewater* (APHA 1995)
- *EML Procedures Manual* (DOE 1990b)
- *Radiochemical Analytical Procedures for Analysis of Environmental Samples* (EPA 1979)
- *Radiochemistry Procedures Manual* (EPA 1984a)
- *Indoor Radon and Radon Decay Product Measurement Protocols* (EPA 1992d)
- *USAEHA Environmental Sampling Guide* (Department of the Army 1993)

This section briefly describes specific equipment and procedures to be used once the sample is prepared for analysis. The results of these analyses (*i.e.*, the levels of radioactivity found in these samples) are the values used to determine the level of residual activity at a site. In a decommissioning effort, the DCGLs are expressed in terms of the concentrations of certain radionuclides. It is of vital importance, therefore, that the analyses be accurate and of adequate sensitivity for the radionuclides of concern. The selection of analytical procedures should be coordinated with the laboratory and specified in the survey plan.

Analytical methods should be adequate to meet the data needs identified in the DQO process. Consultation with the laboratory performing the analysis is recommended before selecting a course of action. MARSSIM is not intended to limit the selection of analytical procedures, rather all applicable methods should be reviewed to provide results that meet the objectives of the survey. The decision maker and survey planning team should decide whether routine methods will be used at the site or if non-routine methods may be acceptable.

- Routine analytical methods are documented with information on minimum performance characteristics, such as detection limit, precision and accuracy, and useful range of radionuclide concentrations and sample sizes. Routine methods may be issued by a recognized organization (*e.g.*, Federal or State agency, professional organization), published in a refereed journal, or developed by an individual laboratory. Table 7.2 lists examples of sources for routine methods.
- Non-routine methods address situations with unusual or problematic matrices, low detection limits, or new parameters, procedures or techniques. Non-routine methods include adjustments to routine methods, new techniques published in refereed literature, and development of new methods.

References that provide information on radiochemical methodology and should be considered in the methods review and selection process are available from such organizations as:

- National Council on Radiation Protection and Measurements (NCRP)
- American Society of Testing and Materials (ASTM)
- Radiological and Environmental Sciences Laboratory (RESL), Idaho Falls, Idaho (Operated by the DOE)
- DOE Technical Measurements Center, Grand Junction, CO
- Environmental Measurements Laboratory (EML); formerly the Health and Safety Laboratory of the DOE

Equipment vendor literature, catalogs, and instrument manuals are often a source of useful information on the characteristics of radiation detection equipment. Table 7.3 provides a summary of common laboratory methods with estimated detection limits.

Analytical procedures in the laboratory consist of several parts that are assembled to produce an SOP for a specific project or sample type. These parts include:

- laboratory sample preparation
- sample dissolution
- sample purification
- preparation for counting
- counting
- data reduction

Table 7.3 Typical Measurement Sensitivities for Laboratory Radiometric Procedures

Sampling and Preparation for Laboratory Measurements

| Sample Type | Radionuclides or Radiation Measured | Procedure | Approximate Measurement Sensitivity |
|-----------------------|---|---|-------------------------------------|
| Smears (filter paper) | Gross alpha | Gas-flow proportional counter; 5-min count Alpha scintillation detector with scaler; 5-min count | 5 dpm 20 dpm |
| | Gross beta | Gas-flow proportional counter; 5-min count End window GM with scaler; 5-min count (unshielded detector) | 10 dpm 80 dpm |
| | Low energy beta (^3H , ^{14}C , ^{63}Ni) | Liquid scintillation spectrometer; 5-min count | 30 dpm |
| Soil Sediment | ^{137}Cs , ^{60}Co , ^{226}Ra (^{214}Bi) ^a , ^{232}Th (^{228}Ac), ^{235}U | Germanium detector (25% relative efficiency) with multichannel analyzer; pulse height analyzer; 500-g sample; 15-min analysis | 0.04-0.1 Bq/g (1-3 pCi/g) |
| | 234 , 235 , ^{238}U ; 238 , 239 , ^{240}Pu ; 227 , 228 , 230 , ^{232}Th ; other alpha emitters | Alpha spectroscopy with multichannel analyzer - pyrosulfate fusion and solvent extraction; surface barrier detector; pulse height analyzer; 1-g sample; 16-hr count | 0.004-0.02 Bq/g (0.1-0.5 pCi/g) |
| Water | Gross alpha | Gas-flow proportional counter; 100-ml sample, 200-min count | 0.04 Bq/L (1 pCi/l) |
| | Gross beta | Gas-flow proportional counter; 100-ml sample, 200-min count | 0.04 Bq/L (1 pCi/L) |
| | ^{137}Cs , ^{60}Co , ^{226}Ra (^{214}Bi), ^{232}Th (^{228}Ac), ^{235}U | Germanium detector (25% relative efficiency) with multichannel analyzer; pulse height analyzer; 3.5L sample, 16-hr count | 0.4 Bq/L (10 pCi/L) |
| | 234 , 235 , ^{238}U ; 238 , 239 , ^{240}Pu ; 227 , 228 , 230 , ^{232}Th ; other alpha emitters | Alpha spectroscopy with multichannel analyzer - solvent extraction; surface barrier detector; pulse height analyzer; 100 ml sample, 30 min count | 0.004-0.02 Bq/L (0.1-0.5 pCi/L) |
| | ^3H | Liquid scintillation spectrometry; 5-ml sample, 30-min count | 10 Bq/L (300 pCi/L) |

^a Indicates that a member of the decay series is measured to determine activity level of the parent radionuclide of primary interest.

7.7.1 Photon Emitting Radionuclides

There is no special sample preparation required for counting samples using a germanium detector or a sodium iodide detector beyond placing the sample in a known geometry for which the detector has been calibrated. The samples can be measured as they arrive at the laboratory, or the sample can be dried, ground to a uniform particle size, and mixed to provide a more homogeneous sample if required by the SOPs.

The samples are typically counted using a germanium detector with a multichannel analyzer or a sodium iodide detector with a multichannel analyzer. Germanium detectors have better resolution and can identify peaks (and the associated radionuclides) at lower concentrations. Sodium iodide detectors often have a higher efficiency and are significantly less expensive than germanium detectors. Low-energy photons (*i.e.*, x-rays and gamma rays below 50 keV) can be measured using specially designed detectors with an entrance window made from a very light metal, typically beryllium. Descriptions of germanium and sodium iodide detectors are provided in Appendix H.

Data reduction is usually the critical step in measuring photon emitting radionuclides. There are often several hundred individual gamma ray energies detected within a single sample. Computer software is usually used to identify the peaks, associate them with the proper energy, associate the energy with one or more radionuclides, correct for the efficiency of the detector and the geometry of the sample, and provide results in terms of concentrations with the associated uncertainty. It is important that the software be either a well-documented commercial package or thoroughly evaluated and documented before use.

7.7.2 Beta Emitting Radionuclides

Laboratory sample preparation is an important step in the analysis of surface soil and other solid samples for beta emitting radionuclides. The laboratory will typically have a sample preparation procedure that involves drying the sample and grinding the soil so that all of the particles are less than a specified size to provide a homogeneous sample. A small portion of the homogenized sample is usually all that is required for the individual analysis.

Once the sample has been prepared, a small portion is dissolved, fused, or leached to provide a clear solution containing the radionuclide of interest. The only way to ensure that the sample is solubilized is to completely dissolve the sample. However, this can be an expensive and time-consuming step in the analysis. In some cases, leaching with strong acids can consistently provide greater than 80% recovery of the radionuclide of interest (NCRP 1976a) and may be acceptable for certain applications. Gross beta measurements may be performed on material that has not been dissolved.

After dissolution, the sample is purified using a variety of chemical reactions to remove bulk chemical and radionuclide impurities. The objective is to provide a chemically and radiologically pure sample for measurement. Examples of purification techniques include precipitation, liquid-liquid extraction, ion-exchange chromatography, distillation, and electrodeposition. Gross beta measurements may be performed on material that has not been purified.

After the sample is purified, it is prepared for counting. Beta emitting radionuclides are usually prepared for a specific type of counter in a specified geometry. Solid material is usually precipitated and collected on a filter in a circular geometry to provide a homogeneous sample. Liquid samples are typically converted to the appropriate chemical form and diluted to a specified volume in preparation for counting.

Measurements of solid samples are typically performed using a gas-flow proportional counter. Because total beta activity is measured, it is important that the purification step be performed to remove any interfering radionuclides. Liquid samples are usually diluted using a liquid scintillation cocktail and counted using a liquid scintillation spectrometer. Liquid scintillation spectrometers can be used for low-energy beta emitting radionuclides, such as ^3H and ^{63}Ni . They also have high counting efficiencies, but often have a high instrument background as well. Gas-flow proportional counters have a very low background. Appendix H provides a description of both the gas-flow proportional counter and the liquid scintillation spectrometer.

Data reduction for beta emitting radionuclides is less complicated than that for photon emitting radionuclides. Since the beta detectors report total beta activity, the calculation to determine the concentration for the radionuclide of interest is straightforward.

7.7.3 Alpha Emitting Radionuclides

Laboratory sample preparation for alpha emitting radionuclides is similar to that for beta emitting radionuclides. Sample dissolution and purification tasks are also similar to those performed for beta emitting radionuclides.

Because of the limited penetrating power of alpha particles, the preparation for counting is often a critical step. Gross alpha measurements can be made using small sample sizes with a gas-flow proportional counter, but self-absorption of the alpha particles results in a relatively high detection limit for this technique. Liquid scintillation spectrometers can also be used to measure alpha emitting radionuclides but the resolution limits the usefulness of this technique. Most alpha emitting radionuclides are measured in a vacuum (to limit absorption by air) using alpha spectroscopy. This method requires that the sample be prepared as a virtually weightless mount in a specific geometry. Electrodeposition is the traditional method for preparing samples for counting. This technique provides the highest resolution, but it requires a significant amount of

training and expertise on the part of the analyst to produce a high quality sample. Precipitation of the radionuclide of interest on the surface of a substrate is often used to prepare samples for alpha spectroscopy. While this technique generally produces a spectrum with lower resolution, the preparation time is relatively short compared to electrodeposition, and personnel can be trained to prepare acceptable samples relatively quickly.

Alpha emitting radionuclides are typically measured using alpha spectroscopy. The data reduction requirements for alpha spectroscopy are greater than those for beta emitting radionuclides, and similar to those for photon emitting radionuclides. Alpha spectroscopy produces a spectrum of alpha particles detected at different energies, but because the sample is purified prior to counting, all of the alpha particles come from radionuclides of a single element. This simplifies the process of associating each peak with a specific radionuclide, but the lower resolution associated with alpha spectroscopy increases the difficulty of identifying the peaks. Although commercial software packages are available for interpreting alpha spectroscopy results, an experienced operator is required to ensure that the software is working properly.

7.8 Sample Tracking

Sample tracking refers to the identification of samples, their location, and the individuals responsible for their custody and transfer of the custody. This process covers the entire process from collection of the samples and remains intact through the analysis and final holding or disposal. It begins with the taking of a sample where its identification and designation of the sample are critical to being able to relate the analytical result to a site location.

Tracking samples from collection to receipt at the analytical laboratory is normally done through a Chain of Custody process, and documented on a Chain-of-Custody (COC) record. Once samples are received by the laboratory, internal tracking (e.g., COC) procedures should be in place and codified through SOPs that assure integrity of the samples. Documentation of changes in the custody of a sample(s) is important. This is especially true for samples that may be used as evidence to establish compliance with a release criterion. In such cases, there should be sufficient evidence to demonstrate that the integrity of the sample is not compromised from the time it is collected to the time it is analyzed. During this time, the sample should either be under the positive control of a responsible individual or secured and protected from any activity that could change the true value of the results or the nature of the sample. When this degree of sample handling or custody is necessary, written procedures should be developed for field operations and for interfacing between the field operations and the analytical laboratory. This ensures that a clear transfer of the custodial responsibility is well documented and no questions exist as to who is responsible for the sample at any time.

7.8.1 Field Tracking Considerations

- Field personnel are responsible for maintaining field logbooks with adequate information to relate the sample identifier (sample number) to its location and for recording other information necessary to adequately interpret results of sample analytical data.
- The sample collector is responsible for the care and custody of the samples until they are properly transferred or dispatched. This means that samples are in their possession, under constant observation, or secured. Samples may be secured in a sealed container, locked vehicle, locked room, *etc.*
- Sample labels should be completed for each sample using waterproof ink.
- The survey manager or designee determines whether or not proper custody procedures were followed during the field work, and decides if additional sampling is indicated.
- If photographs are included as part of the sampling documentation, the name of the photographer, date, time, site location, and site description should be entered sequentially in a logbook as the photos are taken. After the photographs are developed, the prints should be serially numbered.

7.8.2 Transfer of Custody

- All samples leaving the site should be accompanied by a Chain-of-Custody record. This record documents sample custody transfer from the sampler, often through another person, to the laboratory. The individuals relinquishing the samples should sign and date the record. The record should include a list, including sample designation (number), of the samples in the shipping container and the analysis requested for each sample.
- Shipping containers should be sealed and include a tamper indicating seal that will indicate if the container seal has been disturbed. The method of shipment, courier name, or other pertinent information should be listed in the Chain-of-Custody record.
- The original Chain-of-Custody record should accompany the samples. A copy of the record should be retained by the individual or organization relinquishing the samples.
- Discuss the custody objectives with the shipper to ensure that the objectives are met. For example, if the samples are sent by mail and the originator of the sample requires a record that the shipment was delivered, the package should be registered with return receipt requested. If, on the other hand, the objective is to simply provide a written record of the shipment, a certificate of mailing may be a less expensive and appropriate alternative.
- The individual receiving the samples should sign and date the record. The condition of the container and the tamper indicating seal should be noted on the Chain-of-Custody record. Any problems with the individual samples, such as a broken container, should be noted on the record.

7.8.3 Laboratory Tracking

When the samples are received by the laboratory they are prepared for radiochemical analyses. This includes the fractionation of the sample into aliquots. The tracking and Chain-of-Custody documentation within the laboratory become somewhat complicated due to the fact that several portions of the original sample may exist in the laboratory at a given time. The use of a computer based Laboratory Information System (LIMS) can greatly assist in tracking samples and fractions through the analytical system.

The minimal laboratory tracking process consists of the following:

- transfer of custody on receipt of the samples (original Chain-of-Custody form is retained by the laboratory and submitted with the data package for the samples)
- documentation of sample storage (location and amount)
- documentation of removal and return of sample aliquots (amount, date and time, person removing or returning, and reason for removal)
- transfer of the samples and residues to the receiving authority (usually the site from which they were taken)

The procedure for accomplishing the above varies from laboratory to laboratory, but the exact details of performing the operations of sample tracking should be contained in a SOP.

7.9 Packaging and Transporting Samples

All samples being shipped for radiochemical analysis should be properly packaged and labeled before transport offsite or within the site. The primary concern is the possibility of spills, leaks, or breakage of the sample containers. In addition to resulting in the loss of samples and cross-contamination, the possible release of hazardous material poses a threat to the safety of persons handling and transporting the package.

Suggestions on packaging and shipping radioactive environmental samples are listed below.

- 1) Review NRC requirements (10 CFR part 71) and Department of Transportation (DOT) requirements (49 CFR parts 170 through 189) for packaging and shipping radioactive environmental samples.
- 2) Visually inspect each sample container for indication of leaks or defects in the sample container.

Sampling and Preparation for Laboratory Measurements

- a) Liquid samples should be shipped in plastic containers, if possible, and the caps on the containers should be secured with tape. One exception to the use of plastic bottles is samples collected for ^3H analyses which may require glass containers.
 - b) Heavy plastic bags, with sealable tops, can be used to contain solid samples (*e.g.*, soil, sediment, air filters). The zip-lock should be secured with tape. Heavy plastic lawn bags can be used to contain vegetation samples. The tops should be closed with a "tie" that is covered by tape to prevent it from loosening and slipping off.
- 3) Wipe individual sample containers with a damp cloth or paper towel to remove any exterior contamination. The outer surfaces of containers holding samples collected in a contaminated area should be surveyed with a hand-held instrument(s), appropriate for the suspected type of radioactivity (β/γ or α).
- 4) If glass sample containers are used, place sample containers inside individual plastic bags and seal in order to contain the sample in case of breakage.
- 5) Use packing material (*e.g.*, paper, styrofoam, "bubble wrap") to immobilize and isolate each sample container and buffer hard knocks on the outer container during shipping. This is especially important in cold weather when plastic containers may become brittle and water samples may freeze.
- 6) When liquid samples are shipped, include a sufficient quantity of an absorbent material (*e.g.*, vermiculite) to absorb all liquid packed in the shipping container in case of breakage. This absorbent material may suffice as the packing material described above in item 5.
- 7) Include the original, signed and dated, Chain-of-Custody (COC) form, identifying each sample in the package. It is good practice to place the COC form in a plastic bag to prevent it from becoming wet or contaminated in case of a spill during shipment. If possible, avoid having multiple packages of samples covered by a single COC form.
- 8) Seal closed the package and apply COC tape in such a manner that it must be torn (broken) in order to open the package. The tape should carry the signature of the sender, and the date and time, so that it cannot be removed and replaced undetected.
- 9) Ice chests, constructed of metal or hard plastic, make excellent shipping containers for radioactive environmental samples.

If samples are sent offsite for analysis, the shipper is responsible for complying with all applicable Federal, State, and local regulations. Applicable Federal regulations are briefly addressed below. Any State or local regulation will very likely reflect a Federal regulation.

7.9.1 U.S. Nuclear Regulatory Commission Regulations

NRC regulations for packaging, preparation, and shipment of licensed material are contained in 10 CFR Part 71: "Packaging and Transportation of Radioactive materials".

Samples containing low levels of radioactivity are exempted as set forth in §§ 71.10. A licensee is exempt from all requirements of Part 71 if the specific activity of the sample being shipped is not greater than 74,000 Bq/kg (2,000 pCi/g).

Low Specific Activity Material (LSAM) is defined in §§ 71.4: "Definitions." Samples classified as LSAM need only meet the requirements of the U.S. Department of Transportation (DOT), discussed below, and the requirements of §§ 71.88: "Air transport of plutonium." Most environmental samples will fall into this category.

7.9.2 U.S. Department of Transportation Regulations

The U.S. Department of Transportation provides regulations governing the transport of hazardous materials under the Hazardous Materials Transportation Act of 1975 (88 Stat. 2156, Public Law 93-633). Applicable requirements of the regulations are found in 49 CFR Parts 170 through 189. Shippers of samples containing radioactivity should be aware of the current rules in the following areas.

- Accident Reporting - 49 CFR 171
- Marking and Labeling Packages for Shipment - 49 CFR 172
- Packaging - 49 CFR 173
- Placarding a Package - 49 CFR 172
- Registration of Shipper/Carrier - 49 CFR 107
- Shipper Required Training - 49 CFR 172
- Shipping Papers & Emergency Information - 49 CFR 172
- Transport by Air - 49 CFR 175

Sampling and Preparation for Laboratory Measurements

- Transport by Rail - 49 CFR 174
- Transport by Vessel - 49 CFR 176
- Transport on Public Highway - 49 CFR 177

7.9.3 U.S. Postal Service Regulations

Any package containing radioactive materials is nonmailable if required to bear the U.S. Department of Transportation's Radioactive White-1 (49 CFR 172.436), Radioactive Yellow-II (49 CFR 172.438), or Radioactive Yellow-III (49 CFR 172.440) label, or if it contains quantities of radioactive material in excess of those authorized in Publication 6, Radioactive Material, of the U.S. Postal Service.

8 INTERPRETATION OF SURVEY RESULTS

8.1 Introduction

This chapter discusses the interpretation of survey results, primarily those of the final status survey. Interpreting a survey's results is most straightforward when measurement data are entirely higher or lower than the $DCGL_w$. In such cases, the decision that a survey unit meets or exceeds the release criterion requires little in terms of data analysis. However, formal statistical tests provide a valuable tool when a survey unit's measurements are neither clearly above nor entirely below the $DCGL_w$. Nevertheless, the survey design *always* makes use of the statistical tests in helping to assure that the number of sampling points and the measurement sensitivity are adequate, but not excessive, for the decision to be made.

Section 8.2 discusses the assessment of data quality. The remainder of this chapter deals with application of the statistical tests used in the decision-making process, and the evaluation of the test results. In addition, an example checklist is provided to assist the user in obtaining the necessary information for interpreting the results of a final status survey.

8.2 Data Quality Assessment

Data Quality Assessment (DQA) is a scientific and statistical evaluation that determines if the data are of the right type, quality, and quantity to support their intended use. An overview of the DQA process appears in Section 2.3 and Appendix E. There are five steps in the DQA process:

- Review the Data Quality Objectives (DQOs) and Survey Design
- Conduct a Preliminary Data Review
- Select the Statistical Test
- Verify the Assumptions of the Statistical Test
- Draw Conclusions from the Data

The effort expended during the DQA evaluation should be consistent with the graded approach used in developing the survey design. More information on DQA is located in Appendix E, and the EPA Guidance Document QA/G-9 (EPA 1996a). Data should be verified and validated as described in Section 9.3 prior to the DQA evaluation.

8.2.1 Review the Data Quality Objectives (DQOs) and Sampling Design

The first step in the DQA evaluation is a review of the DQO outputs to ensure that they are still applicable. For example, if the data suggest the survey unit was misclassified as Class 3 instead of Class 1, then the original DQOs should be redeveloped for the correct classification.

The sampling design and data collection documentation should be reviewed for consistency with the DQOs. For example, the review should check that the appropriate number of samples were taken in the correct locations and that they were analyzed with measurement systems with appropriate sensitivity. Example checklists for different types of surveys are given in Chapter 5.

Determining that the sampling design provides adequate power is important to decision making, particularly in cases where the levels of residual radioactivity are near the $DCGL_w$. This can be done both prospectively, during survey design to test the efficacy of a proposed design, and retrospectively, during interpretation of survey results to determine that the objectives of the design are met. The procedure for generating power curves for specific tests is discussed in Appendix I. Note that the accuracy of a prospective power curve depends on estimates of the data variability, σ , and the number of measurements. After the data are analyzed, a sample estimate of the data variability, namely the sample standard deviation (s) and the actual number of valid measurements will be known. The consequence of inadequate power is that a survey unit that actually meets the release criterion has a higher probability of being incorrectly deemed *not* to meet the release criterion.

8.2.2 Conduct a Preliminary Data Review

To learn about the structure of the data—identifying patterns, relationships, or potential anomalies—one can review quality assurance (QA) and quality control (QC) reports, prepare graphs of the data, and calculate basic statistical quantities.

8.2.2.1 Data Evaluation and Conversion

Radiological survey data are usually obtained in units, such as the number of counts per unit time, that have no intrinsic meaning relative to DCGLs. For comparison of survey data to DCGLs, the survey data from field and laboratory measurements are converted to DCGL units. Further information on instrument calibration and data conversion is given in Section 6.2.7.

Basic statistical quantities that should be calculated for the sample data set are the:

- mean
- standard deviation
- median

Example:

Suppose the following 20 concentration values are from a survey unit:

90.7, 83.5, 86.4, 88.5, 84.4, 74.2, 84.1, 87.6, 78.2, 77.6,
86.4, 76.3, 86.5, 77.4, 90.3, 90.1, 79.1, 92.4, 75.5, 80.5.

First, the average of the data (83.5) and the sample standard deviation (5.7) should be calculated.

The average of the data can be compared to the reference area average and the $DCGL_w$ to get a preliminary indication of the survey unit status. Where remediation is inadequate, this comparison may readily reveal that a survey unit contains excess residual radioactivity—even before applying statistical tests. For example, if the average of the data exceeds the $DCGL_w$ and the radionuclide of interest does not appear in background, then the survey unit clearly does not meet the release criterion. On the other hand, if every measurement in the survey unit is below the $DCGL_w$, the survey unit clearly meets the release criterion.¹

The value of the sample standard deviation is especially important. If too large compared to that assumed during the survey design, this may indicate an insufficient number of samples were collected to achieve the desired power of the statistical test. Again, inadequate power can lead to unnecessary remediation.

The median is the middle value of the data set when the number of data points is odd, and is the average of the two middle values when the number of data points is even. Thus 50% of the data points are above the median, and 50% are below the median. Large differences between the mean and the median would be an early indication of skewness in the data. This would also be evident in a histogram of the data. For the example data above, the median is 84.25 (*i.e.*, $(84.1 + 84.4)/2$). The difference between the median and the mean (*i.e.*, $84.25 - 83.5 = 0.75$) is a small fraction of the sample standard deviation (*i.e.*, 5.7). Thus, in this instance, the mean and median would not be considered significantly different.

Examining the minimum, maximum, and range of the data may provide additional useful information. The minimum in this example is 74.2 and the maximum is 92.4, so the range is $92.4 - 74.2 = 18.2$. This is only 3.2 standard deviations. Thus, the range is not unusually large. When there are 30 or fewer data points, values of the range much larger than about 4 to 5 standard deviations would be unusual. For larger data sets the range might be wider.

¹ It can be verified that if every measurement is below the $DCGL_w$, the conclusion from the statistical tests will always be that the survey unit does not exceed the release criterion.

8.2.2.2 Graphical Data Review

At a minimum, a graphical data review should consist of a posting plot and a histogram. Quantile plots are also useful diagnostic tools, particularly in the two-sample case, to compare the survey unit and reference area. These are discussed in Appendix I, Section I.8.

A *posting plot* is simply a map of the survey unit with the data values entered at the measurement locations. This potentially reveals heterogeneities in the data—especially possible patches of elevated residual radioactivity. Even in a reference area, a posting plot can reveal spatial trends in background data that might affect the results of the two-sample statistical tests.

If the data above were obtained using a triangular grid in a rectangular survey unit, the posting plot might resemble the display in Figure 8.1. Figure 8.1a shows no unusual patterns in the data. Figure 8.1b shows a different plot of the same values, but with individual results associated with different locations within the survey unit. In this plot there is an obvious trend towards smaller values as one moves from left to right across the survey unit. This trend is not apparent in the simple initial listing of the data. The trend may become more apparent if isopleths are added to the posting plot.

If the posting plot reveals systematic spatial trends in the survey unit, the cause of the trends would need to be investigated. In some cases, such trends could be due to residual radioactivity, but may also be due to inhomogeneities in the survey unit background. Other diagnostic tools for examining spatial data trends may be found in EPA Guidance Document QA/G-9 (EPA 1996a). The use of geostatistical tools to evaluate spatial data trends may also be useful in some cases (EPA 1989a).

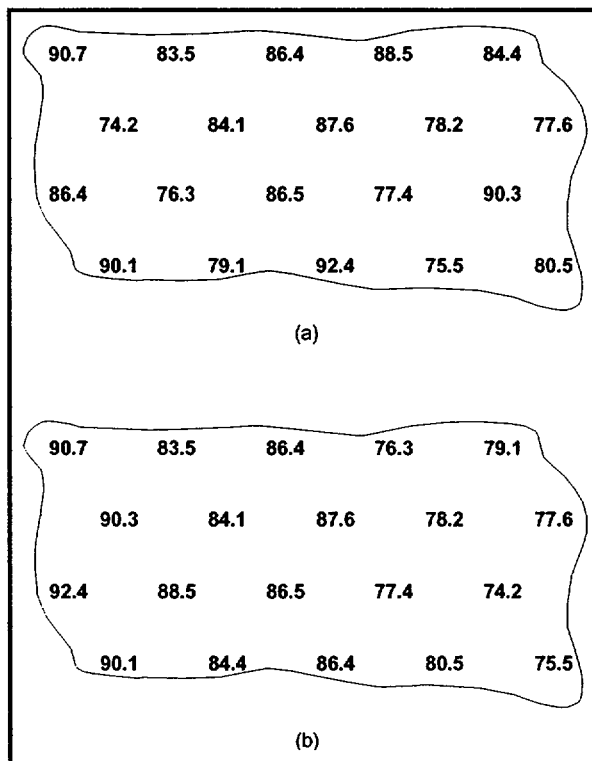


Figure 8.1 Examples of Posting Plots

A *frequency plot* (or a histogram) is a useful tool for examining the general shape of a data distribution. This plot is a bar chart of the number of data points within a certain range of values. A frequency plot of the example data is shown in Figure 8.2). A simple method for generating a

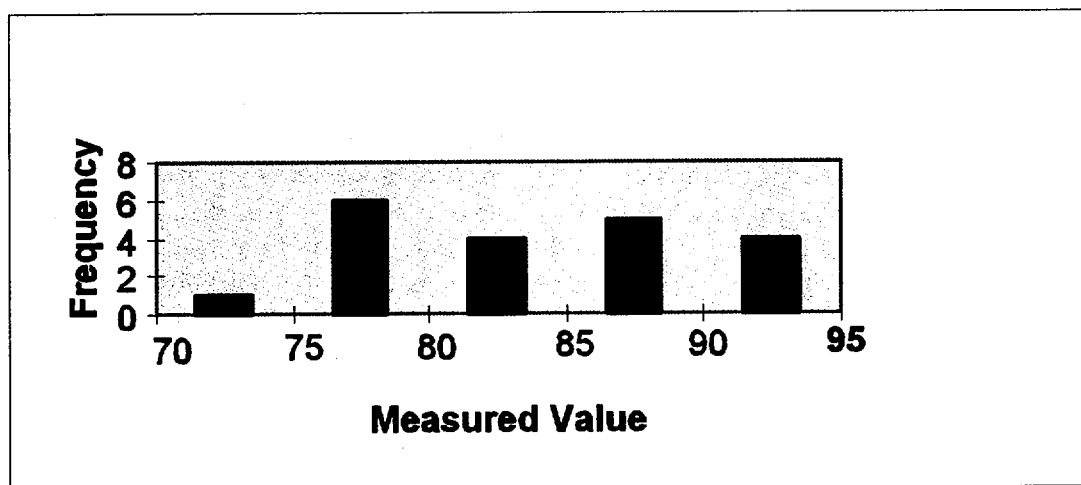


Figure 8.2 Example of a Frequency Plot

rough frequency plot is the stem and leaf display discussed in Appendix I, Section I.7. The frequency plot will reveal any obvious departures from symmetry, such as skewness or bimodality (two peaks), in the data distributions for the survey unit or reference area. The presence of two peaks in the survey unit frequency plot may indicate the existence of isolated areas of residual radioactivity. In some cases it may be possible to determine an appropriate background for the survey unit using this information. The interpretation of the data for this purpose will generally be highly dependent on site-specific considerations and should only be pursued after a consultation with the responsible regulatory agency.

The presence of two peaks in the background reference area or survey unit frequency plot may indicate a mixture of background concentration distributions due to different soil types, construction materials, *etc.* The greater variability in the data due to the presence of such a mixture will reduce the power of the statistical tests to detect an adequately remediated survey unit. These situations should be avoided whenever possible by carefully matching the background reference areas to the survey units, and choosing survey units with homogeneous backgrounds.

Skewness or other asymmetry can impact the accuracy of the statistical tests. A data transformation (*e.g.*, taking the logarithms of the data) can sometimes be used to make the distribution more symmetric. The statistical tests would then be performed on the transformed data. When the underlying data distribution is highly skewed, it is often because there are a few high areas. Since the EMC is used to detect such measurements, the difference between using the median and the mean as a measure for the degree to which uniform residual radioactivity remains in a survey unit tends to diminish in importance.

8.2.3 Select the Tests

An overview of the statistical considerations important for final status surveys appears in Section 2.5 and Appendix D. The most appropriate procedure for summarizing and analyzing the data is chosen based on the preliminary data review. The parameter of interest is the mean concentration in the survey unit. The nonparametric tests recommended in this manual, in their most general form, are tests of the median. If one assumes that the data are from a symmetric distribution—where the median and the mean are effectively equal—these are also tests of the mean. If the assumption of symmetry is violated, then nonparametric tests of the median approximately test the mean. Computer simulations (*e.g.*, Hardin and Gilbert, 1993) have shown that the approximation is a good one. That is, the correct decision will be made about whether or not the mean concentration exceeds the DCGL, even when the data come from a skewed distribution. In this regard, the nonparametric tests are found to be correct more often than the commonly used Student's *t* test. The robust performance of the Sign and WRS tests over a wide range of conditions is the reason that they are recommended in this manual.

When a given set of assumptions is true, a parametric test designed for exactly that set of conditions will have the highest power. For example, if the data are from a normal distribution, the Student's *t* test will have higher power than the nonparametric tests. It should be noted that for large enough sample sizes (*e.g.*, large number of measurements), the Student's *t* test is not a great deal more powerful than the nonparametric tests. On the other hand, when the assumption of normality is violated, the nonparametric tests can be very much more powerful than the *t* test. Therefore, any statistical test may be used provided that the data are consistent with the assumptions underlying their use. When these assumptions are violated, the prudent approach is to use the nonparametric tests which generally involve fewer assumptions than their parametric equivalents.

The one-sample statistical test (Sign test) described in Section 5.5.2.3 should only be used if the contaminant is not present in background and radionuclide-specific measurements are made. The one-sample test may also be used if the contaminant is present at such a small fraction of the DCGL_w value as to be considered insignificant. In this case, background concentrations of the radionuclide are included with the residual radioactivity (*i.e.*, the entire amount is attributed to facility operations). Thus, the total concentration of the radionuclide is compared to the release criterion. This option should only be used if one expects that ignoring the background concentration will not affect the outcome of the statistical tests. The advantage of ignoring a small background contribution is that no reference area is needed. This can simplify the final status survey considerably.

The one-sample Sign test (Section 8.3.1) evaluates whether the median of the data is above or below the DCGL_w. If the data distribution is symmetric, the median is equal to the mean. In cases where the data are severely skewed, the mean may be above the DCGL_w, while the median

is below the $DCGL_w$. In such cases, the survey unit does *not* meet the release criterion regardless of the result of the statistical tests. On the other hand, if the largest measurement is below the $DCGL_w$, the Sign test will always show that the survey unit meets the release criterion.

For final status surveys, the two-sample statistical test (Wilcoxon Rank Sum test, discussed in Section 5.5.2.2) should be used when the radionuclide of concern appears in background or if measurements are used that are not radionuclide specific. The two-sample Wilcoxon Rank Sum (WRS) test (Section 8.4.1) assumes the reference area and survey unit data distributions are similar except for a possible shift in the medians. When the data are severely skewed, the value for the mean difference may be above the $DCGL_w$, while the median difference is below the $DCGL_w$. In such cases, the survey unit does *not* meet the release criterion regardless of the result of the statistical test. On the other hand, if the difference between the largest survey unit measurement and the smallest reference area measurement is less than the $DCGL_w$, the WRS test will always show that the survey unit meets the release criterion.

8.2.4 Verify the Assumptions of the Tests

An evaluation to determine that the data are consistent with the underlying assumptions made for the statistical procedures helps to validate the use of a test. One may also determine that certain departures from these assumptions are acceptable when given the actual data and other information about the study. The nonparametric tests described in this chapter assume that the data from the reference area or survey unit consist of independent samples from each distribution.

Spatial dependencies that potentially affect the assumptions can be assessed using posting plots (Section 8.2.2.2). More sophisticated tools for determining the extent of spatial dependencies are also available (*e.g.*, EPA QA/G-9). These methods tend to be complex and are best used with guidance from a professional statistician.

Asymmetry in the data can be diagnosed with a stem and leaf display, a histogram, or a Quantile plot. As discussed in the previous section, data transformations can sometimes be used to minimize the effects of asymmetry.

One of the primary advantages of the nonparametric tests used in this report is that they involve fewer assumptions about the data than their parametric counterparts. If parametric tests are used, (*e.g.*, Student's *t* test), then any additional assumptions made in using them should be verified (*e.g.*, testing for normality). These issues are discussed in detail in EPA QA/G-9 (EPA 1996a).

One of the more important assumptions made in the survey design described in Chapter 5 is that the sample sizes determined for the tests are sufficient to achieve the data quality objectives set for the Type I (α) and Type II (β) error rates. Verification of the power of the tests ($1-\beta$) to detect adequate remediation may be of particular interest. Methods for assessing the power are discussed in Appendix I.9. If the hypothesis that the survey unit residual radioactivity exceeds the release criterion is accepted, there should be reasonable assurance that the test is equally effective in determining that a survey unit has residual contamination less than the DCGL_w. Otherwise, unnecessary remediation may result. For this reason, it is better to plan the surveys cautiously—even to the point of:

- overestimating the potential data variability
- taking too many samples
- overestimating minimum detectable concentrations (MDCs)

If one is unable to show that the DQOs were met with reasonable assurance, a resurvey may be needed. Examples of assumptions and possible methods for their assessment are summarized in Table 8.1.

Table 8.1 Methods for Checking the Assumptions of Statistical Tests

| Assumption | Diagnostic |
|----------------------|---------------------------|
| Spatial Independence | Posting Plot |
| Symmetry | Histogram, Quantile Plot |
| Data Variance | Sample Standard Deviation |
| Power is Adequate | Retrospective Power Chart |

8.2.5 Draw Conclusions from the Data

The types of measurements that can be made in a survey unit are 1) direct measurements at discrete locations, 2) samples collected at discrete locations, and 3) scans. The statistical tests are only applied to measurements made at discrete locations. Specific details for conducting the statistical tests are given in Sections 8.3 and 8.4. When the data clearly show that a survey unit meets or exceeds the release criterion, the result is often obvious without performing the formal statistical analysis. Table 8.2 describes examples of circumstances leading to specific conclusions based on a simple examination of the data.

Table 8.2 Summary of Statistical Tests**Radionuclide not in background and radionuclide-specific measurements made:**

| Survey Result | Conclusion |
|--|---|
| All measurements less than $DCGL_w$ | Survey unit meets release criterion |
| Average greater than $DCGL_w$ | Survey unit does not meet release criterion |
| Any measurement greater than $DCGL_w$ and the average less than $DCGL_w$ | Conduct Sign test and elevated measurement comparison |

Radionuclide in background or radionuclide non-specific (gross) measurements made:

| Survey Result | Conclusion |
|--|--|
| Difference between largest survey unit measurement and smallest reference area measurement is less than $DCGL_w$ | Survey unit meets release criterion |
| Difference of survey unit average and reference area average is greater than $DCGL_w$ | Survey unit does not meet release criterion |
| Difference between any survey unit measurement and any reference area measurement greater than $DCGL_w$ and the difference of survey unit average and reference area average is less than $DCGL_w$ | Conduct WRS test and elevated measurement comparison |

Both the measurements at discrete locations and the scans are subject to the elevated measurement comparison (EMC). The result of the EMC is not conclusive as to whether the survey unit meets or exceeds the release criterion, but is a flag or trigger for further investigation. The investigation may involve taking further measurements to determine that the area and level of the elevated residual radioactivity are such that the resulting dose or risk meets the release criterion.² The investigation should also provide adequate assurance, using the DQO process, that there are no other undiscovered areas of elevated residual radioactivity in the survey unit that might otherwise result in a dose or risk exceeding the release criterion. In some cases, this may lead to re-classifying all or part of a survey unit—unless the results of the investigation indicate that reclassification is not necessary. The investigation level appropriate for each class of survey unit and type of measurement is shown in Table 5.8 and is described in Section 5.5.2.6.

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

8.2.6 Example

To illustrate the data interpretation process, consider an example facility with 14 survey units consisting of interior concrete surfaces, one interior survey unit with drywall surfaces, and two exterior survey units. The contaminant of concern is ^{60}Co . The interior surfaces were measured with a gas-flow proportional counter (see Appendix H) with an active surface area of 20 cm^2 to determine total beta-gamma activity. Because these measurements are not radionuclide specific, appropriate reference areas were chosen for comparison. The exterior soil was measured with a germanium spectrometer to provide radionuclide-specific results. A reference area is not needed because ^{60}Co does not have a significant background in soil.

The exterior Class 3 survey unit incorporates areas that are not expected to contain residual radioactivity. The exterior Class 2 survey unit is similar to the Class 3 survey unit, but is expected to contain residual radioactivity below the DCGL_w . The Class 1 Interior Concrete survey units are expected to contain small areas of elevated activity that may or may not exceed the DCGL_w . The Class 2 Interior Drywall survey unit is similar to the Class 1 Interior Concrete survey unit, but the drywall is expected to have a lower background, less measurement variability, and a more uniform distribution of contamination. The Class 2 survey unit is not expected to contain areas of activity above the DCGL_w . Section 8.3 describes the Sign test used to evaluate the survey units where the contaminant is not present in background. Section 8.4 describes the WRS test used to evaluate the survey units where the contaminant is present in background. Section 8.5 discusses the evaluation of the results of the statistical tests and the decision regarding compliance with the release criterion. The survey design parameters and DQOs developed for these survey units are summarized in Table 8.3.

Table 8.3 Final Status Survey Parameters for Example Survey Units

| Survey Unit | Type | DQO | | DCGL_w | Estimated Standard Deviation, σ | | Test/Section |
|-------------------|---------|----------|---------|--------------------------------|--|-------------------------------|--------------|
| | | α | β | | Survey | Reference | |
| Interior Concrete | Class 1 | .05 | .05 | 5000 dpm per 100 cm^2 | 625 dpm per 100 cm^2 | 220 dpm per 100 cm^2 | WRS/App. A |
| Interior Drywall | Class 2 | .025 | .05 | 5000 dpm per 100 cm^2 | 200 dpm per 100 cm^2 | 200 dpm per 100 cm^2 | WRS/8.4.3 |
| Exterior Lawn | Class 2 | .025 | .025 | 140 Bq/kg | 3.8 Bq/kg | N/A | Sign/8.3.3 |
| Exterior Lawn | Class 3 | .025 | .01 | 140 Bq/kg | 3.8 Bq/kg | N/A | Sign/8.3.4 |

8.3 Contaminant Not Present in Background

The statistical test discussed in this section is used to compare each survey unit directly with the applicable release criterion. A reference area is not included because the measurement technique is radionuclide-specific and the radionuclide of concern is not present in background (see Section 8.2.6). In this case the contaminant levels are compared directly with the $DCGL_w$. The method in this section should only be used if the contaminant is not present in background or is present at such a small fraction of the $DCGL_w$ value as to be considered insignificant. In addition, one-sample tests are applicable only if radionuclide-specific measurements are made to determine the concentrations. Otherwise, the method in Section 8.4 is recommended.

Reference areas and reference samples are not needed when there is sufficient information to indicate there is essentially no background concentration for the radionuclide being considered. With only a single set of survey unit samples, the statistical test used here is called a one-sample test. See Section 5.5 for further information appropriate to following the example and discussion presented here.

8.3.1 One-Sample Statistical Test

The Sign test is designed to detect uniform failure of remedial action throughout the survey unit. This test does not assume that the data follow any particular distribution, such as normal or log-normal. In addition to the Sign Test, the $DCGL_{EMC}$ (see Section 5.5.2.4) is compared to each measurement to ensure none exceeds the $DCGL_{EMC}$. If a measurement exceeds this $DCGL$, then additional investigation is recommended, at least locally, to determine the actual areal extent of the elevated concentration.

The hypothesis tested by the Sign test is

Null Hypothesis

H_0 : The median concentration of residual radioactivity in the survey unit is greater than the $DCGL_w$

versus

Alternative Hypothesis

H_a : The median concentration of residual radioactivity in the survey unit is less than the $DCGL_w$

The null hypothesis is assumed to be true unless the statistical test indicates that it should be rejected in favor of the alternative. The null hypothesis states that the probability of a measurement less than the $DCGL_w$ is less than one-half, *i.e.*, the 50th percentile (or median) is

greater than the $DCGL_w$. Note that some individual survey unit measurements may exceed the $DCGL_w$ even when the survey unit as a whole meets the release criterion. In fact, a survey unit average that is close to the $DCGL_w$ might have almost half of its individual measurements greater than the $DCGL_w$. Such a survey unit may still not exceed the release criterion.

The assumption is that the survey unit measurements are independent random samples from a symmetric distribution. If the distribution of measurements is symmetric, the median and the mean are the same.

The hypothesis specifies a release criterion in terms of a $DCGL_w$. The test should have sufficient power ($1-\beta$, as specified in the DQOs) to detect residual radioactivity concentrations at the Lower Boundary of the Gray Region (LBGR). If σ is the standard deviation of the measurements in the survey unit, then Δ/σ expresses the size of the shift (*i.e.*, $\Delta = DCGL_w - LBGR$) as the number of standard deviations that would be considered "large" for the distribution of measurements in the survey unit. The procedure for determining Δ/σ is given in Section 5.5.2.3.

8.3.2 Applying the Sign Test

The Sign test is applied as outlined in the following five steps, and further illustrated by the examples in Sections 8.3.3 and 8.3.4.

1. List the survey unit measurements, X_i , $i = 1, 2, 3, \dots, N$.
2. Subtract each measurement, X_i , from the $DCGL_w$ to obtain the differences:
$$D_i = DCGL_w - X_i, i = 1, 2, 3, \dots, N.$$
3. Discard each difference that is exactly zero and reduce the sample size, N , by the number of such zero measurements.
4. Count the number of positive differences. The result is the test statistic $S+$. Note that a positive difference corresponds to a measurement below the $DCGL_w$ and contributes evidence that the survey unit meets the release criterion.
5. Large values of $S+$ indicate that the null hypothesis (that the survey unit exceeds the release criterion) is false. The value of $S+$ is compared to the critical values in Table I.3. If $S+$ is greater than the critical value, k , in that table, the null hypothesis is rejected.

8.3.3 Sign Test Example: Class 2 Exterior Soil Survey Unit

For the Class 2 Exterior Soil survey unit, the one-sample nonparametric statistical test is appropriate since the radionuclide of concern does not appear in background and radionuclide-specific measurements were made.

Table 8.3 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.025$. The $DCGL_w$ is 140 Bq/kg (3.8 pCi/g) and the estimated standard deviation of the measurements is $\sigma = 3.8$ Bq/kg (0.10 pCi/g). Since the estimated standard deviation is much smaller than the $DCGL_w$, the LBGR should be set so that Δ/σ is about 3.

$$\begin{aligned} \text{If } \Delta/\sigma &= (DCGL_w - LBGR)/\sigma \\ &= 3 \\ \text{then } LBGR &= DCGL_w - 3\sigma \\ &= 140 - (3 \times 3.8) \\ &= 128 \text{ Bq/kg (3.5 pCi/g).} \end{aligned}$$

Table 5.5 indicates the number of measurements estimated for the Sign Test, N , is 20 ($\alpha = 0.025$, $\beta = 0.025$, and $\Delta/\sigma = 3$). (Table I.2a in Appendix I also lists the number of measurements estimated for the Sign test.) This survey unit is Class 2, so the 20 measurements needed were made on a random-start triangular grid. When laying out the grid, 22 measurement locations were identified.

The 22 measurements taken on the exterior lawn Class 2 survey unit are shown in the first column of Table 8.4. The mean of these data is 129 Bq/kg (3.5 pCi/g) and the standard deviation is 11 Bq/kg (0.30 pCi/g). Since the number of measurements is even, the median of the data is the average of the two middle values $(126+128)/2 = 127$ Bq/kg (3.4 pCi/g). A Quantile Plot of the data is shown in Appendix I.8, Figure I.3.

There are five measurements that exceed the $DCGL_w$ value of 140 Bq/kg: 142, 143, 145, 148, and 148. However, none exceed the mean of the data plus three standard deviations: $127 + (3 \times 11) = 160$ Bq/kg (4.3 pCi/g). Thus, these values appear to reflect the overall variability of the concentration measurements rather than to indicate an area of elevated activity—*provided* that these measurements were scattered through the survey unit. However, if a posting plot demonstrates that the locations of these measurements are grouped together, then that portion of the survey unit containing these locations merits further investigation.

The middle column of Table 8.4 contains the differences, $DCGL_w - \text{Data}$, and the last column contains the signs of the differences. The bottom row shows the number of measurements with positive differences, which is the test statistic $S+$. In this case, $S+ = 17$.

The value of $S+$ is compared to the appropriate critical value in Table I.3. In this case, for $N = 22$ and $\alpha = 0.025$, the critical value is 16. Since $S+ = 17$ exceeds this value, the null hypothesis that the survey unit exceeds the release criterion is rejected.

Table 8.4 Example Sign Analysis: Class 2 Exterior Soil Survey Unit

| Data (Bq/kg) | DCGL _w -Data (Bq/kg) | Sign |
|--|------------------------------------|------|
| 121 | 19 | 1 |
| 143 | -3 | -1 |
| 145 | -5 | -1 |
| 112 | 28 | 1 |
| 125 | 15 | 1 |
| 132 | 8 | 1 |
| 122 | 18 | 1 |
| 114 | 26 | 1 |
| 123 | 17 | 1 |
| 148 | -8 | -1 |
| 115 | 25 | 1 |
| 113 | 27 | 1 |
| 126 | 14 | 1 |
| 134 | 6 | 1 |
| 148 | -8 | -1 |
| 130 | 10 | 1 |
| 119 | 21 | 1 |
| 136 | 4 | 1 |
| 128 | 12 | 1 |
| 125 | 15 | 1 |
| 142 | -2 | -1 |
| 129 | 11 | 1 |
| Number of positive differences S+ = 17 | | |

8.3.4 Sign Test Example: Class 3 Exterior Soil Survey Unit

For the Class 3 exterior soil survey unit, the one-sample nonparametric statistical test is again appropriate since the radionuclide of concern does not appear in background and radionuclide-specific measurements were made.

Table 8.3 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.01$. The DCGL_w is 140 Bq/kg (3.8 pCi/g) and the estimated standard deviation of the measurements is $\sigma = 3.8$ Bq/kg (0.10 pCi/g). Since the estimated standard deviation is much smaller than the DCGL_w, the lower bound for the gray region should be set so that Δ/σ is about 3.

$$\begin{aligned}
 \text{If } \Delta/\sigma &= (\text{DCGL}_w - \text{LBGR})/\sigma \\
 &= 3 \\
 \text{then } \text{LBGR} &= \text{DCGL}_w - 3\sigma \\
 &= 140 - (3 \times 4) \\
 &= 128 \text{ Bq/kg (3.5 pCi/g)}.
 \end{aligned}$$

Table 5.5 indicates that the sample size estimated for the Sign Test, N , is 23 ($\alpha = 0.025$, $\beta = 0.01$, and $\Delta/\sigma = 3$). This survey unit is Class 3, so the measurements were made at random locations within the survey unit.

The 23 measurements taken on the exterior lawn are shown in the first column of Table 8.5. Notice that some of these measurements are negative (-0.37 in cell A6). This might occur if an analysis background (e.g., the Compton continuum under a spectrum peak) is subtracted to obtain the net concentration value. The data analysis is both easier and more accurate when numerical values are reported *as obtained* rather than reporting the results as “less than” or not detected. The mean of these data is 2.1 Bq/kg (0.057 pCi/g) and the standard deviation is 3.3 Bq/kg (0.089 pCi/g). None of the data exceed $2.1 + (3 \times 3.3) = 12.0$ Bq/kg (0.32 pCi/g). Since N is odd, the median is the middle (12th highest) value, namely 2.6 Bq/kg (0.070 pCi/g).

An initial review of the data reveals that every data point is below the DCGL_w , so the survey unit meets the release criterion specified in Table 8.3. For purely illustrative purposes, the Sign test analysis is performed. The middle column of Table 8.5 contains the quantity $\text{DCGL}_w - \text{Data}$. Since every data point is below the DCGL_w , the sign of $\text{DCGL}_w - \text{Data}$ is always positive. The number of positive differences is equal to the number of measurements, N , and so the Sign test statistic $S+$ is 23. The null hypothesis will always be rejected at the maximum value of $S+$ (which in this case is 23) and the survey unit passes. Thus, the application of the Sign test in such cases requires no calculations and one need not consult a table for a critical value. If the survey is properly designed, the critical value must always be less than N .

Passing a survey unit without making a single calculation may seem an unconventional approach. However, the key is in the survey design which is intended to ensure enough measurements are made to satisfy the DQOs. As in the previous example, after the data are collected the conclusions and power of the test can be checked by constructing a retrospective power curve as outlined in Appendix I, Section I.9.

One final consideration remains regarding the survey unit classification: “Was any definite amount of residual radioactivity found in the survey unit?” This will depend on the MDC of the measurement method. Generally the MDC is at least 3 or 4 times the estimated measurement standard deviation. In the present case, the largest observation, 9.3 Bq/kg (0.25 pCi/g), is less than three times the estimated measurement standard deviation of 3.8 Bq/kg (0.10 pCi/g). Thus, it is unlikely that any of the measurements could be considered indicative of positive contamination. This means that the Class 3 survey unit classification was appropriate.

Table 8.5 Sign Test Example Data for Class 3 Exterior Survey Unit

| | A | B | C |
|----|-------------------------------------|-------------------------|------|
| 1 | Data | DCGL _w -Data | Sign |
| 2 | 3.0 | 137.0 | 1 |
| 3 | 3.0 | 137.0 | 1 |
| 4 | 1.9 | 138.1 | 1 |
| 5 | 0.37 | 139.6 | 1 |
| 6 | -0.37 | 140.4 | 1 |
| 7 | 6.3 | 133.7 | 1 |
| 8 | -3.7 | 143.7 | 1 |
| 9 | 2.6 | 137.4 | 1 |
| 10 | 3.0 | 137.0 | 1 |
| 11 | -4.1 | 144.1 | 1 |
| 12 | 3.0 | 137.0 | 1 |
| 13 | 3.7 | 136.3 | 1 |
| 14 | 2.6 | 137.4 | 1 |
| 15 | 4.4 | 135.6 | 1 |
| 16 | -3.3 | 143.3 | 1 |
| 17 | 2.1 | 137.9 | 1 |
| 18 | 6.3 | 133.7 | 1 |
| 19 | 4.4 | 135.6 | 1 |
| 20 | -0.37 | 140.4 | 1 |
| 21 | 4.1 | 135.9 | 1 |
| 22 | -1.1 | 141.1 | 1 |
| 23 | 1.1 | 138.9 | 1 |
| 24 | 9.3 | 130.7 | 1 |
| 25 | Number of positive differences S+ = | | 23 |

If one determines that residual radioactivity is definitely present, this would indicate that the survey unit was initially mis-classified. Ordinarily, MARSSIM recommends a resurvey using a Class 1 or Class 2 design. If one determines that the survey unit is a Class 2, a resurvey might be avoided if the survey unit does not exceed the maximum size for such a classification. In this case, the only difference in survey design would be whether the measurements were obtained on a random or on a triangular grid. Provided that the initial survey's scanning methodology is sufficiently sensitive to detect areas at DCGL_w without the use of an area factor, this difference in the survey grids alone would not affect the outcome of the statistical analysis. Therefore, if the above conditions were met, a resurvey might not be necessary.

8.4 Contaminant Present in Background

The statistical tests discussed in this section will be used to compare each survey unit with an appropriately chosen, site-specific reference area. Each reference area should be selected on the basis of its similarity to the survey unit, as discussed in Section 4.5.

8.4.1 Two-Sample Statistical Test

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

The WRS test is most effective when residual radioactivity is uniformly present throughout a survey unit. The test is designed to detect whether or not this activity exceeds the $DCGL_w$. The advantage of the nonparametric WRS test is that it does not assume that the data are normally or log-normally distributed. The WRS test also allows for "less than" measurements to be present in the reference area and the survey units. As a general rule, the WRS test can be used with up to 40 percent "less than" measurements in either the reference area or the survey unit. However, the use of "less than" values in data reporting is not recommended as discussed in Section 2.3.5. When possible, report the actual result of a measurement together with its uncertainty.

The hypothesis tested by the WRS test is

Null Hypothesis

H_0 : The median concentration in the survey unit exceeds that in the reference area by more than the $DCGL_w$

versus

Alternative Hypothesis

H_a : The median concentration in the survey unit exceeds that in the reference area by less than the $DCGL_w$

The null hypothesis is assumed to be true unless the statistical test indicates that it should be rejected in favor of the alternative. One assumes that any difference between the reference area and survey unit concentration distributions is due to a shift in the survey unit concentrations to higher values (*i.e.*, due to the presence of residual radioactivity in addition to background). Note that some or all of the survey unit measurements may be larger than some reference area

measurements, while still meeting the release criterion. Indeed, some survey unit measurements may exceed some reference area measurements by more than the $DCGL_w$. The result of the hypothesis test determines whether or not the survey unit as a whole is deemed to meet the release criterion. The EMC is used to screen individual measurements.

Two assumptions underlying this test are: 1) samples from the reference area and survey unit are independent, identically distributed random samples, and 2) each measurement is independent of every other measurement, regardless of the set of samples from which it came.

8.4.2 Applying the Wilcoxon Rank Sum Test

The WRS test is applied as outlined in the following six steps and further illustrated by the examples in Section 8.4.3 and Appendix A.

1. Obtain the adjusted reference area measurements, Z_i , by adding the $DCGL_w$ to each reference area measurement, X_i . $Z_i = X_i + DCGL_w$
2. The m adjusted reference sample measurements, Z_i , from the reference area and the n sample measurements, Y_i , from the survey unit are pooled and ranked in order of increasing size from 1 to N , where $N = m + n$.
3. If several measurements are tied (*i.e.*, have the same value), they are all assigned the average rank of that group of tied measurements.
4. If there are t "less than" values, they are all given the average of the ranks from 1 to t . Therefore, they are all assigned the rank $t(t+1)/(2t) = (t+1)/2$, which is the average of the first t integers. If there is more than one detection limit, all observations below the largest detection limit should be treated as "less than" values.³
5. Sum the ranks of the adjusted measurements from the reference area, W_r . Note that since the sum of the first N integers is $N(N+1)/2$, one can equivalently sum the ranks of the measurements from the survey unit, W_s , and compute $W_r = N(N+1)/2 - W_s$.
6. Compare W_r with the critical value given in Table I.4 for the appropriate values of n , m , and α . If W_r is greater than the tabulated value, reject the hypothesis that the survey unit exceeds the release criterion.

³ If more than 40 percent of the data from either the reference area or survey unit are "less than," the WRS test *cannot* be used. Such a large proportion of non-detects suggest that the DQO process be re-visited for this survey to determine if the survey unit was properly classified or the appropriate measurement method was used. As stated previously, the use of "less than" values in data reporting is not recommended. Wherever possible, the actual result of a measurement, together with its uncertainty, should be reported.

8.4.3 Wilcoxon Rank Sum Test Example: Class 2 Interior Drywall Survey Unit

In this example, the gas-flow proportional counter measures total beta-gamma activity (see Appendix H) and the measurements are not radionuclide specific. The two-sample nonparametric test is appropriate for the Class 2 interior drywall survey unit because gross beta-gamma activity contributes to background even though the radionuclide of interest does not appear in background.

Table 8.3 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.05$. The $DCGL_w$ is $8,300 \text{ Bq/m}^2$ ($5,000 \text{ dpm per } 100 \text{ cm}^2$) and the estimated standard deviation of the measurements is about $\sigma = 1040 \text{ Bq/m}^2$ ($625 \text{ dpm per } 100 \text{ cm}^2$). The estimated standard deviation is 8 times less than the $DCGL_w$. With this level of precision, the width of the gray region can be made fairly narrow. As noted earlier, sample sizes do not decrease very much once Δ/σ exceeds 3 or 4. In this example, the lower bound for the gray region was set so that Δ/σ is about 4.

$$\begin{aligned} \text{If } \Delta/\sigma &= (DCGL_w - LBGR)/\sigma \\ &= 4 \\ \text{then } LBGR &= DCGL_w - 4\sigma \\ &= 3,000 - (4 \times 375) \\ &= 4,200 \text{ Bq/m}^2 \text{ (2,500 dpm per } 100 \text{ cm}^2\text{)}. \end{aligned}$$

In Table 5.3, one finds that the number of measurements estimated for the WRS test is 11 in each survey unit and 11 in each reference area ($\alpha = 0.025$, $\beta = 0.05$, and $\Delta/\sigma = 4$). (Table I.2b in Appendix I also lists the number of measurements estimated for the WRS test.) This survey unit was classified as Class 2, so the 11 measurements needed in the survey unit and the 11 measurements needed in the reference area were made using a random-start triangular grid.⁴

Table 8.6 lists the data obtained from the gas-flow proportional counter in units of counts per minute. A reading of 160 cpm with this instrument corresponds to the $DCGL_w$ of $8,300 \text{ Bq/m}^2$ ($5,000 \text{ dpm per } 100 \text{ cm}^2$). Column A lists the measurement results as they were obtained. The average and standard deviation of the reference area measurements are 44 and 4.4 cpm, respectively. The average and standard deviation of the survey unit measurements are 98 and 5.3 cpm, respectively.

⁴A random start systematic grid is used in Class 2 and 3 survey units primarily to limit the size of any potential elevated areas. Since areas of elevated activity are not an issue in the reference areas, the measurement locations can be either random or on a random start systematic grid (see Section 5.5.2.5).

Table 8.6 WRS Test for Class 2 Interior Drywall Survey Unit

| | A | B | C | D | E |
|-----------|-----------------------|-------------|--------------------------|--------------|---------------------------------|
| 1 | Data (cpm) | Area | Adjusted Data | Ranks | Reference Area Ranks |
| 2 | 49 | R | 209 | 22 | 22 |
| 3 | 35 | R | 195 | 12 | 12 |
| 4 | 45 | R | 205 | 17.5 | 17.5 |
| 5 | 45 | R | 205 | 17.5 | 17.5 |
| 6 | 41 | R | 201 | 14 | 14 |
| 7 | 44 | R | 204 | 16 | 16 |
| 8 | 48 | R | 208 | 21 | 21 |
| 9 | 37 | R | 197 | 13 | 13 |
| 10 | 46 | R | 206 | 19 | 19 |
| 11 | 42 | R | 202 | 15 | 15 |
| 12 | 47 | R | 207 | 20 | 20 |
| 13 | 104 | S | 104 | 9.5 | 0 |
| 14 | 94 | S | 94 | 4 | 0 |
| 15 | 98 | S | 98 | 6 | 0 |
| 16 | 99 | S | 99 | 7 | 0 |
| 17 | 90 | S | 90 | 1 | 0 |
| 18 | 104 | S | 104 | 9.5 | 0 |
| 19 | 95 | S | 95 | 5 | 0 |
| 20 | 105 | S | 105 | 11 | 0 |
| 21 | 93 | S | 93 | 3 | 0 |
| 22 | 101 | S | 101 | 8 | 0 |
| 23 | 92 | S | 92 | 2 | 0 |
| 24 | Sum = | | | 253 | 187 |

In column B, the code "R" denotes a reference area measurement, and "S" denotes a survey unit measurement. Column C contains the Adjusted Data. The Adjusted Data are obtained by adding the $DCGL_w$ to the reference area measurements (see Section 8.4.2, Step 1). The ranks of the adjusted data appear in Column D. They range from 1 to 22, since there is a total of 11+11 measurements (see Section 8.4.2, Step 2).

Note that there were two cases of measurements tied with the same value, at 104 and 209. Each tied measurement is always assigned the average of the ranks. Therefore, both measurements at 104, are assigned rank $(9+10)/2 = 9.5$ (see Section 8.4.2, Step 3). Also note that the sum of *all* of the ranks is still $22(22+1)/2 = 253$. Checking this value with the formula in Step 5 of Section 8.4.2 is recommended to guard against errors in the rankings.

Column E contains only the ranks belonging to the reference area measurements. The total is 187. This is compared with the entry for the critical value of 156 in Table I.4 for $\alpha = 0.025$, with $n = 11$ and $m = 11$. Since the sum of the reference area ranks is greater than the critical value, the null hypothesis (*i.e.*, that the average survey unit concentration exceeds the DCGL_w) is rejected.

The analysis for the WRS test is very well suited to the use of a computer spreadsheet. The spreadsheet formulas used for the example above are given in Appendix I.10, Table I.11.

8.4.4 Class 1 Interior Concrete Survey Unit

As in the previous example, the gas-flow proportional counter measures total beta-gamma activity (see Appendix H) and the measurements are not radionuclide specific. The two-sample nonparametric test is appropriate for the Class 1 interior concrete survey unit because gross beta-gamma activity contributes to background even though the radionuclide of interest does not appear in background.

Appendix A provides a detailed description of the calculations for the Class 1 interior concrete survey unit.

8.4.5 Multiple Radionuclides

The use of the unity rule when there is more than one radionuclide to be considered is discussed in Appendix I.11. An example application appears in Section I.11.4.

8.5 Evaluating the Results: The Decision

Once the data and the results of the tests are obtained, the specific steps required to achieve site release depend on the procedures instituted by the governing regulatory agency and site-specific ALARA considerations. The following suggested considerations are for the interpretation of the test results with respect to the release limit established for the site or survey unit. Note that the tests need not be performed in any particular order.

8.5.1 Elevated Measurement Comparison

The Elevated Measurement Comparison (EMC) consists of comparing each measurement from the survey unit with the *investigation levels* discussed in Section 5.5.2.6 and Section 8.2.5. The EMC is performed for both measurements obtained on the systematic-sampling grid and for locations flagged by scanning measurements. Any measurement from the survey unit that is equal to or greater than an *investigation level* indicates an area of relatively high concentrations that should be investigated—regardless of the outcome of the nonparametric statistical tests.

Interpretation of Survey Results

The statistical tests may not reject H_0 when only a very few high measurements are obtained in the survey unit. The use of the EMC against the investigation levels may be viewed as assurance that unusually large measurements will receive proper attention regardless of the outcome of those tests and that any area having the potential for significant dose contributions will be identified. The EMC is intended to flag potential failures in the remediation process. This should not be considered the primary means to identify whether or not a site meets the release criterion.

The derived concentration guideline level for the EMC is:

$$DCGL_{EMC} = A_m \times DCGL_w \quad 8-1$$

where A_m is the area factor for the area of the systematic grid area. Note that $DCGL_{EMC}$ is an *a priori* limit, established both by the $DCGL_w$ and by the survey design (*i.e.*, grid spacing and scanning MDC). The true extent of an area of elevated activity can only be determined after performing the survey and taking additional measurements. Upon the completion of further investigation, the *a posteriori* limit, $DCGL_{EMC} = A_m \times DCGL_w$, can be established using the value of A_m appropriate for the *actual area of elevated concentration*. The area of elevated activity is generally bordered by concentration measurements below the $DCGL_w$. An individual elevated measurement on a systematic grid could conceivably represent an area four times as large as the systematic grid area used to define the $DCGL_{EMC}$. This is the area bounded by the nearest neighbors of the elevated measurement location. The results of the investigation should show that the appropriate $DCGL_{EMC}$ is not exceeded. Area factors are discussed in Section 5.5.2.4.

If measurements above the stated scanning MDC are found by sampling or by direct measurement at locations that were not flagged by the scanning survey, this may indicate that the scanning method did not meet the DQOs.

The preceding discussion primarily concerns Class 1 survey units. Measurements exceeding $DCGL_w$ in Class 2 or Class 3 areas may indicate survey unit mis-classification. Scanning coverage for Class 2 and Class 3 survey units is less stringent than for Class 1. If the investigation levels of Section 8.2.5 are exceeded, an investigation should: 1) ensure that the area of elevated activity discovered meets the release criterion, and 2) provide reasonable assurance that other undiscovered areas of elevated activity do not exist. If further investigation determines that the survey unit was mis-classified with regard to contamination potential, then a resurvey using the method appropriate for the new survey unit classification may be appropriate.

8.5.2 Interpretation of Statistical Test Results

The result of the statistical test is the decision to reject or not to reject the null hypothesis. Provided that the results of investigations triggered by the EMC were resolved, a rejection of the null hypothesis leads to the decision that the survey unit meets the release criterion. However, estimating the average residual radioactivity in the survey unit may also be necessary so that dose or risk calculations can be made. This estimate is designated $\bar{\delta}$ (see Appendix D, Section D.6). The average concentration is generally the best estimator for $\bar{\delta}$ (EPA 1992g).

If residual radioactivity is found in an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule (Section 4.3.3) can be used to ensure that the total dose is within the release criterion:

$$\frac{\bar{\delta}}{DCGL_w} + \frac{(\text{average concentration in elevated area} - \bar{\delta})}{(\text{area factor for elevated area})(DCGL_w)} < 1 \quad 8-2$$

If there is more than one elevated area, a separate term should be included for each. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally apply only to Class 1 survey units, since areas of elevated activity should not exist in Class 2 or Class 3 survey units.

A retrospective power analysis for the test will often be useful, especially when the null hypothesis is not rejected (see Appendix I.9). When the null hypothesis is not rejected, it may be because it is in fact true, or it may be because the test did not have sufficient power to detect that it is not true. The power of the test will be primarily affected by changes in the actual number of measurements obtained and their standard deviation. An effective survey design will slightly overestimate both the number of measurements and the standard deviation to ensure adequate power. This insures that a survey unit is not subjected to additional remediation simply because the final status survey is not sensitive enough to detect that residual radioactivity is below the guideline level. When the null hypothesis is rejected, the power of the test becomes a somewhat moot question. Nonetheless, even in this case, a retrospective power curve can be a useful diagnostic tool and an aid to designing future surveys.

8.5.3 If the Survey Unit Fails

The guidance provided in MARSSIM is fairly explicit concerning the steps that should be taken to show that a survey unit meets release criteria. Less has been said about the procedures that should be used if at any point the survey unit fails. This is primarily because there are many different ways that a survey unit may fail the final status survey. The overall level of residual

Interpretation of Survey Results

radioactivity may not pass the nonparametric statistical tests. Further investigation following the elevated measurement comparison may show that there is a large enough area with a concentration too high to meet the release criterion. Investigation levels may have caused locations to be flagged during scanning that indicate unexpected levels of residual radioactivity for the survey unit classification. Site-specific information is needed to fully evaluate all of the possible reasons for failure, their causes, and their remedies.

When a survey unit fails to demonstrate compliance with the release criterion, the first step is to review and confirm the data that led to the decision. Once this is done, the DQO Process (Appendix D) can be used to identify and evaluate potential solutions to the problem. The level of residual radioactivity in the survey unit should be determined to help define the problem. Once the problem has been stated the decision concerning the survey unit should be developed into a decision rule. Next, determine the additional data, if any, needed to document that the survey unit demonstrates compliance with the release criterion. Alternatives to resolving the decision statement should be developed for each survey unit that fails the tests. These alternatives are evaluated against the DQOs, and a survey design that meets the objectives of the project is selected.

For example, a Class 2 survey unit passes the nonparametric statistical tests, but has several measurements on the sampling grid that exceed the $DCGL_w$. This is unexpected in a Class 2 area, and so these measurements are flagged for further investigation. Additional sampling confirms that there are several areas where the concentration exceeds the $DCGL_w$. This indicates that the survey unit was mis-classified. However, the scanning technique that was used was sufficient to detect residual radioactivity at the $DCGL_{EMC}$ calculated for the sample grid. No areas exceeding the $DCGL_{EMC}$ were found. Thus, the only difference between the final status survey actually done, and that which would be required for a Class 1 area, is that the scanning may not have covered 100% of the survey unit area. In this case, one might simply increase the scan coverage to 100%. Reasons why the survey unit was misclassified should be noted. If no areas exceeding the $DCGL_{EMC}$ are found, the survey unit essentially demonstrates compliance with the release criterion as a Class 1 survey unit.

If, in the example above, the scanning technique was not sufficiently sensitive, it may be possible to re-classify as Class 1 only that portion of the survey unit containing the higher measurements. This portion would be re-sampled at the higher measurement density required for a Class 1 survey unit, with the rest of the survey unit remaining Class 2.

A second example might be a Class 1 Survey unit that passes the nonparametric statistical tests and contains some areas that were flagged for investigation during scanning. Further investigation, sampling and analysis indicates one area is truly elevated. This area has a concentration that exceeds the $DCGL_w$ by a factor greater than the area factor calculated for its actual size. This area is then remediated. Remediation control sampling shows that the residual

radioactivity was removed, and no other areas were contaminated with removed material. In this case one may simply document the original final status survey, the fact that remediation was performed, the results of the remedial action support survey, and the additional remediation data. In some cases, additional final status survey data may not be needed to demonstrate compliance with the release criterion.

As a last example, consider a Class 1 area which fails the nonparametric statistical tests. Confirmatory data indicates that the average concentration in the survey unit does exceed the $DCGL_w$ over a majority of its area. This indicates remediation of the entire survey unit is necessary, followed by another final status survey. Reasons for performing a final status survey in a survey unit with significant levels of residual radioactivity should be noted.

These examples are meant to illustrate the actions that may be necessary to secure the release of a survey unit that has failed to meet the release criterion. The DQO Process should be revisited to plan how to attain the original objective, that is to safely release the survey unit by showing that it meets the release criterion. Whatever data are necessary to meet this objective will be in addition to the final status survey data already in hand.

8.5.4 Removable Activity

Some regulatory agencies may require that smear samples be taken at indoor grid locations as an indication of removable surface activity. The percentage of removable activity assumed in the exposure pathway models has a great impact on dose calculations. However, measurements of smears are very difficult to interpret quantitatively. Therefore, the results of smear samples should not be used for determining compliance. Rather, they should be used as a diagnostic tool to determine if further investigation is necessary.

8.6 Documentation

Documentation of the final status survey should provide a complete and unambiguous record of the radiological status of the survey unit relative to the established DCGLs. In addition, sufficient data and information should be provided to enable an independent evaluation of the results of the survey including repeating measurements at some future time. The documentation should comply with all applicable regulatory requirements. Additional information on documentation is provided in Chapter 3, Chapter 5, Chapter 9, and Appendix N.

Much of the information in the final status report will be available from other decommissioning documents. However, to the extent practicable, this report should be a stand-alone document with minimum information incorporated by reference. This document should describe the

Interpretation of Survey Results

instrumentation or analytical methods used, how the data were converted to DCGL units, the process of comparing the results to the DCGLs, and the process of determining that the data quality objectives were met.

The results of actions taken as a consequence of individual measurements or sample concentrations in excess of the investigation levels should be reported together with any additional data, remediation, or re-surveys performed to demonstrate that issues concerning potential areas of elevated activity were resolved. The results of the data evaluation using statistical methods to determine if release criteria were satisfied should be described. If criteria were not met or if results indicate a need for additional data, appropriate further actions should be determined by the site management in consultation with the responsible regulatory agency.

EXAMPLE DATA INTERPRETATION CHECKLIST

CONVERT DATA TO STANDARD UNITS

- _____ Structure activity in Bq/m² (dpm/100 cm²)
- _____ Solid media (soil, *etc.*) activity in Bq/kg (pCi/g)

EVALUATE ELEVATED MEASUREMENTS

- _____ Identify elevated data
- _____ Compare data with derived elevated area criteria
- _____ Determine need to remediate and/or reinvestigate elevated condition
- _____ Compare data with survey unit classification criteria
- _____ Determine need to investigate and/or reclassify

ASSESS SURVEY DATA

- _____ Review DQOs and survey design
- _____ Verify that data of adequate quantity and quality were obtained
- _____ Perform preliminary assessments (graphical methods) for unusual or suspicious trends or results—investigate further as appropriate

PERFORM STATISTICAL TESTS

- _____ Select appropriate tests for category of contaminant
- _____ Conduct tests
- _____ Compare test results against hypotheses
- _____ Confirm power level of tests

COMPARE RESULTS TO GUIDELINES

- _____ Determine average or median concentrations
- _____ Confirm that residual activity satisfies guidelines

COMPARE RESULTS WITH DQOs*

- _____ Determine whether all DQOs are satisfied
- _____ Explain/describe deviations from design-basis DQOs

* ALARA may be included in the DQOs.

9 QUALITY ASSURANCE AND QUALITY CONTROL

9.1 Introduction

The goal of quality assurance and quality control (QA/QC) is to identify and implement sampling and analytical methodologies which limit the introduction of error into analytical data. For MARSSIM data collection and evaluation, a system is needed to ensure that radiation surveys produce results that are of the type and quality needed and expected for their intended use. A *quality system* is a management system that describes the elements necessary to plan, implement, and assess the effectiveness of QA/QC activities. This system establishes many functions including: quality management policies and guidelines for the development of organization- and project-specific quality plans; criteria and guidelines for assessing data quality; assessments to ascertain effectiveness of QA/QC implementation; and training programs related to QA/QC implementation. A quality system ensures that MARSSIM decisions will be supported by sufficient data of adequate quality and usability for their intended purpose, and further ensures that such data are authentic, appropriately documented, and technically defensible.

Any organization collecting and evaluating data for a particular program must be concerned with the quality of results. The organization must have results that: meet a well-defined need, use, or purpose; comply with program requirements; and reflect consideration of cost and economics. To meet the objective, the organization should control the technical, administrative, and human factors affecting the quality of results. Control should be oriented toward the appraisal, reduction, elimination, and prevention of deficiencies that affect quality.

Quality systems already exist for many organizations involved in the use of radioactive materials. There are self-imposed internal quality management systems (*e.g.*, DOE) or there are systems required by regulation by another entity (*e.g.*, NRC) which require a quality system as a condition of the operating license.¹ These systems are typically called Quality Assurance Programs. An organization may also obtain services from another organization that already has a quality system in place. When developing an organization-specific quality system, there is no need to develop new quality management systems, to the extent that a facility's current Quality Assurance Program can be used. Standard ANSI/ASQC E4-1994 (ASQC 1995) provides national consensus quality standards for environmental programs. It addresses both quality systems and the collection and evaluation of environmental data. Annex B of ANSI/ASQC E4-1994

¹ Numerous quality assurance and quality control (QA/QC) requirements and guidance documents have been applied to environmental programs. Until now, each Federal agency has developed or chosen QA/QC requirements to fit its particular mission and needs. Some of these requirements include DOE Order 5700.6c (DOE 1991c); EPA QA/R-2 (EPA 1994f); EPA QA/R-5 (EPA 1994c); 10 CFR 50, App. B; NUREG-1293, Rev. 1 (NRC 1991); Reg Guide 4.15 (NRC 1979); and MIL-Q-9858A (DOD 1963). In addition, there are several consensus standards for QA/QC, including ASME NQA-1 (ASME 1989), and ISO 9000/ASQC Q9000 series (ISO 1987). ANSI/ASQC E4-1994 (ASQC 1995) is a consensus standard specifically for environmental data collection.

(ASQC 1995) and Appendix K of MARSSIM illustrate how existing quality system documents compare with organization- and project-specific environmental quality system documents.

Table 9.1 illustrates elements of a quality system as they relate to the Data Life Cycle. Applying a quality system to a project is typically done in three phases as described in Section 2.3: 1) the planning phase where the Data Quality Objectives (DQOs) are developed following the process described in Appendix D and documented in the Quality Assurance Project Plan (QAPP),² 2) the implementation phase involving the collection of environmental data in accordance with approved procedures and protocols, and 3) the assessment phase including the verification and validation of survey results as discussed in Section 9.3 and the evaluation of the environmental data using Data Quality Assessment (DQA) as discussed in Section 8.2 and Appendix E.

Detailed guidance on quality systems is not provided in MARSSIM because a quality system should be in place and functioning prior to beginning environmental data collection activities.

Table 9.1 The Elements of a Quality System Related to the Data Life Cycle

| Data Life Cycle | Quality System Elements |
|------------------------|---|
| Planning | Data Quality Objectives (DQOs) Quality Assurance Project Plans (QAPPs) Standard Operating Procedures (SOPs) |
| Implementation | QAPPs SOPs Data collection Assessments and audits |
| Assessment | Data validation and verification Data Quality Assessment (DQA) |

A graded approach bases the level of controls on the intended use of the results and the degree of confidence needed in their quality. Applying a graded approach may mean that some organizations (*e.g.*, those using the simplified procedures in Appendix B) make use of existing plans and procedures to conduct surveys. For many other organizations, the need for cleanup and restoration of contaminated facilities may create the need for one or more QAPPs suitable to the special needs of environmental data gathering, especially as it relates to the demonstration of compliance with regulatory requirements. There may even be a need to update or revise an existing quality management system.

² The quality assurance project plan is sometimes abbreviated QAPjP. MARSSIM adopts the terminology and abbreviations used in ANSI/ASQC E4-1994 (ASQC 1995) and EPA QA/R-5 (EPA 1994c).

9.2 Development of a Quality Assurance Project Plan

The Quality Assurance Project Plan (QAPP)³ is the critical planning document for any environmental data collection operation because it documents how QA/QC activities will be implemented during the life cycle of a project (EPA 1997a). The QAPP is the blueprint for identifying how the quality system of the organization performing the work is reflected in a particular project and in associated technical goals. This section provides information on how to develop a QAPP based on the DQO process. The results of the DQO process provide key inputs to the QAPP and will largely determine the level of detail in the QAPP.

The consensus standard ANSI/ASQC E4-1994 (ASQC 1995) describes the minimum set of quality elements required to conduct programs involving environmental data collection and evaluation. Table 9.2 lists the quality elements for collection and evaluation of environmental data from ANSI/ASQC E4-1994. These quality elements are provided as examples that should be addressed when developing a QAPP. This table also includes references for obtaining additional information on each of these quality elements. Many of these elements will be addressed in existing documents, such as the organization's Quality Assurance Program or Quality Management Plan. Each of these quality elements should be considered during survey planning to determine the degree to which they will be addressed in the QAPP. Additional quality elements may need to be added to this list as a result of organizational preferences or requirements of Federal and State regulatory authorities. For example, safety and health or public participation may be included as elements to be considered during the development of a QAPP.

The QAPP should be developed using a graded approach as discussed in Section 9.1. In other words, existing procedures and survey designs can be included by reference. This is especially useful for sites using a simplified survey design process (*e.g.*, surveys designed using Appendix B).

A QAPP should be developed to document the results of the planning phase of the Data Life Cycle (see Section 2.3). The level of detail provided in the QAPP for relevant quality elements is determined using the DQO process during survey planning activities. Information that is already provided in existing documents does not need to be repeated in the QAPP, and can be included by reference (EPA 1997a).

³ MARSSIM uses the term Quality Assurance Project Plan to describe a single document that incorporates all of the elements of the survey design. This term is consistent with ANSI/ASQC E4-1994 (ASQC 1995) and EPA guidance (EPA 1994c, EPA 1997a), and is recommended to promote consistency. The use of the term QAPP in MARSSIM does not exclude the use of other terms (*e.g.*, Decommissioning Plan, Sampling and Analysis Plan, Field Sampling Plan) to describe survey planning documentation as long as the information in the documentation supports the objectives of the survey.

Table 9.2 Examples of QAPP Elements for Site Surveys and Investigations

| QAPP Element | Information Source | |
|--|---|---|
| Planning and Scoping (reference the QA Manual for information on the quality system) | ASQC 1995 EPA 1994c EPA 1997a NRC 1997c EPA 1993d | Part A, Sections 2.1 and 2.7; Part B, Section 3.1 Sections A4, A5, A6 and A7 Chapter III, Sections A4, A5, A6, and A7 Chapter 14 Project Objectives |
| Design of Data Collection Operations (including training) | ASQC 1995 EPA 1994c EPA 1997a EPA 1993d | Part A, Section 2.3; Part B, Section 3.2 Sections A9 and B1 Chapter III, Sections A9 and B1 Sampling Design |
| Implementation of Planned Operations (including documents and records) | ASQC 1995 EPA 1994c EPA 1997a NRC 1997c EPA 1993d | Part A, Section 2.8; Part B, Section 3.3 Sections A1, A2, A3, B2, B3, B4, B5, B6, B7, B8, B9, and B10 Chapter III, Sections A1, A2, A3, B2, B3, B4, B5, B6, B7, B8, B9, and B10 Chapter 5 Sampling Execution, Sample Analysis |
| Assessment and Response | ASQC 1995 EPA 1994c EPA 1997a EPA 1993d | Part A, Section 2.9, Part B, Section 3.4 Sections C1 and C2 Chapter III, Sections C1 and C2 Exhibit 3, Reference Box 3 |
| Assessment and Verification of Data Usability | ASQC 1995 EPA 1994c EPA 1997a NRC 1997c EPA 1993d | Part B, Section 3.5 Sections D1, D2, and D3 Chapter III, Sections D1, D2, and D3 Chapter 20, Appendix J, Appendix Q Assessment of Data Quality |

For example, the quality system description, personnel qualifications and requirements, and Standard Operating Procedures (SOPs) for the laboratory analysis of samples may simply be references to existing documents (*e.g.*, Quality Management Plan, Laboratory Procedure Manual). SOPs for performing direct measurements with a specific instrument may be attached to the QAPP because this information may not be readily available from other sources.

There is no particular format recommended for developing a QAPP. Figure 9.1 provides an example of a QAPP format presented in EPA QA/R-5 (EPA 1994c). Appendix K compares the quality elements presented in this example to the quality elements found in EPA QAMS-005-80 (EPA 1980d), ASME NQA-1 (ASME 1989), DOE Order 5700.6c (DOE 1991c), MIL-Q-9858A (DOD 1963), and ISO 9000 (ISO 1987).

| |
|--|
| Project Management |
| Title and Approval Sheet |
| Table of Contents |
| Distribution List |
| Project/Task Organization |
| Problem Definition/Background |
| Project Task Description |
| Quality Objectives and Criteria for Measurement Data |
| Special Training Requirements/Certification |
| Measurement/Data Acquisition |
| Sampling Process Design (Experimental Design) |
| Sampling Methods Requirements |
| Sample Handling and Custody Requirements |
| Analytical Methods Requirements |
| Quality Control Requirements |
| Instrument/Equipment Testing, Inspection, and Maintenance Requirements |
| Instrument Calibration and Frequency |
| Inspection/Acceptance Requirements for Supplies and Consumables |
| Assessment/Oversight |
| Assessments and Response Actions |
| Reports to Management |
| Data Validation and Usability |
| Data Review, Validation, and Verification Requirements |
| Validation and Verification Methods |
| Reconciliation with User Requirements |

Figure 9.1 Example of a QAPP Format

9.3 Data Assessment

Assessment of environmental data is used to evaluate whether the data meet the objectives of the survey, and whether the data are sufficient to determine compliance with the DCGL (EPA 1992a, 1992b, 1996a). The assessment phase of the Data Life Cycle consists of three phases: data verification, data validation, and Data Quality Assessment (DQA). This section provides guidance on verifying and validating data collected during a final status survey designed to demonstrate compliance with a dose- or risk-based regulation. Guidance on DQA is provided in Chapter 8 and Appendix E. As with all components of a successful survey, the level of effort associated with the assessment of survey data should be consistent with the objectives of the survey (*i.e.*, a graded approach).

9.3.1 Data Verification

Data verification ensures that the requirements stated in the planning documents (*e.g.*, Quality Assurance Project Plan, Standard Operating Procedures) are implemented as prescribed. This means that deficiencies or problems that occur during implementation should be documented and reported. This also means that activities performed during the implementation phase are assessed regularly with findings documented and reported to management. Corrective actions undertaken should be reviewed for adequacy and appropriateness and documented in response to the findings. Data verification activities should be planned and documented in the QAPP. These assessments may include but are not limited to inspections, QC checks, surveillance, technical reviews, performance evaluations, and audits.

To ensure that conditions requiring corrective actions are identified and addressed promptly, data verification activities should be initiated as part of data collection during the implementation phase of the survey. The performance of tasks by personnel is generally compared to a prescribed method documented in the SOPs, and is generally assessed using inspections, surveillance, or audits. Self-assessments and independent assessments may be planned, scheduled, and performed as part of the survey. Self-assessment also means that personnel doing work should document and report deficiencies or problems that they encounter to their supervisors or management.

The performance of equipment such as radiation detectors or measurement systems such as an instrument and human operator can be monitored using control charts. Control charts are used to record the results of quantitative QC checks such as background and daily calibration or performance checks. Control charts document instrument and measurement system performance on a regular basis and identify conditions requiring corrective actions on a real time basis. Control charts are especially useful for surveys that extend over a significant period of time (*e.g.*, weeks instead of days) and for equipment that is owned by a company that is frequently used to collect survey data. Surveys that are accomplished in one or two days and use rented instruments may not benefit significantly from the preparation and use of control charts. The use of control charts is usually documented in the SOPs.

A technical review is an independent assessment that provides an in-depth analysis and evaluation of documents, activities, material, data, or items that require technical verification to ensure that established requirements are satisfied (ASQC 1995). A technical review typically requires a significant effort in time and resources and may not be necessary for all surveys. A complex survey using a combination of scanning, direct measurements, and sampling for multiple survey units is more likely to benefit from a detailed technical review than a simple survey design calling for relatively few measurements using one or two measurement techniques for a single survey unit.

9.3.2 Data Validation

Data validation activities ensure that the results of data collection activities support the objectives of the survey as documented in the QAPP, or support a determination that these objectives should be modified. Data Usability is the process of ensuring or determining whether the quality of the data produced meets the intended use of the data (EPA 1992a, EPA 1997a). Data verification compares the collected data with the prescribed activities documented in the SOPs; data validation compares the collected data to the DQOs documented in the QAPP. Corrective actions may improve data quality and reduce uncertainty, and may eliminate the need to qualify or reject data.

9.3.2.1 Data Qualifiers

Qualified data are any data that have been modified or adjusted as part of statistical or mathematical evaluation, data validation, or data verification operations (ASQC 1995). Data may be qualified or rejected as a result of data validation or data verification activities. Data qualifier codes or flags are often used to identify data that has been qualified. Any scheme used should be fully explained in the QAPP and survey documentation. The following are examples of data qualifier codes or flags derived from national qualifiers assigned to results in the contract laboratory program (CLP; EPA 1994g).

- U or <MDC The radionuclide of interest was analyzed for, but the radionuclide concentration was below the minimum detectable concentration (MDC). Section 2.3.5 recommends that the actual result of the analysis be reported so this qualifier would inform the reader that the result reported is also below the MDC.
- J The associated value reported is a modified, adjusted, or estimated quantity. This qualifier might be used to identify results based on surrogate measurements (see Section 4.3.2) or gross activity measurements (*e.g.*, gross alpha, gross beta). The implication of this qualifier is that the estimate may be inaccurate or imprecise which might mean the result is inappropriate for the statistical evaluation of the results. Surrogate measurements that are not inaccurate or imprecise may or may not be associated with this qualifier. It is recommended that the potential uncertainties associated with surrogate or gross measurements be quantified and included with the results.
- R The associated value reported is unusable. The result is rejected due to serious analytical deficiencies or quality control results. These data would be rejected because they do not meet the data quality objectives of the survey.
- O The associated value reported was determined to be an outlier.

9.3.2.2 Data Validation Descriptors

Data validation is often defined by six data descriptors. These six data descriptors are summarized in Table 9.3 and discussed in detail in Appendix N. The decision maker or reviewer examines the data, documentation, and reports for each of the six data descriptors to determine if performance is within the limits specified in the DQOs during planning. The data validation process for each data descriptor should be conducted according to procedures documented in the QAPP.

Table 9.3 Suggested Content or Consideration, Impact if Not Met, and Corrective Actions for Data Descriptors

| Data Descriptor | Suggested Content or Consideration | Impact if Not Met | Corrective Action |
|---------------------------|--|---|---|
| Reports to Decision Maker | <ul style="list-style-type: none"> • Site description • Survey design with measurement locations • Analytical method and detection limit • Detection limits (MDCs) • Background radiation data • Results on per measurement basis, qualified for analytical limitations • Field conditions for media and environment • Preliminary reports • Meteorological data, if indicated by DQOs • Field reports | <ul style="list-style-type: none"> • Unable to perform a quantitative radiation survey and site investigation | <ul style="list-style-type: none"> • Request missing information • Perform qualitative or semi-quantitative site investigation |
| Documentation | <ul style="list-style-type: none"> • Chain-of-custody records • SOPs • Field and analytical records • Measurement results related to geographic location | <ul style="list-style-type: none"> • Unable to identify appropriate concentration for survey unit measurements • Unable to have adequate assurance of measurement results | <ul style="list-style-type: none"> • Request that locations be identified • Resurveying or resampling • Correct deficiencies |
| Data Sources | <ul style="list-style-type: none"> • Historical data used meets DQO's | <ul style="list-style-type: none"> • Potential for Type I and Type II decision errors • Lower confidence of data quality | <ul style="list-style-type: none"> • Resurveying, resampling, or reanalysis for unsuitable or questionable measurements |

Table 9.3 (continued)

| Data Descriptor | Suggested Content or Consideration | Impact if Not Met | Corrective Action |
|--|---|---|---|
| Analytical Method and Detection Limit | <ul style="list-style-type: none"> ● Routine methods used to analyze radionuclides of potential concern | <ul style="list-style-type: none"> ● Unquantified precision and accuracy ● Potential for Type I and Type II decision errors | <ul style="list-style-type: none"> ● Reanalysis ● Resurveying, resampling, or reanalysis ● Documented statements of limitation |
| Data Review | <ul style="list-style-type: none"> ● Defined level of data review for all data | <ul style="list-style-type: none"> ● Potential for Type I and Type II decision errors ● Increased variability and bias due to analytical process, calculation errors, or transcription errors | <ul style="list-style-type: none"> ● Perform data review |
| Data Quality Indicators | <ul style="list-style-type: none"> ● Surveying and sampling variability identified for each radionuclide ● QC measurements to identify and quantify precision and accuracy ● Surveying, sampling, and analytical precision and accuracy quantified | <ul style="list-style-type: none"> ● Unable to quantify levels for uncertainty ● Potential for Type I and Type II decision errors | <ul style="list-style-type: none"> ● Resurveying or resampling ● Perform qualitative site investigation ● Documented discussion of potential limitations |

Data collected should meet performance objectives for each data descriptor. If they do not, deviations should be noted and any necessary corrective action performed. Corrective action should be taken to improve data usability when performance fails to meet objectives.

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