

FRMAC ASSESSMENT MANUAL

METHODS

VOLUME 1



The Federal Manual for Assessing Environmental Data During a Radiological Emergency

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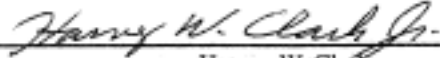
FRMAC Assessment Manual

Methods

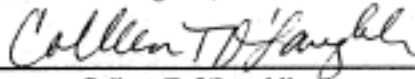
Volume 1



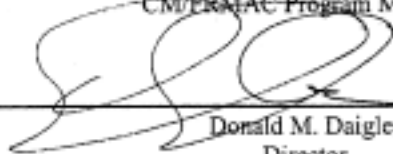
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FRMAC is an acronym for Federal Radiological Monitoring and Assessment Center.

PREFACE

This Federal Radiological Monitoring and Assessment Center (*FRMAC*) *Assessment Manual* has been extensively peer reviewed and reflects the consensus of radiological emergency response elements in the Federal family. We expect to receive many comments and suggestions related to content and application as the manual is used. These comments and suggestions will be evaluated by the FRMAC Assessment Working Group, and they will be incorporated in future revisions as appropriate.

This manual has been prepared primarily by representatives of those Federal agencies that can be expected to play the major roles during a radiological emergency: the U.S. National Nuclear Security Administration, Nuclear Regulatory Commission, and Environmental Protection Agency. As such, all three agencies approve and authorize the release of this document. Significant contributions were also made by the U.S. Department of Agriculture and the Food and Drug Administration regarding food safety issues. A broader audience, including representatives of the Council of Radiation Control Program Directors, was employed throughout the development and review process as a peer review group.

To ensure consistency, completeness, and the highest quality of assessed data produced by the FRMAC, an attempt was made to compile the most appropriate assessment methods and values available in this manual. The criteria were (1) scientifically defensible, (2) simple, (3) applicable to a FRMAC deployment, and (4) likelihood of being adopted by others.

The primary purposes of this manual are as follows:

- To provide users with a sound scientific basis in technical and assessment processes, plus conversion values that have been agreed upon ahead of time. This assures the user that the correct values will be used and the results will be consistent among users from shift to shift.
- To provide users with all of the technical values and assessment processes expected to be used during a radiological response in one document for quick and easy use. However, reference documents will be available at the FRMAC for special assessments that are not included in this manual.

This printing includes both controlled and uncontrolled copies. The controlled copies will be updated as needed. Each organization with responsibility to use this manual during a response maintains controlled copies. Only controlled copies should be used during a response.

The U.S. National Nuclear Security Administration, Nevada Operations Office, has responsibility for maintaining the master copy. Please provide comments to the FRMAC Program Manager, U.S. National Nuclear Security Administration, Nevada Operations Office, Emergency Management and Nonproliferation Division, P.O. Box 98518, Las Vegas, NV 89193-8518.

The next revision of the FRMAC Assessment Manual is planned to commence as soon as the EPA finalizes revision of the EPA PAG manual. This revision of the Assessment Manual was

intended to reflect the content of the new EPA PAG manual, but it was decided that this manual should go to print as soon as practical, rather than be substantially delayed. As such, several topics to be revised have been deferred to the next revision cycle.

ACKNOWLEDGMENTS

The primary author and revision editor for Volumes 1 and 2 was Elizabeth Thompson, with Westinghouse Safety Management Solutions LLC (WSMS), whose contribution was outstanding both in quality and magnitude.

Special recognition goes to the members of the FRMAC Assessment Working Group for their work in developing a health physics community consensus and identification of best practices for adoption.

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Idaho National Engineering and Environmental Laboratory) and Richard Toohey (Oak Ridge Associated Universities) for assisting with best practice advice and review. Thanks also to Gary Mansfield (LLNL) for his contributions to several areas of this effort. Finally, contributions by Thomas McKenna (International Atomic Energy Agency) provided the new manual development team with both the original calculation tools used to develop the previous manual and provided continuity between the new and original development teams.

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OVERVIEW

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READ THIS FIRST!**INTRODUCTION**

The Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manual is the tool used to organize and guide activities of the Assessment Division within FRMAC. In a radiological emergency, it is necessary to quickly interpret radiological measurements, predict worker and public doses, and make recommendations in accordance with protection guidelines issued by governmental agencies. This manual integrates many health physics tools and techniques used to make these assessments.

Volume 1 contains the scientific bases and computational methods for assessment calculations. Key reference data used in these calculations are provided in Volume 2. Volume 3 provides “What-If” analyses for five typical analyses. These default scenarios include:

- A nuclear power plant accident,
- A nuclear weapon accident,
- An aged fission product accident,
- A nuclear fuel accident, and
- A radionuclide thermoelectric generator accident.

Plans are in place to add a nuclear yield scenario and a “dirty bomb” (a.k.a. RDD) scenario.

This manual may be used for training for FRMAC assessors. This tool should provide guidance and tools that will be useful in responding to radiological incidents.

This manual represents a consensus of how best to handle a radiological emergency from representatives of eighteen organizations. It is not an exhaustive compendium of health physics, but rather a distillation of key techniques, information, and shortcuts. Some methods are very simplified to assure a timely assessment of data, while others provide a more deliberate but careful approach. The manual is only intended to address the issues that arise during the early and intermediate phases of a radiological incident (evacuation, sheltering, relocation, and food embargo...). It does not address recovery phase issues such as remediation. The manual tools and analyses to make decisions regarding population return or other recovery phase actions.

The manual is not prescriptive. The user may employ many alternative methods. Situations may arise when the methods described in the Assessment Manual will not be sufficient. Therefore, assessors must be skilled sufficiently in health physics to recognize when, which, and how alternatives must be employed. Imprudent use of these methods could lead to incorrect assessments, resulting in poor decisions. Further information can be found under the “Get Oriented” and “Admonitions” sections.

GET ORIENTED

- Consumers of FRMAC Assessment products should review “Overview of Assessment.”
- Newcomers to Assessment must read and understand the contents of Overview of Assessment, and briefly review Section 6, “Administration, Internal Procedures, and Tools”. Newcomers must read and understand the applicable pre-assessed accident scenario section in Volume 3 for the specific problem at hand.
- Assessment group members or all individuals routinely assigned to the Assessment group must be conversant with the entirety of this manual (all 3 volumes). Keep the manual set handy.

ADMONITIONS

1. Consult the accident-specific scenario section of Volume 3 for the problem at hand first.
2. Determine State-specific PAGs that apply.
3. Use the default DRLs and DILs until sufficient measurements are available to eliminate assumptions used in their calculation. This may take several days.
4. Never use more than two significant figures, because the approximations used, and the limitations and uncertainties of the assumptions, will not support more.
5. NEVER add additional conservatism! The methodologies used in the manual are already conservative and will overestimate dose. Adding additional conservatism makes it difficult to relate assessment to risk and will create confusion.
6. Determine if DRLs and DILs can be validly applied to the entire radiological footprint. If so, proceed with use of DRLs/DILs. If not, compute doses location-by-location.
7. Document all interpretations, analyses, DRL/DIL revisions and calculations by completing Assessment QA Cover Sheet (Worksheet 6.1) for each product. Document and explain any deviations from the manual’s methodology. Cite any directives to do so and concurrences.
8. FRMAC does not make Protective Action Recommendations (PARs). NEVER present an assessment product so that it may be construed as a recommendation.
9. Set QA flags on data ASAP. Release data and assessments as often and quickly as possible.
10. Establish frequent and close contacts with the FRMAC Senior Scientific Advisor and with the Federal Advisory Team.

OVERVIEW OF ASSESSMENT

OBJECTIVES

This section, Overview of Assessment, is intended as a primer for those who will be working in or with FRMAC and for those using its products. It also provides FRMAC Assessment staff with goals and basic concepts of operations. Reading this section will ensure establishment of a common basis for understanding and dialogue.

ASSESSMENT OBJECTIVES

The objectives of the FRMAC Assessment function are twofold:

1. First, and most importantly, is to provide interpretations of radiological conditions in the environment in terms of recognized Federal or State PAGs.
2. Second, and longer term, is characterization of the radiological environment, which is used by State, Federal and other stakeholders to address re-entry, return, and recovery issues.

Regardless of origin or cause of the radioactive contamination, these objectives remain as the primary roles of the Assessment group in FRMAC.

The only purpose of the FRMAC Assessment function is to support and augment the technical needs of the State and lead Federal agency. It serves as the integrating point for all environmental data collected by the Federal family and any State or local responders that wish to join forces. It also facilitates a uniform and consistent analysis of that data. As such, it is the single point for dissemination of data and analyses for the entire Federal family. The Federal Emergency Management Agency (FEMA) plays a major role in the emergency response, but that role does not include environmental data collection or analysis.

The PAGs, mentioned above, are the criteria for making several key decisions such as: evacuation, sheltering, relocation and food embargo. Generally, they help control health risks by placing restrictions on the radiological dose received via the principal pathways. They are recognized to represent a broad consensus and are published in various Federal guidance documents. The proposed course of action devised to reduce delivery of radiation doses that would exceed a particular PAG is termed a Protective Action Recommendation (PAR). All radiological measurements or predictions must be interpreted in terms of the PAGs to develop Protective Action Recommendations (PARs). FRMAC Assessment will provide these interpretations as prescribed in the Federal guidance for the corresponding PAG. FRMAC Assessment will perform the interpretations as requested by the State and Lead Federal Agency (LFA); however, a default-prioritized strategy will be applied in the absence of specific tasking. However, FRMAC Assessment will not offer or develop PARs. Implementation of Protective Action Recommendations is solely the responsibility of the State.

The State's effort to develop PARs is supported by the lead Federal agency, the utility, and the Federal Advisory Team, not FRMAC. The Advisory team is comprised of representatives from those Federal agencies that developed the PAGs and that have specific statutory responsibilities for public health. There is a close relationship between the Advisory Team and FRMAC Assessment. Generally, the Advisory Team will collocate with FRMAC, often near Assessment. The Advisory Team not only uses FRMAC Assessment interpretations to develop their advice, but it also reviews application of the Federal guidance (PAGs) by the Assessment group. The Assessment group will work closely with the Advisory Team to tailor its products for greatest value and applicability. Finally, Assessment also depends upon the Advisory Team to create ad-hoc guidance, where none exists, and to recommend incident specific adjustments to assessment assumptions, parameters and methodology.

It is critical to understand that FRMAC does not issue PARs. FRMAC performs measurements, analyses and assessments. Assessments must be transformed into PARs by the State and LFA. It may appear that FRMAC Assessment is involved in PAR development since key members from States and LFA organizations involved in PAR development may be working at FRMAC and because the Advisory Team may be in close proximity.

Every effort will be made to respect and preserve the jurisdiction of the State and LFA regarding PARs.

The primary function and objective of FRMAC Assessment is the interpretation of the radiological scenario in terms of the PAGs. This evaluation occurs primarily during the early and intermediate phases of the emergency response. However, radiological characterization of the environment is the second objective of FRMAC Assessment. Characterization is a longer-term endeavor and is critical to return and recovery. Somewhere in this time frame, management of FRMAC passes to EPA, but FRMAC Assessment remains a key function. Assessment will integrate data, apply rigorous quality measures, perform statistical analyses and publish results. From the outset of the emergency response, the intent is for FRMAC to work toward a formal Data Quality Objective process. This will require defensible and detailed records, chain-of-custody and a comprehensive database. The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) is likely to play a large role. Assessment methodology is expected to be adapted to an incident specific approach. Therefore, this manual does not attempt to establish the details of radiological characterization to the degree of detail invested in application of the PAGs.

The key to achievement of the FRMAC Assessment's objectives is the broad-based staff. The staff, which is drawn from multiple agencies, has a variety of skills. The staff mix not only includes health physics professionals, but also data analysts, cartographers, modelers, meteorologists, and computer scientists. This mix facilitates the analysis, interpretation, presentation, and preservation of the radiological data collected during the incident. These individuals are primarily drawn from the National Nuclear Security Administration and the Environmental Protection Agency. However, staff also includes members from the Nuclear Regulatory Commission, Department of Agriculture, Food and Drug Administration, Centers for Disease Control, and other Federal agencies as required. Participation of State and local scientific specialists is invited and very valuable, because they add insight into specifics of the locality and interpretation of an unfamiliar environment. Participation by State, local and LFA

specialists is invited and valuable, because they can have direct access to the data and observe how the evaluations are being handled, which enhances credibility of FRMAC Assessment's products when delivered.

MANUAL OBJECTIVES

The objectives of the FRMAC Assessment Manual are fivefold:

- Serve as a guide to consumers of assessments

This first section, Overview of Assessment, specifically targets decision-makers and those in public affairs. It is intended as a primer to help consumers of FRMAC assessments to understand what to expect from Assessment and to comprehend the products they receive.
- Document the assessment process

The manual defines all aspects of the Assessment group's operations. It provides descriptions of organization, functions, and objectives; it provides default response levels, data requirements, and assessment methods; and it includes conversion factors, modifying factors, and overview of available Assessment tools.
- Provide technical basis for assessments

The manual describes each assessment method in detail (including concepts), provides references to scientific publications and guidance documents; in addition, it cites the assumptions implicit to conversion factors and calculations.
- Cite consensus of Federal family

The manual is based both on the guidance issued by the NRC, EPA and FDA and on consensus standards, such as those of the ICRP and NCRP. It was developed by the FRMAC Assessment Working Group, which is comprised of health physics practitioners representing over a dozen facilities from six Federal agencies (NNSA, NRC, EPA, FDA, USDA, and CDC). It has had broad review throughout that community.
- Orientation and Training guide for Assessment group members

The manual is not intended to train individuals to be health physicists. It is intended to train health physicists to assess environmental radiological data obtained in an emergency. It also trains Assessment group members on the concept of operations employed in daily activity. Finally, it can be used to orient those not involved with FRMAC Assessment with Assessment's function and its products.

UTILIZATION

USING THIS MANUAL

Audience

Consumers of FRMAC Assessment Products

All consumers of FRMAC Assessment products should at least review Overview of Assessment. It is imperative that consumers understand the products and processes used by the Assessment Group. Requests for assessments should make use of Assessment products that have been pre-planned and described in this manual to the fullest extent possible. Special requests beyond the pre-planned products must be based on the capabilities available in the group. Effective utilization of the Assessment products depends on a thorough understanding of their meaning and limitations. Confidence in the products requires an appreciation of the production process and quality measures. Timely delivery of Assessment products depends not only on the efficiency of the Assessment team, but also on realistic expectations of the delivery time line as described here.

Newcomers to Assessment

All those who will be working in the Assessment group for the first time must read and understand the contents of Overview of Assessment, to be productive. Participation by individuals from State, local and Federal agencies is strongly encouraged, because it is beneficial for both that agency and FRMAC. However, that participation will not achieve its full value unless the participant understands the basic framework, operation and objectives of the Assessment group. The newcomer should also briefly review the contents of Section 6 (Vol. 1), Internal Administrative Procedures, because it describes job duties and usage of the assessment tools. Finally, the newcomer must review the appropriate pre-assessed default scenario section in Volume 3 thoroughly enough to apply it.

Assessment Group Members

All individuals routinely assigned to the Assessment group must be conversant with the entirety of this manual, because it governs all operations and technical methodology. When assigned to the group, obtain your job assignment and read the job description. Always review the contents and layout of the manual before commencing work. Read the pre-assessed default scenario section for the specific problem at hand in detail. Finally, keep the manual handy, particularly when using assessment tools or performing calculations.

Organization

This FRMAC Assessment Manual is organized into three volumes. The scope of the manual addresses EPA Early Phase PAGs, EPA Intermediate Phase PAGs, and FDA Ingestion PAGs. It was not the intent of this manual to address emergency worker protection to any level of detail, because that is a matter for FRMAC Health and Safety. However, guidance is provided to cover basic limitations and facilitate preparation of assessment products to aid Health and Safety oversight. The manual also does not address recovery and restoration, because it is anticipated that a formal incident specific DQO or MARSSIM process developed during that phase will govern those concerns.

Volume 1, “Methods,” provides: 1) an overview of Assessment, 2) detailed descriptions of generalized assessment methodologies, and 3) procedures for internal operations. The detailed methodology descriptions are organized by time phase of relevance (Emergency Workers, Early Phase, Intermediate Phase and Ingestion Phase). The Assessment Manual does not address the Recovery Phase.

Volume 2, “Tables, Charts, Worksheets, Glossary, References,” presents all supporting information necessary to employ the assessment methods provided in Volume 1, “Methods.”

Volume 3, “Pre-assessed Default Scenarios,” offers default assessment guidance for six different types of accidents. A section is devoted to each generic scenario, which offers default DRLs/DILs and specially tailored methodologies. The scenarios covered include:

- Nuclear Power Plant Accident
- Nuclear Weapon Accident
- Aged Fission Product Accident
- Nuclear Fuel Accident
- Radioisotopic Thermoelectric Generator/Accident
- Nuclear Yield Accident

Philosophy

Seven concepts underlie the manner in which the FRMAC Assessment Manual was constructed:

1. As much as can be anticipated should be pre-planned and organized. Therefore, methods, factors, defaults, and tools must be prepared in advance.
2. Assessments will be required immediately. Methods must provide a graded approach from “quick and dirty” to sophisticated. Therefore, approximations, shortcuts, and defaults must be available from the outset. Utilization of surrogate measurements is fundamental to the assessment process.
3. Opportunity and requirements for quality will grow with time. Therefore, these methods have a limited life before modification or replacement will be necessary.

4. Time during the emergency will be too short to permit learning while doing. Therefore, assessors must be trained on these methods before attempting to apply them.
5. Users of the manual are already very knowledgeable about environmental measurements and dose calculation. More importantly, they are already familiar with the issues arising in a radiological emergency. Therefore, this manual serves assessors the same way that checklists and a flight manual serve a pilot.
6. Real world situations always have aspects beyond those anticipated. Assessment methods may require modification and adaptation. Therefore, assessors must use judgement based on understanding of the underlying scientific/regulatory concepts.
7. The quality of Assessment products is judged in terms of both timeliness and reliability. Assessors will have to use judgement based on experience.

USING ASSESSMENT PRODUCTS

Utilization Principles

There are three fundamental principles to keep in mind when using Assessment products:

- The assessment products already contain ample conservatism. Don't add more, because it will divorce decisions from quantitative risk. It may also lead to different assessment groups obtaining conflicting results, which could be damaging to the credibility of those managing the accident.
- Quality and reliability of the Assessment products improve with time. Early in the emergency response, in the absence of measurements, models play a key role. Later, models are supplanted by measurements. The nature of decisions based on Assessment products must be commensurate with the data quality at that point in time.
- Quality measures imposed are adjusted to be commensurate with the urgency of the decision at hand and the risk of potential consequences from an incorrect decision. At first, accuracy is sacrificed for speed; subsequently however, the emphasis shifts to quality in every measure.

Introduction to Assessment Products

Assessment prepares a variety of information products, each designed for a particular audience and application. These products fall into three main categories: 1) primary products, 2) standard products, and 3) internal products. The products may be interpretations, analyses, and assessed data sets or reference information. Most Assessment products are presented as maps or data sets, while others are provided as tables or calculations. The full set of pre-planned Assessment products is described in detail later in the "Assessment Products" section. The focus here is utilization by users of the Assessment products.

Primary Assessment Products

The primary Assessment products are the “**PAG Zone Maps**” and “**Monitoring/Sampling Status Maps**.” These are targeted for decision-makers and the public. FRMAC emphasizes production, approval, and release of these primary products. Therefore, they are released for use outside of the FRMAC at least once each shift. The maps summarize the best appraisal of the radiological scenario possible up to the current time. All other Assessment products are the underpinning of these primary products. If a question is unanswered or a decision is unclear based upon these primary Assessment products, then consult with the Assessment Manager. Explanations and additional products can then be obtained to resolve the issue. Specific products are requested via consulting with the Assessment Manager because there may be products already available that will suffice. Development of special products will sidetrack resources from pursuit of previously requested deliverables.

The **PAG Zone Maps** indicate where particular PAGs are exceeded, e.g., EPA Early Phase PAGs, EPA Intermediate Phase PAGs, FDA Ingestion PAGs. These maps appear repeatedly, only changing in their quality and reliability as time progresses. Initially, the PAG Zone Maps are based only on predictions, perhaps with a few sparse data points. Eventually, these are based only on detailed, high quality measurements. Ample conservatism has been applied in the interpretation. Do not add more.

The **Monitoring/Sampling Status Maps** summarize the location and type of both monitoring and sampling data collected up to the current time. The purpose of these maps is twofold:

- Portray the progress of the monitoring effort
- Convey some concept of quality and confidence for the PAG Zone Map

The maps continually grow in density and diversity of data collected. They do not reflect the level of radiation, concentration, or dose.

Standard Assessment Products

The standard Assessment products are enumerated below, but described more fully in the “Assessment Products” section. These are targeted for health physics professionals performing independent interpretations or analyses. This data also is made available outside the FRMAC, however, it is not available on a regular schedule and it is set as a lower priority than the release of the primary Assessment products. In fact, a specific request may be necessary to initiate release, because the required review to validate quality may be pre-empted by other work of higher priority. If the LFA, Advisory Team or State(s) have representatives in the Assessment group, then they can see which of the products are available or might be easily made available to their organization upon request. The standard Assessment products are comprised of the following:

- Predictive model (ARAC, SHARC, or other appropriate model) outputs (hard copy) of exposure rate, deposition or various doses.

- Contour maps (digital or hard copy) summarizing measurements of exposure rate, deposition or estimations of various doses.
- Assessed data sets (digital or hard copy) of field measurements or analysis results for samples. Assessed data that has been reviewed for quality and approved.
- Calculation analyses (hard copy text) including: DRLs/DILs, Dose Conversion Factors (DCFs), dose ratios (usually TEDE/EDE), radionuclide mix, resuspension factor, and evaluations of dose reduction factors for mitigation measures.

Internal Assessment Products

All of the above Assessment products, and others, are created as drafts or preliminary results during the Assessment process. However, these are not available for release outside of the FRMAC, because their quality cannot be assured. However, they usually precede released products by a considerable margin. Representatives of the LFA, Advisory Team or State(s) may have full access to the internal Assessment products within the FRMAC. This information can be used to relay progress of Assessment or developing trends to their counterparts. Nevertheless, they should NEVER be released except as an approved Assessment product through the FRMAC Director. Moreover, they must NEVER be used for decision making unless properly reviewed and released.

DIFFERENCES BETWEEN FRMAC APPROACH AND PUBLISHED GUIDANCE

The FRMAC Assessment Manual (April 2003) is not entirely consistent with current Federal guidance. Although the intent was to be compatible with all Federal guidance, it was published before the revision of the EPA PAG manual. Therefore, the new FRMAC Assessment Manual employs what the Assessment Working Group believes to be best practice and most likely to be used in the new EPA PAG manual.

Known Differences

1. With the exception of the early inhalation DCFs, the inhalation DCFs used by the FRMAC Assessment Manual are those from Federal Guidance Reports 11 and 12, which are used in the current EPA PAG manual (EPA92). Early inhalation DCFs derived from NRPB85 have been replaced by DCFs derived from Ec01.
2. The resuspension model used by the FRMAC Assessment Manual is not that used in the current EPA PAG manual (EPA92). The model now used is that recommended in NCRP Publication 129 (NCRP99), which reflects the observations from Chernobyl and many other locations. The greatest difference is that the new model does not use separate resuspension factors for arid and non-arid cases. It reports a single time-dependent value, which more closely resembles the old “non-arid” case.
3. The FRMAC Assessment Manual employs the new FDA guidance, which was promulgated in “Accidental Radioactive Contamination of Human Food and Animal Feeds:

Recommendations for State and Local Agencies” (FDA98). However, the manual does not extend the FDA guidance to other radionuclides beyond those cited in the FDA PAG document.

4. The FRMAC Assessment Manual treats water as food using the new FDA guidance in FDA98. It is yet unclear how the new EPA PAG manual will treat water. It is important to note that FDA included water as part of the diet, when calculating the DILs. Therefore, this approach is both conservative and appropriate.

The EPA is responsible for establishing protective action guidance for radiological emergencies that potentially affect drinking water. There is no guidance provided for drinking water protective actions in the "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA92). EPA is currently in the process of reviewing and revising the 1992 manual, and is considering several options for drinking water protection during nuclear incidents in the revision.

In order to complete this revision of the FRMAC Assessment Manual, the FRMAC Assessment Working Group has decided preliminarily to adopt the FDA's food protective action guidance in FDA98 for drinking water during the initial phases of an emergency, until EPA promulgates final guidance. The FDA's recommendation for protective actions for food is one of the options being considered for drinking water protection by the EPA.

Consequences

- Early (short-term) doses for comparison to early health effects thresholds are more realistic.
- Inhalation doses due to resuspension are more realistic, particularly after the first few days.
- Food assessments will be compatible with USDA Food Safety Inspection Service criteria.
- Drinking water assessments will be based on concentrations acceptable for food.

ASSESSMENT PROCESS

INTRODUCTION

Definition

Assessment is defined as the evaluation and interpretation of environmental radiological data obtained during or following a radiological emergency. The primary products of Assessment are interpretations of the radiological scenario in terms of the PAGs, and later prepare a detailed radiological characterization of the affected area.

The radiological data being assessed may be either measurements or model predictions. Initially, the Assessment will be based largely on predictive modeling. Thus, initially uncertainty is large. Until a substantial number of measurements are available, dependence on models persists. Therefore, as soon as possible the models will be validated and re-normalized, if necessary, using the available measurements. This reduces uncertainty and improves confidence. Eventually, a thorough characterization will be completed and assessment will be based on measurements instead of models. This provides the best quality of assessment products. However, models may still play a roll in assessment as tools for interpolation and extrapolation.

The primary Assessment products (PAG Zone Maps and Monitoring/Sampling Status Maps) are produced from the start and updated at least once per shift. The basic difference between releases is their quality. Later releases will be based upon more and better measurements. Other Assessment products, such as exposure rate or deposition maps, similarly improve in quality as the assessment assimilates more data.

Environmental data include field survey measurements, aerial radiological surveys and analyses of various samples, such as: soil, air, water, vegetation, and foods. Two evaluations are performed. First, data are evaluated to assure quality and integrity of the data set. Faulty data are corrected or eliminated from further consideration. Data, whose quality has been verified, are termed "Assessed." Then the assessed data are evaluated to construct a single, consistent overview of the entire radiological scenario from all of the data available. The overview is comprised of maps of exposure rate, nuclide deposition, or specific doses. The management of the data set and its protection are defined as Assessment functions.

An interpretation defines the areas in which a specific PAG is or may be exceeded. Several interpretations, corresponding to each PAG to be considered, are necessary to convey the entire radiological impact of the event. These interpretations are performed by comparison of magnitudes reported on the maps with DRLs/DILs corresponding to certain dose limits prescribed in the PAGs. Calculations of DRLs, conversion factors and other parameters are performed by Assessment as needed. Publication of the interpretations, the assessed radiological data set, and the above calculations are defined as Assessment functions.

Assessment does not plan and is not prepared to address dosimetry, bioassay, or dose reconstruction for members of the public. However, this could change at the direction of FRMAC management. Note, FRMAC Health and Safety provides this support for FRMAC staff.

Organization

Assessment is functionally organized into six components:

Overview

The Overview function consists of three distinct tasks: 1) create the "Big Picture" of the radiological scenario and the interpretation products; 2) assist in development of the overall strategy for monitoring, sampling, and analysis; and 3) perform the quality reviews of data and

approve both data and interpretations for release by the Assessment manager. This is a continuously iterative process, which adds detail and quality to the products of each cycle. Overview directs application of conversion factors to data sets, directs plotting of results, and performs the comparison with the DRLs/DILs. It develops the graphical presentations that become the familiar map products produced by Geographical Information System (GIS). Finally, the overview function pursues resolution of quality issues, assigns quality “flags” in the database, and assures consistency of Assessment products.

Data Center

The Data Center function logs, tracks, manipulates, and reports all of the environmental data collected by the FRMAC. As part of this process it performs the initial screening of all data for quality by checking completeness and consistency of records (times, locations, units, exponents, instruments, etc.). The data is entered into a relational database (DCENT) by the data center, which makes all data immediately available to GIS for plotting. The database is used for applying conversion factors and corrections as well as a tool for data retrieval and report generation. The data center function captures, catalogs, and retains all original field records and laboratory reports in a data archive, such that it is traceable and accountable. Data is never removed from the database. Requests for data sets, either electronic or hardcopy, are filled by the Data Center and released to the FRMAC Director by the Assessment Manager.

GIS

The GIS function is the most visible activity in Assessment, because of its graphic products and displays. It is used to create and distribute the presentation quality map products that represent the results of the Assessment process. GIS is a database management system for spatial information. As such, it complements the Data Center database for textual information. The GIS is used as the primary means of data plotting and visualization. Interpretations and interpolations sketched by Overview are superimposed on maps and annotated by GIS. GIS also serves as an analytical tool. It can combine data types such as a street address index with the relocation PAG zone to determine the number of residences subject to relocation. GIS is not entirely captive to Assessment. It must serve the needs of the entire FRMAC. Therefore, there is some competition for their services. Priorities are arbitrated by the FRMAC Director. Products are quality reviewed by Overview, approved by the Assessment manager and delivered to the FRMAC Director.

Computations

The computation function serves two key purposes: 1) performs all conversion factor and DRL calculations and 2) monitors the validity of assumptions implicit to the DRLs/DILs, conversion factors, and the methods themselves. Computations will report when conditions warrant revision of DRLs/DILs or conversion factors and report when a method must be adjusted or replaced. The potential effectiveness of mitigation measures and any detailed dose pathway considerations are investigated by Computations. Results of their work are reported periodically in brief text summaries released to the FRMAC Director by the Assessment manager. Finally, Computations

will be enlisted by Overview to investigate and analyze monitoring or laboratory techniques to resolve a quality issue.

Predictions

The prediction function provides modeling of plume concentration, ground depositions, exposure rates, and potential population doses resulting from release of radioactivity (actual or potential). Typically, predictions are obtained from Lawrence Livermore National Laboratory's ARAC model (Atmospheric Release Advisory Capability). Initially, modeling is the basis for early interpretations of potential consequences. As field data are accumulated the models are renormalized to match observations and used to extrapolate sparse measurements. Modeling may still play a role even after completing detailed measurements by serving as an interpolation tool. Predictions are distributed as Assessment products.

Meteorology

The meteorological function serves both the modeling needs of Assessment and the operational planning needs of the FRMAC. It includes collection of on-site observations, preparation of predictions tailored to the immediate vicinity and time of interest and ready access to the full wealth of meteorological information. This is of particular value for deployment of field monitors and aerial surveys. The support is provided through NOAA's Air Resources Laboratory, Special Operations and Research Division (ARL/SORD). Regular weather briefings, updates, and timely warnings are provided to the FRMAC.

Tasking

All tasking of the Assessment group for support or products is through the FRMAC Director. Requests are captured on an Action Request, which is then prioritized by the FRMAC Director. Their completion is tracked through a formal Action Request tracking system. In the absence of specific tasking Assessment will proceed to work with default priorities, which seek to address the most serious potential health effects first.

The Assessment manager will help expedite tasking of the Monitoring Division in two ways. First, the Assessment manager will continually provide the monitoring manager with input to and feedback on the Implementation Plan to assure Monitoring Plan objectives are achieved. Second, the Assessment manager will assign priorities and detection limits to all samples submitted to the laboratory, such that they reflect the goals of both the Monitoring Plan and Action Requests.

Derived Response Levels & Derived Intervention Levels

The Derived Response Levels (DRLs) and Derived Intervention Levels (DILs) are valuable shortcut methods to quickly assess data in terms of PAGs. DRLs and DILs are central to FRMAC's initial and usual approach to radiological assessment. Regulatory bodies have

promulgated PAGs. A PAG is the projected dose to an individual from an accidental release of radioactive material at which a specific protective action to reduce or avoid that dose is warranted (EPA92). These PAGs cite risk-based limits on doses for specific pathways and time periods. For example, part of the EPA Early Phase PAG establishes an Action Level on the projected dose to the whole person considering all means of exposure for a four-day period. However, projected dose is not measurable. Conversion factors must be applied to field measurements and sample analyses to estimate doses for specific conditions.

The DRL is the level of some directly measurable quantity at which the dose for a specific pathway and period might exceed a particular PAG. DRLs are computed backwards from the dose to a specific kind of measurement for a given set of assumptions. This way, measurements observed to exceed a particular DRL imply that the potential dose may exceed the corresponding PAG and warrant protective action. For example, the area in which exposure rate is observed to exceed the DRL for Relocation can be designated as the area where the Relocation PAG may be exceeded.

DILs are computationally the same as DRLs. However, DILs are special in that they have been computed and promulgated by FDA as Federal guidance. DRLs are computed by FRMAC as required. These two terms are consistently used throughout the FRMAC Assessment Manual to clearly differentiate between FRMAC originated values and those developed by FDA.

Generally, DRLs and DILs are prepared for easily measurable quantities, such as exposure rate or a particularly detectable radionuclide concentration. Many DRLs/DILs are needed to assess the data. A unique DRL/DIL is required for each type of measurement and each PAG addressed. Default values are prepared for reasonably probable situations. These defaults are used until assumptions can be eliminated. Often a DRL must be revised to compensate for radioactive decay. If a DIL must be recomputed by FRMAC, it will then be called a DRL.

Usually a DRL/DIL is applied to all measurements throughout the contamination footprint. However, this is not always the case. The DRL method cannot always be used. If the radionuclide mixture varies significantly with location then there may be no simple relation between a single easily monitored quantity and dose. Initially, the DRL method is used until data suggest the method is inappropriate. Then Assessment must compute each dose of interest on a point-by-point, measurement-by-measurement basis. These results must be plotted and a map designating where PAGs are exceeded constructed. This is much slower, but Assessment is prepared to do so if required.

PROCESS

Assessment Methods

Assessment essentially is a recursive process to evaluate an ever-growing body of data to provide an expanding technical basis to support preparation of Protective Action Recommendations. Applying a series of pre-defined Assessment Methods accomplishes this. These pre-defined Assessment Methods enable Assessment to produce a set of maps that designate where the various PAGs are exceeded. The order in which the series of pre-defined Assessment Methods

are applied is such that the potentially most serious health consequences are addressed first. Initial assessments target the highest consequence effects requiring the most time sensitive actions. Later, assessments target issues requiring greater emphasis on quality but less urgency. Each time the process is repeated new, additional data is included in the evaluation. Consequentially, the detail, reliability, and quality of the assessment improve with each cycle.

Volume 1, "Methods," is a toolbox of assessment procedures. Some are always applied, while others are only employed if needed. In Volume 3, "Pre-assessed Default Scenarios," default measurements and DRLs are provided. These will be applied until sufficient data is available to eliminate the assumptions used to determine the defaults. Volume 3 also contains methods to supplement the generic methods or information specifically tailored to the case at hand.

Default Assessment Priorities

At start up Assessment applies a default set of priorities. These prevail until incident specific priorities are directed. Many other Assessment priorities will follow but the five below generally prevail near the top. The default priorities are:

1. Identify where there are potential early health effects (death, injury).
2. Determine areas in which evacuation and/or sheltering are warranted, based on the applicable (Federal or State) Early Phase PAGs.
3. Evaluate unevacuated and sheltered areas as candidates for additional evacuation and sheltering per the applicable (Federal or State) Early Phase PAG.
4. Identify where food and water may be unsatisfactory for consumption per the applicable (Federal or State) Ingestion PAG. If the FDA Ingestion PAG is used, the determination is based on the FDA DILs.
5. When to allow limited reentry for specific purposes such as taking care of farm animals, retrieving pets, or locating valuables left behind.
6. Identify where populations may be subject to relocation to avoid long-term effects per the applicable (Federal or State) Intermediate Phase PAGs.

Workflow

The basic workflow for Assessment mainly proceeds in three overlapping threads, regardless of the Assessment Method:

1. Data Assimilation and Quality Assurance, which compiles the comprehensive data set, involves just the Data Center and Overview functions. The activities that comprise it are: 1) data archival, 2) quality screening, 3) database entry, 4) quality tagging, 5) database queries and 6) data report production. This activity may include distribution.

2. Assessment Products Preparation, which creates the familiar maps of measurements, dose, and PAG zones. This thread primarily involves the Overview and GIS functions. In this thread the team 1) selects an Assessment product and the Assessment Method to prepare it; 2) applies corrections, conversions, and DRLs to the relevant data; and 3) renders the results as graphic using GIS. Then it is approved and made available for distribution.
3. Computations, which supplies the Data Center and Overview functions with the most appropriate conversion factors and DRLs, also monitors the validity of assumptions.

QUALITY

Introduction

Quality of Assessment products is measured both in timeliness and in reliability. A key goal of Assessment is ensuring that the quality of assessment products is adequate to their intended use, while also ensuring the timely generation of those products. A secondary goal is assuring sufficient quality of the radiological characterization to support planning for the recovery phase of the response. The quality of assessment products will improve with time as additional data are collected and models are refined. However, the assessment procedures are designed so that the quality of even the earliest products will be known and will be as high as achievable under the circumstances.

"Data quality" refers to the accuracy, integrity, applicability, and completeness of the products generated by the assessment process. The data quality of an assessment depends on the quality of the inputs to the assessment, the quality of the environmental transport and dosimetry models used in the assessment, the quality of any simplifying assumptions made, and the quality of the actual calculations performed.

Requirements for particular assessment products will drive data collection priorities. The type and quality of monitoring data must be appropriate for the intended use. Therefore, the data quality needs for each assessment product must be clear. This is addressed using the Data Quality Objective (DQO) process (EPA94b).

During the early and intermediate phases of an emergency a formal Data Quality Objective (DQO) process cannot be employed. However, the DQO process must be employed in the recovery phase. Therefore, Assessment will attempt to apply the principles of the DQO process wherever practical. This is particularly evident in Volume 3, "Pre-assessed Default Scenarios," where the process was used to define the default measurements and DRLs. Most importantly, the DQO process is the basis for Assessment's contribution to the Monitoring Implementation Plan. The Monitoring Implementation Plan specifies which measurements or samples are to be acquired, where they are to be acquired, and how they are to be acquired. It also specifies the required sensitivity and analyses.

Understanding Data Quality Objectives

Data Quality Objectives (DQOs) are the 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 data
- Specify tolerable limits on decision errors, which will be used as a basis for establishing the quantity and quality of data needed to support FRMAC decisions.

The DQOs are then used to develop a scientific and resource-effective data-collection design.

The DQO Process is a series of seven planning steps, based on the scientific method, for establishing criteria for data quality and establishing survey designs. It provides a systematic procedure for defining the criteria that a survey design should satisfy, including when to collect samples, where to collect samples, the tolerable level of decision errors for the data and how many samples to collect. Although the DQO Process is depicted as a linear sequence of steps below, in practice it is iterative; the outputs from one step may lead to reconsideration of prior steps. During the first six steps of the DQO Process, the Monitoring Team will develop the decision performance criteria (DQOs) that will be used to develop the data-collection design. The final step of the Process involves developing the data-collection design based on the DQOs. The first six steps should be completed before the Monitoring team attempts to develop the data-collection design because this final step is dependent on a clear understanding of the first six steps taken as a whole.

Each of the seven steps is described briefly below. A more detailed description can be found in Section 6 of this document.

Step 1: State the Problem. Concisely describe the problem to be studied. Review similar prior responses and existing information to gain a sufficient understanding to define the problem. (Example elements of Problem Description: Study objectives/regulatory context, persons or agencies/organizations involved in the study, persons or agencies/organizations who have an interest in the study, political issues surrounding the emergency, sources and amount of funding, and previous survey (e.g., AMS) results.)

Step 2: Identify the Decision. Identify what question(s) the surveying (radiological monitoring and sampling) will attempt to resolve, and what actions may result. (Example Decision: Does the mean contaminant concentration exceed EPA's Relocation PAG?)

Step 3: Identify the Inputs to the Decision. Identify the information that needs to be obtained and the measurements that need to be taken to resolve the decision statement.

Step 4: Define the study boundaries. Define spatial and temporal components of the population that will be covered by the decision statement so that the data can be easily interpreted. Essentially, determine when and where data should be collected.

Step 5: Develop a Decision Rule. Define the statistical parameter of interest, specify the action level, and integrate the previous DQO outputs into a single statement that describes the logical basis for choosing among alternative actions.

Step 6: Specify Tolerable Limits on Decision Errors. Define the decision-maker's tolerable decision error rates based on a consideration of the consequences of making an incorrect decision.

Step 7: Optimize the Design. Evaluate information from the previous steps and generate alternative data-collection designs. Choose the most resource-effective design that meets all DQOs.

Questions about the DQO Process

When should the DQO Process be used? The DQO Process should be used during the planning stage of FRMAC environmental monitoring activities BEFORE the data are collected. In general, it should be FRMAC's Standard Operating Procedure to apply the DQO Process to plan all data collection efforts that will require or result in a substantial commitment of resources.

Should the DQO Process be applied intensively to ALL emergency response phases FRMAC is involved with? No, the DQO Process is a flexible planning tool that can be used more or less intensively as the situation requires. For situations that require multiple decisions, such as emergency monitoring and assessment, where the resolution of one decision leads to the evaluation of subsequent decisions, the DQO Process can be used repeatedly through all the response phases. Often, the decisions that are made early in the response will be preliminary in nature. They might require only a limited planning and evaluation effort. As the emergency phase nears conclusion and the possibility of making a decision error becomes more critical, the DQO Process would be applied more intensively.

What is a data-collection design? A data-collection design specifies the final configuration of the environmental monitoring or measurement effort required to satisfy the DQOs. It designates the types and quantities of samples or monitoring information to be collected; it specifies where, when, and under what conditions the data should be collected; it identifies what variables are to be measured; and outlines the FRMAC monitoring and assessment procedures to ensure that sampling design and measurement errors are controlled sufficiently to meet tolerable decision error rates specified in the DQOs.

What are the outputs of the DQO Process? The DQO Process leads to the development of a quantitative and qualitative framework for a FRMAC response. Each step of the Process derives valuable criteria that will be used to establish the final data-collection design. The first five steps of the DQO Process identify mostly qualitative criteria such as what problem has initiated the study and what decision it attempts to resolve. They also define the type of data that will be collected, where and when the data will be collected, and a decision rule that defines how the decision will be made. The sixth step defines quantitative criteria expressed as limits on decision errors that the decision-maker can tolerate. The final step is used to develop a data-collection design based on the criteria developed in the first six steps. The final product of the DQO

Process is a data-collection design that meets the quantitative and qualitative needs of the particular emergency response phase.

ASSESSMENT PRODUCTS

The FRMAC presents the offsite environmental radiological data to the LFA, state(s), and local authorities in a recognizable and usable format and in a perspective understandable by managers and decision-makers. To the fullest extent possible, presentation-quality graphics that summarize data and impacts will be prepared using a Geographic Information System (GIS). Discrete data will be prepared in a clear, concise form, and organized specifically for a particular purpose. These products will include a statement regarding the quality and reliability of the information. Radiation levels will be presented in commonly used units and/or in values relative to PAGs levels. Information transmitted by fax, Geographic Information System, or still video will be produced in an easily readable and concise format with sufficient information to properly present the required data. Whenever possible, the information will be tailored to meet the purposes of the intended users. The FRMAC's default products will be issued at least once per shift, while information tailored for the LFA and state(s) will be provided as requested.

The Environmental Systems Research Institute, Inc. (ESRI), ArcInfo or ArcView GIS is used as the primary mapping and spatial analysis tool. The GIS is a computerized database management system that provides for the capture, storage, retrieval, analysis, and display of spatial data. By having layers of information displayed on a computer screen and/or map, a person can see the relationship of one piece of information to another. The GIS is also a database in which attributes of a given piece of data can easily be referenced. For example, a specific measurement can be located on a map and information in the DCENT database about that measurement be extracted. The GIS can also calculate areas of interest. For example, a land-use data layer can be overlaid onto a PAG Zone plot to calculate the area of a given type of land that lies within a defined PAG zone.

The full set of pre-planned Assessment products and other supplementary products are described here. Earlier the utilization of Assessment products was discussed in terms of primary, standard and internal products (Using Assessment Products). Here, they are reviewed according to the type of information presented. The products of Assessment fall into four types of information:

- Interpretations – assessed and analyzed data interpreted in terms of published PAGs,
- Analyses:
 - Assessed data presented as dose, concentration, or exposure
 - Results of calculations (DCFs, DRLs, DILs, radionuclide mix....)
- Assessed Data – measurements or sample analyses whose quality is validated
- Reference Information – information drawn from published references or data bases

The primary products are the “**PAG Zone Maps**” and “**Monitoring/Sampling Status Maps.**” They stand at opposite ends of the Assessment process. The PAG Zone maps are the last step in the process and present interpretations of all the assessed data; the Monitoring/Sampling Status

maps, which summarize all the data available to Assessment (assessed and raw), represent the beginning. These maps will also reflect the status of evacuation, sheltering and agricultural embargo, plus demographics, if required. A number of other standard and internal Assessment products are created on the way to preparation of these primary Assessment products. Production, approval and release of the primary products are expedited to the fullest. Approval and release of the standard products follows with a lower priority.

Interpretations

Interpretations are the capstone of the Assessment process and are targeted for decision-makers and the public. They are the most visible and generally most valuable products of the Assessment Group. The interpretations are presented graphically as maps using a Geographical Information System (GIS). These "PAG Zone" maps indicate where particular PAGs are exceeded. The typical PAG Zone Map set will address:

- EPA Early Phase PAGs
- EPA Intermediate Phase PAGs
- FDA Ingestion PAG

In simple cases, this can all be presented as a single map but usually two (near-field and far-field) maps are used to maintain simplicity and assure readability. The PAG Zone Maps are among the first products issued by assessment and are revised and reissued twice per day. The maps are first prepared using predictive models. As data are acquired, dependence on the model diminishes. Eventually, the maps reflect only assessment of field monitoring and laboratory analyses. The PAG Zone Map may indicate that some regions are based primarily on data, while other regions are still based on modeling.

The value of these interpretations is their intuitive application to decision making. These maps are NOT protective action recommendations, but rather designations of where a protective action is technically justified. For example, a PAG Zone map could indicate areas in which relocation of the population is warranted or regions in which contamination may render crops unsuitable for consumption. Because these maps are so simple and intuitive, they can also be used to convey the extent of the accident and the significance of the consequence to the public.

Analyses

Analyses are products targeted to aid those involved with the technical analysis of the accident's consequence. They may either be maps or the results of calculations. These products are usually used only within the FRMAC and the state(s) and LFA dose assessment groups.

Common analyses presented as maps include:

- Plume projections (predictive or diagnostic)
- Exposure rate and/or contamination contours (decay corrected as needed)

- Dose projections (total or for a period of time or pathway of exposure)
- Dose rate estimates (total or specific pathway)

Calculational analyses typically include:

- Radionuclide Mix
- Derived Response Levels (DRLs)
- Dose Conversion Factors (DCFs)
- Dose ratios (usually TEDE/EDE)
- Dose reduction factors for mitigation measures

Plume Model Projections: Dispersion models can be used to predict the trajectory, various doses, deposition and concentration of airborne radiological materials. They can be generated for an actual or hypothetical release using current meteorological conditions, local topography and an estimated source term. These maps are generated by ARAC staff at LLNL and are sent to FRMAC Assessment personnel. Generally, these predictions are most beneficial during the first few hours or until the airborne release has terminated. Nevertheless, they also can be used as diagnostic tools, when renormalized to field measurements, to interpolate sparse measurements and extrapolate to levels too low to readily measure.

Exposure Rate and/or Contamination Contours: The FRMAC provides radiation contours showing where the contamination is located and the associated radiation levels. Initially, projections of radiation patterns from radiological dispersion models are likely to be the only radiation and contamination levels available. As environmental surveys are conducted, these contours will be refined to be consistent with data from actual measurements. It is anticipated that contamination contours will be updated every few hours to represent the latest information received in the FRMAC. The contours will be identified to show which information is based on monitoring data, interpolated data, or dose projections. The contour levels may be in exposure rates or isotopic concentrations as appropriate or requested.

Dose Projections: By application of suitable Dose Conversion Factors, maps or measurements of deposition, exposure rate or food sample analyses can be presented as specific doses. Contour levels will be selected to include DRLs, maximum levels, and a threshold level to convey the extent of contamination. For example, it may be appropriate to produce contours of the projected four-day, one-month, first-year, second-year, and fifty-year whole-body dose equivalent from external radiation for outdoor locations and/or for sheltered locations. A variety of assumptions about modifying factors may be included in these dose projections including, but not limited to, weathering, resuspension, structure shielding, and occupancy rates. The FRMAC dose projections will be as realistic as possible using reasonable assumptions and transfer values consistent with the uncertainties involved. Such assumptions will be documented or their sources referenced and included with the assessments.

Dose Rate Estimates: Planning and controlling activities such as monitoring/sampling and re-entry in a contaminated area require an understanding of the risks present. Therefore, contour maps of exposure rate (mR/h) and total dose rate (TEDE per time) can be prepared. The

exposure rate map will be routinely prepared, but the total dose rate map will be prepared only on demand. Assumptions and DCFs utilized will be cited.

Calculations: A number of calculations are performed and made available. The radionuclide mix is analyzed to determine both composition and spatial variability. Similarly, the deposition measurements and air samples are measured and analyzed to estimate the resuspension factor and its variability. The Derived Response Levels (DRLs) and Dose Conversion Factors (DCFs) are recomputed as data becomes available to eliminate assumptions or it is shown that assumptions are invalid. To facilitate worker protection, dose ratios for an easily monitored quantity are determined. Finally, the effectiveness of proposed or in-place mitigation measures can be evaluated and reported as analyses.

Assessed Data

Assessed data is comprised of the body of all measurements and laboratory analyses collected by or made available to FRMAC, whose quality has been validated and may also have had necessary corrections applied. It is primarily targeted to technical professionals, but it may be of interest to more than just those in the state(s) or LFA agencies. The data set is maintained in a comprehensive and traceable computer database and available as either reports in hard copy or digital data sets. Reports can be either detailed listings or summaries for data queries.

All of the environmental radiological data acquired by or furnished to the FRMAC will be stored in the FRMAC Data Center on the "DCENT" database. It will be comprehensive because it is intended to include every offsite environmental radiological data point. Every data point acquired by FRMAC will be traceable to an individual instrument, survey team, calibration, and procedure. A complete listing of all data attributes stored in the database is presented in the Data Dictionary (Appendix C). If data must be decay normalized or corrections applied to data from a particular instrument, then it will be performed in the database. No data is deleted. Upon identification as "bad," a faulty data point is flagged in the database and no longer used.

Every effort is made to make the data set as complete, accurate and traceable as possible. All organizations performing measurements or analyses are solicited for their data and QA information. Raw data is not released. Only data that has been checked and verified is made available as a FRMAC Assessment product for release outside FRMAC. A thorough "pedigree" is maintained on every measurement, so that any datum in question can be traced all the way to the field.

A number of pre-defined reports have been established and can be generated immediately upon demand. An example is a report listing the location of all measurements and samples by type, (e.g., radiation measurements, food, vegetation, soil, air, etc.). Many of these are produced about twice per shift. Other reports can be generated to answer specific inquiries, but must be defined and executed as a database query. For example, data can be condensed and summarized to show the radiation situation in specific areas or to correlate sample media from different types of surveys. These products will be generated on demand. Reports can be compiled by the following data categories:

- Media type
- Organization and/or survey team
- Location
- Time of measurement, sample collection, or analysis
- Level of results
- Specific instrument
- Laboratory performing the analysis

Reference Information

Two kinds of reference information are available:

- Publications from the FRMAC Assessment library - The Assessment team carries a library of technical and professional references for internal use. But information can be made available to the state or LFA, if requested. The contents of the FRMAC Assessment library are reviewed in Appendix K, "Reference Library Inventory."
- Demographic information from GIS – The GIS has a number of demographic references and has access to aerial/satellite imagery. Information available includes:
 - Emergency response data such as evacuation routes and locations of police and fire stations, hospitals and clinics, operations centers, shelters, and schools
 - Land-cover data such as forests, agricultural areas, housing areas, wetlands, industrial areas, and range lands

TIMELINE

Assessment products will begin to appear very early, because the Consequence Management Response Team (CMRT) now precedes the FRMAC. The CMRT consists of the NNSA scientist members of FRMAC, and it is maintained at a high state of readiness for very prompt deployment. FRMAC now evolves in three phases: CMRT Phase 1, CMRT Phase 2 and FRMAC. With this organization, FRMAC will have a presence early in Day 1 of the event through the CMRT. The CMRT utilizes the same organization, procedures and guidance as FRMAC.

The timeline for this response is illustrated in Figure 0.1. Formerly, until the full FRMAC arrived (24-36 hours), nothing was available, except through a RAP team. Now, a CMRT Phase 1 team, comprised of 15 first responders, including a data assessor and GIS specialist, will depart within four hours. This team is prepared with plume predictions (ARAC); it is ready to assess both the data available on-scene and data acquired by its five field teams. The plots will be interpreted in terms of PAGs, if indicated. Because Phase 1 is a one-shift skeleton team, Phase 2 will arrive the same day to relieve them. This will more than double the staffing and technical assets available. It is likely that CMRT will deal with the plume/early phase assessment issues.

The FRMAC will begin to develop during the first day as members of the Federal community are activated. As individuals arrive to staff the FRMAC, they will find the familiar FRMAC structure and functions in place, but at minimal staffing levels. Initially, due to limited resources, assessment products will be few and produced only as expressly directed. As the staff grows, the speed, variety, and detail of FRMAC Assessment products will rapidly improve. Once the FRMAC is staffed and operating efficiently, the highest Assessment priority is the prompt issue of the primary products, PAG Zone map and Monitoring/Sampling Status map with reissue at least once each shift. All other Assessment products will become available as well. It is anticipated that the FRMAC will deal with relocation, ingestion, and re-entry issues. As the situation becomes more stable and time critical decisions have been addressed, the FRMAC will begin a DQO process in preparation for recovery phase.

The FRMAC may be augmented by "Home Teams." This is a new concept still under development, but may be employed very soon. The function and lines of communications will be established at that time. Essentially, portions of the FRMAC functions may be performed at one or more "home" locations. This mode of operation permits more expertise to deal with the issues of the problem, while reducing the number of people deployed to the scene. Examples of expected home team functions include: modeling, off-hours product preparation, quality reviews, ingestion pathway analysis, DCF/DRL revision or DQO process development.

Once the situation is stable and all parties agree, management of the FRMAC will transition to EPA. At this point, implementation of a formal DQO process is expected. Moreover, dependence on the Assessment Manual will diminish as it is replaced by methods tailored to the specific incident, time and location.

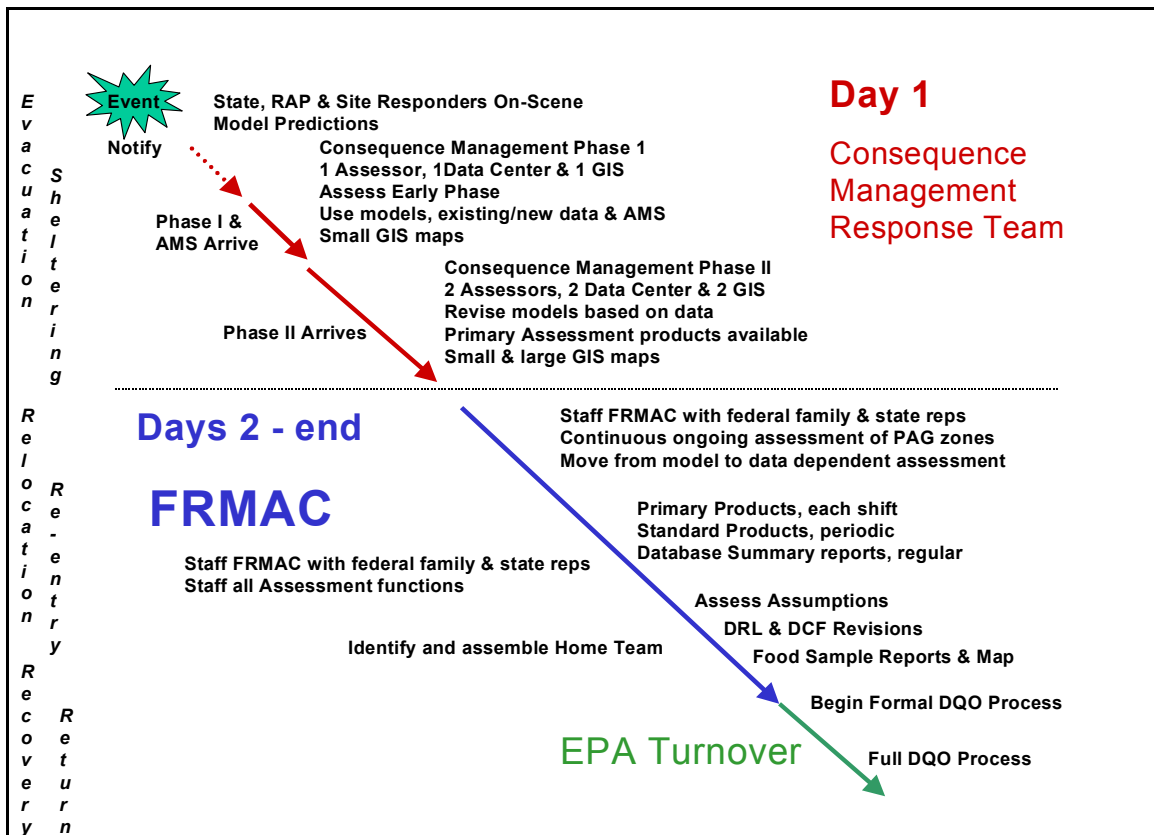


Figure 0.1. Timing of FRMAC Assessment Events

DEFINITION OF TERMS

Several terms and concepts are essential to understanding radiological assessments. Therefore, the key terms are introduced below:

RADIATION/RADIOACTIVITY MEASURES

Radiation and radioactivity are distinct concepts. Both are directly measurable, but not simply related to dose. Radiation is the transport of energy by photons, charged particles (alpha, beta, protons...), or neutrons. Its measure quantifies the amount of energy available for ionization or absorbed in a mass of material. Exposure is the most common type of field radiation measurement. Its unit of measure is the Roentgen (R). Radioactivity describes the amount of material producing radiation. Its measure quantifies the rate of nuclei undergoing decay by emitting radiation. The number of decays per second is defined as Curies (Ci) or Becquerels (Bq). The concentration of radioactivity is reported per unit area or mass.

Exposure Roentgen (R)

The Roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and x-rays, and only in air. One Roentgen is equal depositing to 2.58×10^{-4} coulombs per kg of dry air. It is a measure of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x-rays.

Absorbed Dose (RAD)

The RAD is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy that is actually absorbed in some material; it is used for any source of radiation and any material. One RAD is defined as the absorption of 100 ergs per gram of material. The unit RAD can be used for any of radiation, but it does not describe the biological effects of the different radiations. In SI units $100 \text{ RAD} = 1 \text{ Gray}$

Dose Equivalent (REM)

The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), the absorbed dose (RAD) is multiplied by a quality factor (Q) that is unique to the incident radiation.

In SI Units $100 \text{ REM} = 1 \text{ Sievert}$

Curie (Ci)

The curie is a unit used to measure a radioactivity. One curie is the amount of radioactivity in one gram of Radium, the element that was discovered by Madame Curie. It is also the quantity of a radioactive material that will have 37,000,000,000 transformations in one second. Often radioactivity is expressed in smaller units like: thousandths (mCi), one millionths (uCi), or even billionths (nCi) of a curie. The relationship between Becquerel and curie is $3.7 \times 10^{10} \text{ Bq}$ in one curie.

In SI units $1 \text{ Bequerel (Bq)} = 1 \text{ disintegration per second (dps)}$

COMMITTED EFFECTIVE DOSE EQUIVALENT

Committed effective dose equivalent (CEDE) means the sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor.

Committed Dose Equivalent

Committed dose equivalent (CDE) means the dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body.

Effective Dose Equivalent

Effective Dose Equivalent (EDE) is the sum of the products of the dose equivalent to the body organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Total Effective Dose Equivalent

Total Effective Dose Equivalent (TEDE) is the sum of the Committed Effective Dose Equivalent, CEDE, (for internal exposures) and the Effective Dose Equivalent, EDE, (for external exposures).

Protective Action Guide

The PAG is the projected dose to reference man, or other defined individual, from an accidental release of radioactive material at which a specific protective action to reduce or avoid that dose is warranted. The PAGs are then expressed in terms of measurable quantities called derived response levels (DRLs) or derived intervention levels (DILs), which may be exposure rate or the concentration of radioactivity (EPA92).

There are several distinct PAGs.

Evacuation and Sheltering

Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from the plume or from deposited radioactive materials. Evacuation may be a preemptive action taken in response to a facility condition rather than an actual release. Sheltering is the use of a structure for radiation protection from an airborne plume and/or deposited radioactive materials. Effectiveness diminishes with time due to infiltration. Evacuation and sheltering should be initiated at a projected TEDE of 1,000 mrem and 5,000 mrem for relatively immobile special groups. Other dose limits (CDE) apply to particular organs.

Early Phase

The Early Phase is the period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required. These decisions must be based primarily on predictions of radiological conditions in the environment. This phase may last from hours to

days. For the purpose of dose projection, it is assumed to last for four days. Evacuation should be initiated to avoid a TEDE of 1,000 mrem in the next 4 days.

Relocation

The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Relocation should be initiated to avoid a TEDE of 2,000 mrem in the first year.

Long-Term Objectives

The objectives are to conduct recovery actions designed to reduce radiation levels in the environment to permanently acceptable levels. This period may extend from months to years following the event. Relocation and mitigation measures should be considered to avoid a TEDE of 500 mrem during the second year or 5,000 mrem over 50 years (including the first and second years).

Ingestion PAG

The Food and Drug Administration (FDA) issued new ingestion guidance in August 1998, which defines the ingestion PAG as a committed effective dose equivalent (CEDE) of 500 mrem or a committed dose equivalent (CDE) to any specific organ of 5,000 mrem, whichever is more limiting. An ingestion DIL corresponds to the concentration of radioactivity in food, expressed as Becquerels/kilogram or picoCurie/kilogram, which could lead to an individual in the most sensitive population (e.g., a 1-year-old child) receiving a dose equal to the PAG if no intervention were taken for the year. It is important to note that food intake is for the entire diet, not for any one type of food, and includes drinking water. The ingestion DILs are applicable to foods as prepared for consumption.

Surrogates or “Markers”

Dose cannot be measured. The dose must be calculated from the contribution of every radionuclide present in the mix. Because this is very laborious, a single, simply measured quantity is substituted from which the mix can be inferred. This substitute is called a surrogate or marker. The surrogate may be exposure rate, gross activity, or the activity of a particularly easy to measure nuclide.

Derived Response Levels & Derived Intervention Levels

A Derived Response Level (DRL) is the quantity of a surrogate or radionuclide at which a particular PAG will be exceeded under selected assumptions. Numerous DRLs are required, each corresponding to a particular surrogate/nuclide, PAG, and set of assumptions. DRLs may require revision to reflect radioactive decay or elimination of assumptions. Derived Intervention

Levels (DILs) are identical, except that they have been computed by FDA and promulgated as guidance.

CAVEATS

- These methods are NOT prescriptive. If a method suggested by the Assessment Manual is inappropriate, use a different method even though it is not included in this manual.
- Default accident scenario cases are not necessarily worst possible cases, but may be “typical.”
- Complexity may greatly slow assessment. Complications include changes in site conditions (on-going/multiple releases, changing release pathway, spatial mix variation, weather changes).
- FRMAC conversion factors and decision levels may differ from locally determined values.
- FRMAC conversion factors may not be the newest or best available, but they are widely accepted.
- Expect large differences between assessments based on models versus data.
- Data Quality Objective process is abbreviated initially.
- SI units are not used, but final products may be issued in SI units, if required.

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SECTION 1. GENERAL METHODS

<u>Method</u>	<u>Title</u>	<u>Page</u>
Method M.1.0	Environmental Data Assessment for a Generic Accident	34

METHOD M.1.0 ENVIRONMENTAL DATA ASSESSMENT FOR A GENERIC ACCIDENT

Purpose: A flowchart of the basic (minimal) assessments and methods used for a generic accident are provided.

Discussion: In order to develop turn-back guidance for emergency workers or to perform the assessment of environmental data, the nuclide mix must be known or estimated. All the steps in the "Predeployment Planning" column of the flowchart should be performed before arrival at the accident location. This will ensure that the emergency workers are protected and allow immediate assessment of environmental data. Once the actual nuclide mix is known, the initial assessment should be confirmed.

Steps: Perform the steps in the flowchart on the following page in the order shown. Display results using Method M.6.3.

The Derived Response Levels (DRLs) for several specific accident types have been precalculated and are shown in Volume 3.

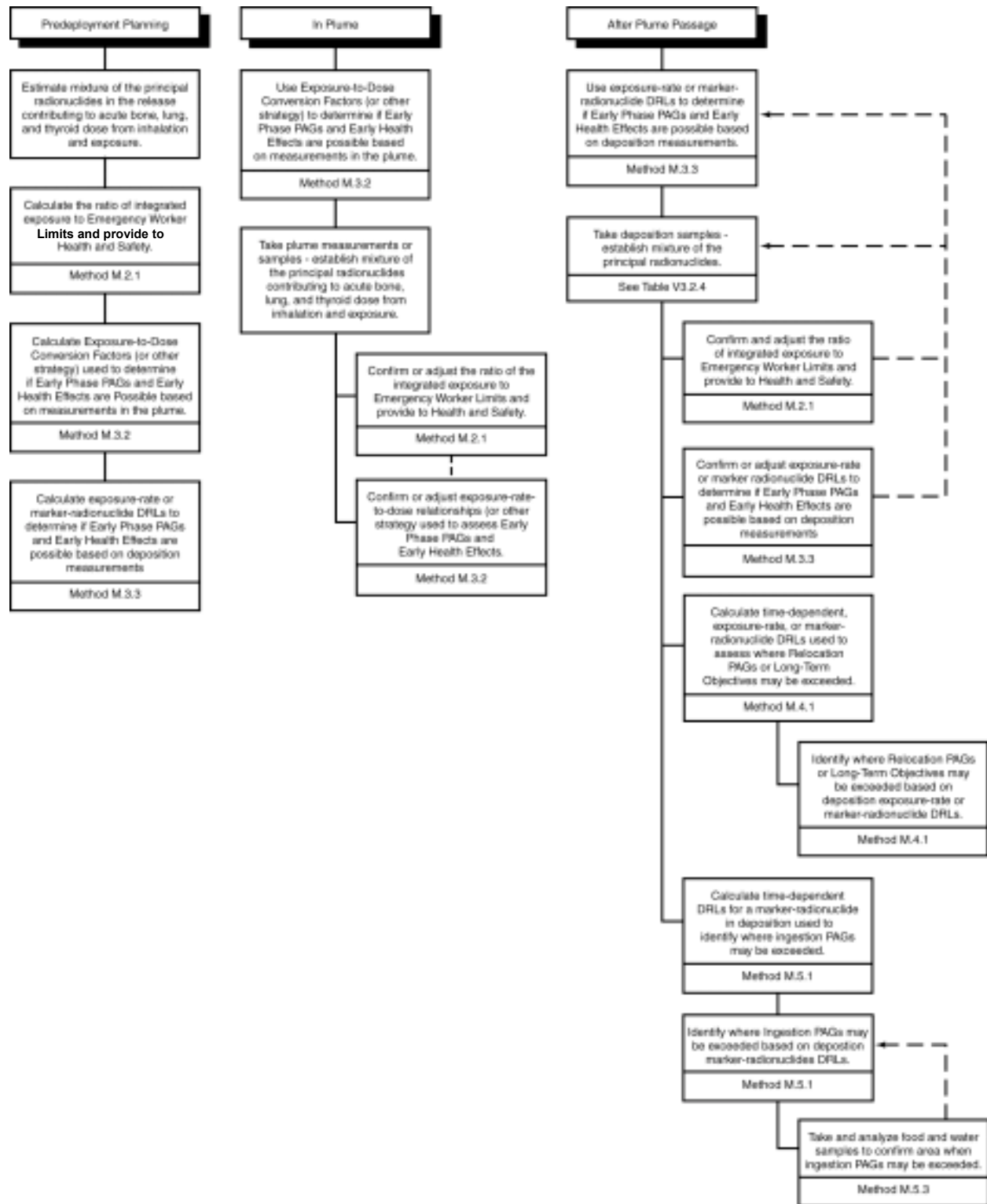


Figure 1.1. Generic Accident Environmental Data Assessment Flowchart

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SECTION 2. EMERGENCY WORKER EARLY PHASE ASSESSMENT

<u>Method</u>	<u>Title</u>	<u>Page</u>
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Method M.2.1	Integrated Exposure Emergency Worker Turn-Back Guidance Determination Based on Model Projections or Environmental Measurements	39

**METHOD M.2.0 GENERAL METHOD FOR ESTIMATING THE BASIS FOR
EMERGENCY WORKER TURN-BACK GUIDANCE**

Purpose: This method provides a means for developing emergency worker turn-back guidance based on direct-reading dosimeter readings. The results of this analysis will be used by Health and Safety in developing turn-back guidance for emergency workers. Turn-back guidance is the integrated exposure on a direct-reading dosimeter indicating that EPA emergency worker guidance may be exceeded. The methods consider the dose received from external exposure and inhalation. These methods are only useful if the release contains significant gamma emitters. If the available instrumentation will not detect the emergency worker turn-back Guidance, establish administrative “stay time limits” based on estimates of Committed Effective Dose Equivalent (CEDE) from inhalation ($H_{e,50}$).

Discussion: The EPA (EPA92) established dose limits for workers performing emergency services. All doses received during an emergency are included in the limit. Table 2.1 summarizes the EPA Emergency Worker Dose Guidance that is stated in terms of the projected TEDE. The TEDE includes the Effective Dose Equivalent (EDE) from external exposure (air and groundshine) and CEDE from inhalation (plume and resuspension). Guidance is also provided for eyes, skin, and other organs. The principles of maintaining doses as low as reasonable achievable (ALARA) should be employed to the extent possible in the context of providing emergency services.

The difficulty in assessing the dose delivered to emergency workers stems from the inability of direct-reading dosimeters to measure the dose contribution by inhalation. The inhalation dose to emergency workers may be estimated during the Early Phase (EPA94a). Once the Early Phase is over, the total dose incurred (during the Early Phase) must be confirmed before an emergency worker is allowed to perform activities that may result in an additional dose. Where possible, stay times should be based on instruments and calculated stay times, both. Stay time limits should be established for each worker and revised for each worker after his cumulative dose is measured, regardless of whether GM tubes, TLDs, etc are available.

Two methods are provided for calculating the integrated exposure on a direct-reading dosimeter that should be used for turn-back guidance:

- Method M.V3.2.1: Integrated Exposure Emergency Worker Turn-Back Guidance for Light-Water Reactor (LWR) Accidents. This method is used for LWR accidents involving core damage.
- Method M.2.1: Integrated Exposure Emergency Worker Turn-Back Guidance Determination Based on Model Projections or Environmental Measurements. This method is used for extended releases where release conditions and nuclide mix are expected to be nearly constant. It is also used for accidents where resuspension is significant.

METHOD M.2.1 INTEGRATED EXPOSURE EMERGENCY WORKER TURN-BACK GUIDANCE DETERMINATION BASED ON MODEL PROJECTIONS OR ENVIRONMENTAL MEASUREMENTS

Purpose: This method provides a means to establish emergency worker turn-back guidance based on direct-reading dosimeter readings. The results of this analysis will be used by Health and Safety in developing turn-back guidance for emergency workers. This method uses dose projections or environmental measurements.

Discussion: This method is based on establishing the relationship between external exposure, CEDE from inhalation, and TEDE. The relationship between integrated dose from external exposure and CEDE or TEDE is referred to as external Exposure-to-Dose Conversion Factors ($ECF_{ext, CEDE \text{ or } TEDE}$). This method does not calculate the turn-back guidance for specific organs (e.g., thyroid). In some cases, the organ dose may be controlling (see Table 2.1). If the organ dose is controlling, substitute the dose to the organ (CDE) from inhalation for the CEDE in this method.

Steps: The steps performed in this method are summarized in the box below. Turn-back guidance may also be calculated using an appropriate computer model (e.g., RASCAL).

- Step 1 Estimate external Exposure-to-Dose Conversion Factors for CEDE from inhalation
- Step 2 Estimate the external Exposure-to-Dose Conversion Factors for TEDE
- Step 3 Calculate turn-back guidance

Step 1 Estimate external Exposure-to-Dose Conversion Factors for CEDE from inhalation.

Calculate the external Exposure-to-Dose Conversion Factors for inhalation CEDE ($ECF_{ext, CEDE}$) based on one of these methods.

Step 1, Option A – Model Dose Projections. If dose projections are available, obtain projections of Effective Dose Equivalent (EDE) from external exposure (e.g., cloud shine) (I) and CEDE ($H_{e,50}$) for a one-hour release in the center of the plume. In this method, the assumption is made that exposure and EDE from external exposure are equal. Estimate the Exposure-to-Dose Conversion Factors for CEDE from inhalation ($ECF_{ext, CEDE}$) as follows:

$$\frac{H_{e,50}}{I} = ECF_{ext, CEDE}$$

$$\left(\frac{mrem}{mR} \right) = \left(\frac{mrem}{mR} \right)$$

Where

- I (mR) = External exposure for one hour in the plume (model projections or field measurements)
- $H_{e,50}$ (mrem) = CEDE from one hour of inhalation in the plume (model projections or Method M.3.2)

Step 1, Option B – Environmental Samples and Measurements. This method is used for extended releases where release conditions and nuclide mix are expected to be constant. It is also useful for accidents where resuspension is critical. Estimate the external Exposure-to-Dose Conversion Factors from inhalation ($ECF_{ext, CEDE}$) based on field measurements of air concentration and exposure rates. Samples should be taken and measurements made, and the ratio continually updated.

Step 1.B.1. Estimate the external exposure (I, mR) for one hour in the plume at the location and time that the air samples are taken.

Step 1.B.2. Using Method M.3.2 (Step 1.2, Option B), calculate the CEDE ($H_{e,50}$, mrem) from inhalation for one hour based on the airborne samples.

- If respiratory protection is provided, reduce the CEDE by the estimated efficiency of the protection. Assume 50 percent reduction if the efficiency is unknown.
- If potassium iodide is administered prior to exposure (within 12 hours) reduce the thyroid CDE and CEDE from iodine inhalation by 90 percent, assuming therapeutic dosage is maintained throughout the exposure period.

Step 1.B.3. Calculate the $ECF_{ext, CEDE}$ as follows:

$$\frac{H_{e,50}}{I} = ECF_{ext, CEDE}$$

$$\left(\frac{mrem}{mR} \right) = \left(\frac{mrem}{mR} \right)$$

Where

- I (mR) = External exposure from one hour in the plume (model projections or field measurements)
- $H_{e,50}$ (mrem) = CEDE from one hour of inhalation in the plume (model projections or Method M.3.2)

Step 2. Estimate the external Exposure-to-Dose Conversion Factors for TEDE.

Calculate the Exposure-to-Dose Conversion Factor for TEDE ($ECF_{ext, TEDE}$) by adding the dose conversion factor (unity) from external exposure for one hour as follows:

$$ECF_{ext, CEDE} + 1 = ECF_{ext, TEDE}$$

Step 3. Calculate turn-back guidance.

Using Worksheet 2.1, develop emergency worker turn-back guidance applicable to direct-reading dosimeters.

Step 3.1. Record in Column B of Worksheet 2.1 the TEDE Exposure-to-Dose Conversion Factors calculated in Step 2.

Step 3.2. Divide Column A by Column B and record the answer in Column C. This is the emergency worker turn-back guidance for their direct-reading dosimeters.

If the available instrumentation will not detect the emergency worker turn-back guidance, administrative “stay time limits” shall be established by Health and Safety Personnel based on estimates for CEDE ($H_{e,50}$) from inhalation.

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SECTION 3. PUBLIC ASSESSMENT - EARLY PHASE

<u>Method</u>	<u>Title</u>	<u>Page</u>
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**METHOD M.3.0 GENERAL METHOD FOR DEVELOPING EARLY PHASE
DERIVED RESPONSE LEVELS (DRLS) AND FOR PROJECTING
DOSES**

Purpose: This method provides means for developing DRLs and projecting doses to relate values measured in the field to EPA Early Phase PAGs (EPA92) and their potential for early health effects.

Discussion: The Early Phase of an accident extends from the identification of a release threat until the release (or threat of release) has ended and areas of major contamination have been identified. The Early Phase usually includes the exposure from four days (96 hours) of exposure to deposition. During the Early Phase of an emergency, there is an urgent need to take protective actions (EPA92) to accomplish the following objectives:

1. **Prevent early health effects** (deaths and injuries) by keeping the short-term external exposure below 50 rem, and by keeping the early inhalation dose below the early health effects thresholds for the thyroid, lung, and bone marrow.
2. **Reduce the risk of delayed health effects** (primarily cancer and genetic effects) by implementing protective actions according to the EPA Early Phase PAGs

Table 3.1 lists the dose thresholds where early health effects will be seen for the organs considered critical for most radiological accidents. External dose, total early bone dose (TEBD), and total early lung dose (TELD) are used for comparison with early health effects thresholds.

Table 3.2 summarizes the Early Phase PAGs. The EPA Early Phase PAGs indicate when immediate protective actions are warranted. These PAGs are expressed in terms of the projected TEDE and thyroid and skin dose. Any dose incurred before the assessment is not considered. This differs from the assessment of early health effects where the goal is to keep the total early dose below a threshold. The EPA PAG for evacuation is 1,000 mrem to 5,000 mrem TEDE. The upper limit (5,000 mrem) applies only for conditions that increase the risk of evacuation. Therefore, in most conditions, evacuation is recommended at the 1,000-mrem projected dose. TEDE includes the Effective Dose Equivalent (EDE) from cloud passage, four days of EDE from ground shine, and the inhalation Committed Effective Dose Equivalent (CEDE) from exposure to the plume and four days of resuspension.

The important dose pathways during the Early Phase are direct exposure from the passing plume and deposition and inhalation from the plume and resuspension. For LWR accidents, direct exposure from the cloud and deposition and early inhalation dose to the thyroid and bone marrow are very important in terms of early health effects. For accidents involving transuranics, lung dose from the passing cloud will be most important for early health effects. For LWR accidents, under most conditions the thyroid dose from inhalation will be the most critical for the EPA Early Phase PAGs.

Atmospheric transport is very complex and concentrations may change rapidly. There may be no definable center or direction of travel for the plume.

In this method:

- External dose from deposition is based on the dose factors in Federal Guidance Report No. 12 (EPA93) and includes daughters where noted (e.g., ^{137}Cs and $^{137\text{m}}\text{Ba}$). The external dose has been corrected only for ground roughness. No other dose modifying factors have been considered. Apply Method M.3.6 “Dose Reduction Due to Sheltering,” if appropriate. These dose factors are based on ICRP30 methodology and are consistent with title 10 CFR 20.
- Inhalation dose includes progeny, is for an adult performing light activity, and is for the lung solubility class resulting in the highest dose. The CEDE and thyroid CDE inhalation dose factors are from Federal Guidance Report No. 11 (EPA88). These dose factors are based on ICRP30 and are consistent with title 10 CFR 20. The Early Dose Factors are for 30 days after inhalation and are from Ec01.
- The effects of weathering are not considered due to the short period of concern, except where specifically noted.
- Doses are typically calculated for plume passage (external exposure and inhalation) and from deposition (external and resuspension) for four days.

Steps: Gather and evaluate environmental data to locate where early health effects or Early Phase PAGs may be exceeded using the methods in Table 3.0 below.

Table V1.3.1. Early Phase Prioritized Tasks

Purpose: This table lists the Early Phase prioritized assessment tasks and the necessary information to complete the task and indicates which Section 3 method to use. The crucial tasks are listed first followed by the support tasks.

Crucial Tasks	Necessary Information	Method
During a release involving radioiodine, determine if thresholds for early health effects or Early Phase PAGs may be exceeded.	Maximum exposure rate (mR/hr) in the plume at 1 m above ground level (AGL).	M.3.1 Evaluating a Release Containing Iodine
During a release, determine if early health effects thresholds or Early Phase PAGs may be exceeded.	Nuclide mix (relative abundance) based on <i>in situ</i> measurements, references, or information provided by the operator. <i>and</i> Maximum exposure rate (mR/hr) in the plume at 1 m AGL. <i>and/or</i> Airborne and deposition concentrations and levels.	M.3.2 Evaluating Plume Exposure Rates, Air Concentrations, or Deposition Levels
After plume passage, evaluate deposition and develop DRLs to determine if Early Phase PAGs may be exceeded.	Nuclide mix (relative abundance) based on <i>in situ</i> measurements, references, or information provided by the operator. <i>and</i> <u>Based on Accident Type, Choose A or B:</u> A. Accidents where exposure-rate measurements identify the area of concern. Maximum exposure rate (mR/hr) in the plume or at 1 m AGL. <i>or</i> B. Accidents where resuspension is a concern and exposure rates are insufficient to identify the area of concern. • Deposition of a gamma-emitting marker radionuclide easily identified in the field or lab. <i>or</i> • When no gamma emitter is detectable, comprehensive isotopic analysis of deposition.	M.3.3 Evaluating Deposition
Recalculate or confirm resuspension factors based on actual data to adjust DRLs or dose.	Resuspension air concentrations relative to deposition ($\mu\text{Ci}/\text{m}^3$)/($\mu\text{Ci}/\text{m}^2$).	M.3.8 Resuspension Factors Based on Samples

Table V1.3.1. Early Phase Prioritized Tasks (Continued)

Support Tasks	Necessary Information	Method
Estimate or confirm release rates for input into model calculations, or characterize an unmonitored release.	Airborne concentrations	M.3.9 Release Rates Based on Airborne Concentrations
Estimate release mixture or doses before field measurements are available.		No specific method – use available information as input to an appropriate model (SHARC, ARAC, etc.)
Estimate future dose rates to the public or emergency workers remaining on deposition.	Maximum exposure rate (mR/hr) at 1 m AGL	M.3.7 Future Exposure (or Dose) Rates from Deposition
Consider radionuclides not contained in Table 3.4 or consider different resuspension factors.	Comprehensive isotopic analysis of deposition Resuspension air concentrations relative to deposition ($\mu\text{Ci}/\text{m}^3$)/($\mu\text{Ci}/\text{m}^2$).	M.3.4 Deposition Dose Conversion Factors
Estimate dose reduction due to shielding from the plume and deposition.	Maximum exposure rate (mR/hr) in the plume or at 1 m AGL.	M.3.6 Dose Reduction Due to Sheltering
Consider radionuclides not contained in Table 3.3 or Table 3.4 or consider different assumptions.		M.3.10 Air Submersion, Ground Shine, Inhalation Dose Conversion Factors, and Exposure Conversion Factors

METHOD M.3.1 EVALUATING A RELEASE CONTAINING IODINE

Purpose: This method is used for LWR accidents (or other scenarios in which iodine could be released) to identify areas in which early health effects are possible and to determine whether Early Phase PAGs might be exceeded based on exposure rates in a plume.

Discussion: During a release, the dose from the plume must be estimated promptly from environmental measurements or model predictions if it is used to determine protective actions for the public. The problem is estimating the dose from inhalation. The timeliest way to project inhalation dose is to base those estimates on the exposure rate in the plume using exposure-to-inhalation dose conversion factors that correlate exposure rates to inhalation dose. This method uses Exposure-to-Dose Conversion Factors from Method M.2.1 or Table V3.2.5. The factors from Table V3.2.5 are very crude, and model projections or analyses of environmental samples should be used with Method 2.1 to calculate the factors as soon as possible.

Steps: The steps performed in this method are summarized in the box below.

Step 1 Estimate thyroid dose and TEDE

Step 2 Assess the consequences

Step 1. Estimate thyroid dose and TEDE as shown below.**Thyroid Dose**

$$T_{ed} \times I \times ECF_{ext,thy} = D_{T(thyroid)}$$

$$(\text{ hr}) \times (\text{ mR/hr}) \times (\text{ mrem/mR}) = (\text{ mrem})$$

TEDE

$$T_{ed} \times [I + (I \times ECF_{ext,CEDE})] = TEDE$$

$$(\text{ hr}) \times [\text{ mR}^* / \text{ hr} + (\text{ mR/hr} \times \text{ mrem/mR})] = (\text{ mrem})$$

Where

$ECF_{ext, CEDE}$ (mrem/mR) = CEDE Exposure-to-Dose Conversion Factor. Use for LWR accidents from Method M.2.1 or Table V3.2.5

$ECF_{ext, thy}$ (mrem/mR) = thyroid Exposure-to-Dose Conversion Factor. Use for LWR accidents from Method M.2.1 or Table V3.2.5

$D_{T(thyroid)}$ (mrem) = thyroid CDE from inhalation

* note exposure rate (mR/hr) \cong EDE (mrem/hr)

$TEDE$ (mrem) = Total Effective Dose Equivalent including external dose (EDE) and CEDE from inhalation

I (mR/hr) = highest exposure rate in the plume

T_{ed} (hr) = exposure duration of release or typical wind persistence (e.g., four hours), whichever is shorter

Step 2. Assess the consequences.

Step 2.1. If the TEDE is greater than the bone marrow early health effects threshold (50 rad) in Table 3.1, inform management that early health effects are possible. This may be very conservative if inhalation dose is a major portion of the dose because Committed Effective Dose Equivalent (CEDE) is for a 50-year commitment. Use Method M.3.2, if possible, to confirm that early health effects are possible.

Step 2.2. If the projected thyroid dose is greater than the State's thyroid PAG (EPA Thyroid PAG is 5,000 mrem) or the TEDE is greater than the State's TEDE PAG (EPA TEDE PAG is 1,000 mrem), then the Early Phase PAGs may be exceeded (See Table 3.2 for EPA PAGs).

Step 2.3. Use Method M.3.5 to estimate the downwind distances from the plume in which early health effects thresholds and PAGs may be exceeded.

METHOD M.3.2 EVALUATING PLUME EXPOSURE RATES, AIR CONCENTRATIONS, OR DEPOSITION LEVELS

Purpose: This method is used to project dose during a release in order to make estimates in the following situations:

- Where the Early Phase PAG may be exceeded by projecting external exposure, TEDE, and thyroid CDE from inhalation ($D_{T(\text{thyroid}),50}$)
- Where early health effects are possible by projecting total early organ dose ($TEOD_{\text{Organ}}$) for the gastrointestinal tract as indicated by the small intestine (GI), red bone marrow (RBM), thyroid, and lung

Discussion: Once the plume has passed, Method 3.3 should be used to develop Derived Response Levels (DRLs) to promptly assess environmental data. The problem in projecting doses from measurements in the plume is the difficulty in estimating the inhalation dose in time to be usable in making protective action decisions. The timeliest way to project inhalation dose is to base the estimates on exposure rates using Exposure-to-Dose Conversion Factors (ECFs). These factors can be calculated in advance as discussed in Step 1.2, Option A based on model projections or air concentrations and exposure rates.

Steps: The steps performed in this method are summarized in the box below.

Step 1	Calculate air submersion, inhalation, and ground shine components of $TEOD_{\text{Organ}}$, thyroid CDE, and TEDE.
	Step 1.1 External air and ground shine dose based on exposure rates.
	and
	Step 1.2 Inhalation dose in the plume using one of the following options:
	Step 1.2, Option A Inhalation dose using external Exposure-to-Dose Conversion Factors for LWR and other accidents, based on model projections or air concentrations and exposure rates.
	or
	Step 1.2, Option B Inhalation dose based on air concentrations.
	and
	Step 1.3 Inhalation dose from resuspension (out of plume) (not important for LWR accidents) based on deposition levels.
Step 2	Add components to estimate $TEOD_{\text{Organ}}$ and TEDE.
Step 3	Assess the consequences.

Step 1. Calculate air submersion, inhalation, and ground shine components of TEOD_{Organ}, and TEDE.

Using Worksheet 3.1 as a guide, calculate the dose contributions from external air submersion (H_a), ground shine (H_g), and inhalation dose from plume and resuspension ($D_{T(GI),E}$, $D_{T(RBM),E}$, $D_{T(thyroid),E}$, $D_{T(lung),E}$, $H_{e,50}$, and $D_{T(thyroid),50}$) using the methods presented below.

Step 1.1. External Air and Ground Shine Dose Based on Exposure Rates. At any point in the plume, the exposure rate may be described as having a component that is due to material already deposited on the ground, and a component that is due to the radioactive material still in the air. For simplicity, it is assumed that external exposure (mR) is numerically approximately equal to both the Effective Dose Equivalent (EDE) (mrem) and the absorbed dose (mrad) from external exposure. Calculate the combined EDE from submersion in the passing cloud (H_a) and from the ground shine (H_g) based on an exposure rate measured at 1 m AGL as follows:

$$I \times T_{ed} = H_a + H_g$$

$$\left(\quad mR / hr \right) \times \left(\quad hr \right) = \left(\quad mrem \right)$$

Where

$$I \text{ (mR/hr)} = \text{average exposure rate in the plume}$$

$$T_{ed} \text{ (hr)} = \text{exposure duration (expected duration or four hours)}$$

$$H_a \text{ (mrem)} = \text{EDE from air (plume) submersion}$$

$$H_g \text{ (mrem)} = \text{EDE from deposition (ground shine)}$$

Step 1.2. Calculate Inhalation Dose. Two methods are provided to estimate inhalation dose. The first method (Step 1.2, Option A) is preferred because it allows exposure rates to be used directly to estimate inhalation dose. With the second method, Step 1.2, Option B, the estimates are based on environmental measurements.

Step 1.2, Option A. Inhalation Dose Based on Exposure-to-Dose Conversion Factors for LWR and Other Accidents. This method allows prompt assessment of the potential inhalation doses based on exposure rates in the plume. For LWR accidents, the conversion factors are valid for accidents involving core damage and an unfiltered release. For other accidents, model projections or analyses of environmental samples are used. Once the conversion factors are calculated, they are used to estimate inhalation dose directly from exposure rates.

Calculate the thyroid Committed Dose Equivalent (CDE) ($D_{T(thyroid),50}$) and Committed Effective Dose Equivalent (CEDE) ($H_{e,50}$) from inhalation of contaminated air using the external Exposure-to-Dose Conversion Factors ($ECF_{ext, thy}$ or $ECF_{ext, CEDE}$) listed below.

$$I \times ECF_{ext, thy} \times T_{ed} = D_{T(thyroid),50}$$

$$I \times ECF_{ext, CEDE} \times T_{ed} = H_{e,50}$$

$$\left(\frac{mR}{hr} \right) \times \left(\frac{mrem}{mR} \right) \times (\quad hr) = (\quad mrem)$$

Where

I (mR/hr) = average exposure rate in the plume

$ECF_{ext, thy}$ (mrem/mR) = Thyroid Exposure-to-Dose Conversion Factor. Use projections or environmental samples to calculate using Method M.2.1

T_{ed} (hr) = exposure duration (expected duration or four hours)

$D_{T(thyroid),50}$ (mrem) = Thyroid CDE from inhalation

$ECF_{ext, CEDE}$ (mrem/mR) = CEDE Exposure-to-Dose Conversion Factor. Use projections or the environmental samples to estimate using Method M.2.1

$H_{e,50}$ (mrem) = CEDE from inhalation

Step 1.2, Option B. Inhalation Dose Based on Air Concentrations. This calculation can be performed using RASCAL (NRC94), ARAC (Su93), or another appropriate model. Calculate the CEDE ($H_{e,50}$), CDE for the thyroid ($D_{T(thyroid),50}$) and organ doses ($D_{T(Organ),E}$, for early bone marrow, early lung, early small intestine, and early thyroid) from inhalation of contaminated air. For reactor accidents, lung dose is not critical. For simplicity, the Dose Conversion Factors (DCFs) are provided in terms of air concentration by assuming a breathing rate of an adult performing light activity (1.2 m³/hr) as recommended by the EPA (EPA88). Note that while the units shown below are mrem, all early doses (and DCFs) are in mrad.

$$\sum_i^n (\chi_i \times DCF_{e,50i}) \times T_{ed} = H_{e,50}$$

$$\sum_i^n (\chi_i \times DCF_{T(thyroid),50,i}) \times T_{ed} = D_{T(thyroid),50}$$

$$\sum_i^n (\chi_i \times DCF_{T(Organ),E,i}) \times T_{ed} = D_{T(Organ),E}$$

$$\sum \left[\left(\frac{\mu Ci}{m^3} \right) \times \left(\frac{mrem/hr}{\mu Ci/m^3} \right) \right] \times (\quad hr) = (\quad mrem)$$

Where

χ_i = air concentration of nuclide i

$DCF_{T(organ),50,i} [(mrem/hr)/(\mu Ci/m^3)]$ = adult organ (in this case, thyroid) CDE inhalation DCF for radionuclide i from Table 3.3, or Method M.3.10

$DCF_{T(organ),E,i} [(mrad/hr)/(\mu Ci/m^3)]$ = adult organ (early bone marrow, early small intestine, early lung, or early thyroid) inhalation DCF for radionuclide i from Table 3.3, or Method M.3.10

$T_{ed} (hr)$ = exposure duration (expected duration or four hours)

$D_{T(organ),(E\ or\ 50)} (mrad\ or\ mrem)$ = organ (early bone marrow, early small intestine, early lung, early thyroid, or CDE thyroid) dose from inhalation

$DCF_{e,50i} [(mrem/hr)/(\mu Ci/m^3)]$ = adult CEDE inhalation DCF from Table 3.3 or Method M.3.10

$H_{e,50} (mrem)$ = CEDE from inhalation

Step 1.3. Inhalation Dose from Resuspension Based on Deposition Levels. This calculation can be performed using ARAC (Su93), RASCAL (NRC94), HOTSPOT (Ho94), or another appropriate model. It is used for accidents where inhalation dose from resuspension may be critical. Resuspension is not critical for reactor accidents. Deposition levels are used because they are easier to determine than air concentrations for a large area. This assessment can be performed using an initial resuspension factor (R_s) of $1 \times 10^{-6} m^{-1}$. If resuspension may be critical, the resuspension factor should be confirmed based on samples using Method M.3.8.

Calculate the organ dose (early bone marrow, early small intestine, early lung, early thyroid, or CDE thyroid) and CEDE ($H_{e,50}$) as follows (noting that while the units shown below are mrem, all early doses and DCFs are in mrad):

$$\sum_i^n (C_{gi} \times R_s \times DCF_{T(organ),E,i}) \times T_{ed} = D_{T(organ),E}$$

$$\sum_i^n (C_{gi} \times R_s \times DCF_{T(thyroid),50,i}) \times T_{ed} = D_{T(thyroid),50}$$

$$\sum_i^n (C_{gi} \times R_s \times DCF_{e,50i}) \times T_{ed} = H_{e,50}$$

$$\sum \left[\left(\mu Ci / m^2 \right) \times \left(m^{-1} \right) \times \left(\frac{mrem / hr}{\mu Ci / m^3} \right) \right] \times (hrs) = (mrem)$$

Where

$C_{gi} (\mu Ci/m^2)$ = Deposition level of radionuclide i

$R_s (m^{-1})$ = Resuspension factor. Use 1×10^{-6} , or Method M.3.8

$DCF_{T(organ),50,i} [(mrem/hr)/(\mu Ci/m^3)]$ = adult organ (CDE thyroid) inhalation Dose Conversion Factor for radionuclide i from Table 3.3, or Method M.3.10

$DCF_{T(organ),E,i} [(mrad/hr)/(\mu Ci/m^3)]$ = adult organ (early red bone marrow, early small intestine, early lung, or early thyroid) inhalation Dose Conversion Factor for radionuclide i from Table 3.3, or Method M.3.10

$T_{ed} (hr)$ = Exposure duration (expected duration or four hours)

$D_{T(organ),E \text{ or } 50} (mrad \text{ or } mrem)$ = organ (early red bone marrow, early small intestine, early lung, early thyroid, or CDE thyroid) dose from inhalation

$DCF_{e,50i} [(mrem/hr)/(\mu Ci/m^3)]$ = adult CEDE inhalation Dose Conversion Factor for radionuclide i from Table 3.3 or Method M.3.10

$H_{e,50} (mrem)$ = CEDE from inhalation

Step 2. Add components to estimate TEOD and TEDE.

Calculate the $TEOD_{Organ}$ (early bone marrow, early small intestine, early lung, or early thyroid) and TEDE as shown below. Be sure the inhalation dose includes the dose from the cloud and from resuspension if both are major contributors to dose. The calculations for TEOD assume that EDE from external exposure is approximately numerically equal to absorbed dose from external exposure.

Total Early Organ Dose ($TEOD_{Organ}$, for early red bone marrow, early small intestine, early lung, or early thyroid):

$$H_a + H_g + D_{T(organ),E} = TEOD_{Organ}$$

$$(\quad mrem) + (\quad mrem) + (\quad mrad) = (\quad mrad)$$

Total Effective Dose Equivalent (TEDE):

$$H_a + H_g + H_{e,50} = TEDE$$

$$(\quad mrem) + (\quad mrem) + (\quad mrem) = (\quad mrem)$$

Step 3. Assess the consequences.

- If the $TEOD_{Organ}$ for any organ is greater than the associated early health effects threshold in Table 3.1, inform management immediately that the early health effects cited are possible.
- If the projected CDE thyroid dose is greater than the State's thyroid PAG (EPA thyroid PAG is 5,000 mrem) or TEDE is greater than the state TEDE PAG (EPA TEDE PAG is 1,000 mrem), the Early Phase PAGs may be exceeded (See Table 3.2 for EPA PAGs).
- If the calculations indicate that the PAGs or early health effects threshold may be exceeded at a greater distance, use Method M.3.5 to estimate the distance of concern.

METHOD M.3.3 EVALUATE DEPOSITION

Purpose: This method is for use after plume passage to promptly assess deposition to identify where Early Phase PAGs may be exceeded.

Two different derived response levels (DRL_{EPg}) can be calculated:

- DRL_{EPg} based on exposure rates (mR/hr)—used when exposure rates from the deposition are high enough to identify where the Early Phase PAGs may be exceeded.
- DRL_{EPgj} based on marker-radionuclide level ($\mu Ci/m^2$)—used if the exposure rate is not high enough to identify the area of concern.

Discussion: Over time the mixture of deposition may change temporally (decay, ingrowth, and weathering) and spatially. However, due to the short period of concern in the Early Phase (4 days), the temporal variations in samples can be ignored. Representative samples of the deposition mixture for various areas can be used as the basis for the Early Phase DRL.

Steps: The steps performed in this method are summarized in the box below.

Method M.3.3.A	Evaluating Deposition when Resuspension is not a Concern
Step 1	Determine the external exposure-rate DRL.
Step 2	Use external exposure-rate DRLs to assess environmental data.
Method M.3.3.B	Evaluating Deposition when Resuspension is a Concern
Steps 1 and 2	Calculate the exposure-rate DRL that considers resuspension.
Step 3	Use exposure-rate DRLs to assess deposition data.
Method M.3.3.C	Evaluating Deposition when Resuspension is a Concern and Exposure Rates Cannot Identify the Area of Concern
Step 1	Calculate the deposition DRL for a marker radionuclide with a discernable gamma emitter.
Step 2	Use marker-radionuclide DRLs to assess environmental data.

Method M.3.3.A. Evaluating Deposition when Resuspension is not a Concern

For deposition containing transuranics, thorium, or other radionuclides where inhalation dose from resuspension is critical, go to Method 3.3.B.

Step A.1. Determine the external exposure-rate DRL.

Before the isotopic concentration is known, determine if external exposure alone is a concern. Calculate the exposure-rate DRL (DRL_{EPg} , mR/hr) from deposition, over a 96-hour period, that results in a dose that exceeds the State’s Early Phase PAGs (P_{EP}). For simplicity, the external

exposure rate (mR/hr) is used interchangeably with the absorbed dose rate (mrad/hr) and the effective dose equivalent (EDE) rate (mrem/hr).

For the early health effects thresholds of 50 rad in 4 days (96 hours) (see Table 3.1)

$$DRL_{EPg} \cong 500 \text{ mR} / \text{hr}$$

For the EPA Early Phase PAG of 1,000 mrem in 96 hours (see Table 3.2)

$$DRL_{EPg} \cong 10 \text{ mR} / \text{hr}$$

For other Early Phase PAGs, calculate the exposure-rate DRL by

$$\frac{P_{EP}}{96 \text{ hr}} = DRL_{EPg}$$

$$\left(\frac{\text{mrem}}{96 \text{ hr}} \right) = (\quad \text{mR} / \text{hr})$$

Where

P_{EP} (mrem)	=	State Early Phase PAG
DRL_{EPg} (mR/hr)	=	Exposure rate that indicates that the Early Phase PAG will be exceeded from exposure only in 4 days.

Step A.2. Use external exposure-rate DRLs to assess environmental data.

Conduct environmental monitoring to identify where the exposure rates from deposition at 1 m AGL are greater than the DRLs calculated in Step 1.

Method M.3.3.B. Evaluating Deposition when Resuspension is a Concern

Perform the following steps only for accidents where resuspension may be a concern. Resuspension is not a concern for reactor accidents.

Step B.1. Identify the major contributors to dose.

Based on an analysis of the deposition or estimates of the nuclide mix, identify the major contributors to dose from external exposure and inhalation from resuspension. The nuclide mix, concentration, or level (only for deposition) can be shown in any units because only the relative amount is important. Table V3.2.6 lists the nuclide ratios of major contributors to dose for LWR accidents. Table V3.3.4 lists nuclear content for typical weapons-grade plutonium.

Step B.2. Calculate the exposure-rate DRL that considers resuspension.

Using Worksheet 3.2, calculate the exposure-rate DRL that will indicate that the Early Phase PAG may be exceeded from deposition considering external exposure and resuspension by performing Steps B.2.1 through B.2.6 (see below for the derivation).

$$DRL_{EPg} = P_{EP} \times \frac{\sum_i^n (C_{gi} \times ECF_{gi})}{\sum_i^n (C_{gi} \times DCF_{EPgi})}$$

$$(mR/hr) = (mrem) \times \frac{\sum \left[(\mu Ci/m^2) \times \left(\frac{mR/hr}{\mu Ci/m^2} \right) \right]}{\sum \left[(\mu Ci/m^2) \times \left(\frac{mrem}{\mu Ci/m^2} \right) \right]}$$

Where

$DRL_{EPg} (mR/hr)$ = Exposure rate indicating that the Early Phase PAGs may be exceeded.

$P_{EP} (mrem)$ = State Early Phase PAG or EPA PAG of 1,000 mrem (Table 3.2).

$C_{gi} (\mu Ci/m^2)$ = Deposition level of radionuclide i .

$ECF_{gi} [(mR/hr)/(\mu Ci/m^2)]$ = Exposure conversion factor for deposition of radionuclide i from Table 3.4. or Method M.3.10.

$DCF_{EPgi} [(mrem)/(\mu Ci/m^2)]$ = Early Phase Deposition Dose Conversion Factor (external exposure and resuspension) for remaining on deposition of radionuclide i for 96 hours from Table 3.5 or Method M.3.4

Step B.2.1. Record the deposition levels (C_{gi} , $\mu Ci/m^2$) of the principal radionuclides in Column A of Worksheet 3.2.

Step B.2.2. Fill in Column B of Worksheet 3.2 with the Deposition Exposure Rate Conversion Factor [ECF_g , $(mR/hr)/(\mu Ci/m^2)$] from Table 3.4.

Step B.2.3. Fill in Column C of Worksheet 3.2 with the Early Phase Deposition Dose Conversion Factors [DCF_{EPg} , $(mrem)/(\mu Ci/m^2)$] for the radionuclides from Table 3.5. For radionuclides not listed in Table 3.5 or for different resuspension factors, calculate the DCF_{EPg} using Method M.3.4.

Step B.2.4. For each radionuclide, multiply Columns A and B on Worksheet 3.2 and record the answer in Column D. Sum Column D.

Step B.2.5. For each radionuclide, multiply Columns A and C on Worksheet 3.2 and record the answer in Column E. Sum Column E.

Step B.2.6. Calculate the Early Phase Exposure Rate Derived Response Level (DRL_{EPg} , mR/hr) as follows:

$$P_{EP} \times \frac{\sum \text{Column D (See Step B.2.4)}}{\sum \text{Column E (See Step B.2.5)}} = DRL_{EPg}$$

$$\left(\text{mrem} \right) \times \left(\frac{\text{mR/hr}}{\text{mrem}} \right) = \left(\text{mR/hr} \right)$$

Where

$P_{EP}(\text{mrem})$ = State Early Phase PAG or EPA PAG of 1,000 mrem including 4 days of exposure and resuspension from deposition (Table 3.2).

$DRL_{EPg}(\text{mR/hr})$ = Exposure rate from deposition indicating that Early Phase PAGs may be exceeded.

Step B.3. Use exposure-rate DRLs to assess deposition data.

If the exposure-rate DRL calculated in Step B.2.6 is not easily detectable (greater than two times background), skip to Method 3.3.C.

Conduct environmental monitoring to identify where the exposure rates from deposition at 1 m AGL are:

- Greater than 100 times the DRL calculated in Step B.2.6 indicating that early health effects are possible. This may be conservative because this includes CEDE from inhalation and not early dose. Inform management immediately if early health effects are possible. Confirm the risk using samples and Method M.3.2 and Table 3.1.
- Greater than the DRL_{EPg} calculated in Step B.2.6 indicating that the Early Phase PAGs may be exceeded.

If the PAGs or early health effects thresholds are exceeded at this distance, use Method M.3.5 to estimate the distance where they may also be exceeded.

Method M.3.3.C Evaluating Deposition when Resuspension is a Concern and Exposure Rates Cannot Identify the Area of Concern

Perform steps below if the exposure-rate DRL (mR/hr) calculated in Step B.2.6 is **NOT** detectable (e.g., greater than two times background).

Step C.1. Calculate the deposition DRL for a marker radionuclide with a discernable gamma emitter.

Calculate the deposition DRL for radionuclide k that will indicate that the Early Phase PAG may be exceeded from deposition resuspension by performing Steps C.1.1 through C.1.2 (see below for derivation). For accidents involving weapons-grade plutonium, americium-241 (^{241}Am) is usually used as the marker radionuclide. Alpha activity can also be used with the alpha DRL equal to 8.69 times ^{241}Am DRL (see Table V3.4).

$$DRL_{EPg} = P_{EP} \times \frac{C_{gk}}{\sum_{i=1}^n (C_{gi} \times DCF_{EPgi})}$$

$$(\mu\text{Ci}/\text{m}^2) = (m\text{rem}) \times \frac{(\mu\text{Ci}/\text{m}^2)}{\sum \left[(\mu\text{Ci}/\text{m}^2) \times \left(\frac{m\text{rem}}{\mu\text{Ci}/\text{m}^2} \right) \right]}$$

Where

$DRL_{EPg} (\mu\text{Ci}/\text{m}^2)$ = Radionuclide level of a radionuclide in deposition indicating that Early Phase PAGs may be exceeded for remaining on deposition for 4 days.

$P_{EP} (m\text{rem})$ = State Early Phase PAG or EPA PAG of 1,000 mrem from remaining on deposition for 4 days (Table 3.2).

$C_{gk} (\mu\text{Ci}/\text{m}^2)$ = Deposition level of marker-radionuclide k .

$C_{gi} (\mu\text{Ci}/\text{m}^2)$ = Deposition level of radionuclide i .

$DCF_{EPgi} [(m\text{rem})/(\mu\text{Ci}/\text{m}^2)]$ = Early Phase Deposition Dose Conversion Factor including 4 days of exposure and resuspension from deposition of radionuclide i from Table 3.5 or Method M.3.4.

Step C.1.1. Select one of the radionuclides in the deposition as a marker-radionuclide k with a photopeak that is discernable in the field.

Step C.1.2. Calculate the Early Phase Derived Response Level (DRL_{EPg}) for a deposition level of marker-radionuclide k as follows:

$$P_{EP} \times \frac{C_{gk}}{\sum (\text{Column E Step B.2.5})} = DRL_{EPg}$$

$$\left(\text{mrem} \right) \times \left(\frac{\mu\text{Ci}/\text{m}^2}{\text{mrem}} \right) = \left(\mu\text{Ci}/\text{m}^2 \right)$$

Where

- P_{EP} (mrem) = State Early Phase PAG or EPA PAG of 1,000 mrem from remaining on deposition for 4 days (Table 3.2).
- C_{gk} ($\mu\text{Ci}/\text{m}^2$) = Deposition level of marker-radionuclide k .
- DRL_{EPg} ($\mu\text{Ci}/\text{m}^2$) = Level of a radionuclide in deposition indicating that Early Phase PAGs may be exceeded.

Step C.2. Use marker-radionuclide DRLs to assess environmental data.

Conduct environmental monitoring to locate where the deposition of radionuclide k is:

- Greater than 100 times the DRL calculated in Step C.1.2, indicating early health effects are possible. This is conservative because it includes CEDE from inhalation and not early dose. Inform management immediately if early health effects are possible. Confirm the risk using samples and Method M.3.2 and Table 3.1.
- Greater than the DRL_{EPg} calculated in Step C.1.2 indicating that Early Phase PAGs may be exceeded.

If the PAGs or early health effects thresholds are exceeded at this distance, use Method M.3.5 to estimate the distance to which they may also be exceeded.

METHOD M.3.4 DEPOSITION DOSE CONVERSION FACTORS

Purpose: This method is used to calculate the Early Phase Deposition Dose Conversion Factor (DCF_{EPg}) for radionuclides not listed in Table 3.5 or to consider different resuspension factors (R_s).

Discussion: The Early Phase Deposition DCF_{EPg} is an estimate of the dose from external exposure and CEDE from inhalation of resuspended material from remaining on contaminated ground for four days (96 hours). Table 3.5 lists DCF_{EPg} for about 100 radionuclides and for an initial resuspension factor (R_s) of $10^{-6} m^{-1}$ for the first day. The initial resuspension factor then declines as $10^{-6}/t$, where t is time in days, for times from 1 day to 1000 days, and is constant at 10^{-9} for times greater than 1000 days. See Chart 4.1 for additional discussion of resuspension.

The method considers the impact of decay. Weathering is not considered because it will have an immeasurable impact during the Early Phase as can be seen from Chart 4.1.

Steps: The steps performed in this method are summarized in the following box.

- Step 1 Calculate DCFs for resuspended material.
 Step 2 Calculate DCFs for external exposure.
 Step 3 Sum the DCF for resuspension and external exposure.
 Step 4 Calculate the Early Phase Deposition DRL.

Step 1. Calculate DCFs for resuspended material.

Calculate the contribution from inhalation of resuspended quantities of radionuclide i ($DCF_{EPgi(\text{resuspension})}$) as follows:

Assuming a constant R_s :

$$T_{EPeepi} \times DCF_{e,50i} \times R_s = DCF_{EPgi(\text{resuspension})}$$

$$\left(\text{hr} \right) \times \left(\frac{\text{mrem/hr}}{\mu\text{Ci/m}^3} \right) \times \left(m^{-1} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci/m}^2} \right)$$

For a varying R_s :

$$\int_{t_1}^{t_2} DCF_{e,50i} \times e^{-\lambda t} \times R_s \times dt = DCF_{e,50i} \int_{t_1}^{t_2} e^{-\lambda t} \frac{10^{-6}}{t} dt = DCF_{Rgi(\text{resuspension})}^*$$

* For the default resuspension factor, this integral may be evaluated numerically in an appropriately constructed spreadsheet.

Where

T_{EPeepi} (Eff.hr) = Early Phase Effective Exposure Period. Effective hours in four days for radionuclide *i* from Table 3.8:

$$T_{EPeepi} = \int_0^{96} e^{-\lambda t} dt = \frac{1}{\lambda} (1 - e^{-\lambda \times 96})$$

$DCF_{e,50i}$ [(mrem/hr)/(μCi/m³)] = CEDE Dose Conversion Factor for radionuclide *i* from Table 3.3 or Method M.3.10.

R_S (m⁻¹) = Resuspension factor from Method M.3.8 or Chart 4.1. The default value is 10⁻⁶/*t*, where *t* is time in days, for times from 1 day to 1000 days; 10⁻⁶ for times less than 1 day; and 10⁻⁹ for times greater than 1000 days.

Step 2. Calculate DCFs for external exposure.

Calculate the contribution from external exposure from the deposition of radionuclide *i* ($DCF_{EPgi(External)}$) as follows:

$$T_{EPeepi} \times DCF_{gi} = DCF_{EPgi(External)}$$

$$\left(\text{hr} \right) \times \left(\frac{\text{mrem/hr}}{\mu\text{Ci/m}^2} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci/m}^2} \right)$$

Where

DCF_{gi} [(mrem/hr)/(μCi/m²)] = Ground shine EDE external Dose Conversion Factor for radionuclide *i* from Table 3.4 or Method M.3.10.

T_{EPeepi} (Eff.hr) = Early Phase Effective Exposure Period. Effective hours in four days for radionuclide *i* from Table 3.8 or as above.

Step 3. Sum the DCF for resuspension and external exposure.

Sum the inhalation and external exposure contributions to calculate the Early Phase Deposition DCF as follows:

$$DCF_{EPgi(Resuspension)} + DCF_{EPgi(External)} = DCF_{EPgi}$$

$$\left(\frac{\text{mrem}}{\mu\text{Ci/m}^2} \right) + \left(\frac{\text{mrem}}{\mu\text{Ci/m}^2} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci/m}^2} \right)$$

Step 4. Calculate the Early Phase Deposition DRL.

Calculate the Early Phase Deposition DRL (DRL_{EPgi}) from the Early Phase Deposition DCF and the PAG as follows:

$$\frac{P_{EP}}{DCF_{EPgi}} = DRL_{EPgi}$$

$$\left(\frac{mrem}{\mu Ci / m^2} \right) = (\quad \mu Ci / m^2)$$

Where

$P_{EP} (mrem)$ = State Early Phase PAG or EPA PAG of 1,000 mrem from remaining on deposition for 4 days (Table 3.2).

METHOD M.3.5 DOWNWIND PROJECTIONS FROM ENVIRONMENTAL MEASUREMENTS

Purpose: The purpose of this method is twofold: 1) estimate exposure, dose, or environmental concentration downwind from a field measurement, 2) estimate how far downwind a specific concentration or dose (related to a PAG) might be exceeded.

Discussion: Four methods are offered, each appropriate to the tools available in order of sophistication. These methods are for the travel distance of the plume and not for the straight-line distance from the source. Release point elevation and terrain effects may result in substantial errors.

Steps: These methods can be performed using ARAC (Su93) or SHARC. Select the most sophisticated method possible (A, then B, then C, and last resort, D).

- Method M.3.5.A – Rerun Model Normalized to Measurements
- Method M.3.5.B – Scale Existing Model to Measurements
- Method M.3.5.C – Extrapolation from Measurements I
- Method M.3.5.D – Extrapolation from Measurements II

Method M.3.5.A – Rerun Model Normalized to Measurements

Before using any other method, attempt to rerun the model normalized to the field measurements available. While more time consuming, it provides the best results. This requires several measurements at various distances downwind. These measurements should be relatively near centerline. The method also requires immediate access to the model or modelers with sufficient time to run the model.

After the model has been normalized and rerun, the desired estimates can be read directly from the plot. The distance to which a particular quantity exceeds a specific value (DRL) can be found by inspection.

Method M.3.5.B – Scale Existing Model to Measurements

This method can be used if a model prediction and measurements of the same quantity are available. Quickly map the measurements onto the predictive plot. By inspection determine a single ratio that would scale the model to fit the measurements (multiply the plot legend by the ratio). The method assumes meteorological conditions have not changed or would not change the predictions.

Reading the value at that location from the plot and multiplying it by the scale factor can yield estimates of the quantity at the desired location. It may also be possible to scale additional predictions by the same factor. However, caution must be used, because many predicted quantities are not simply related.

Method M.3.5.C – Extrapolation from Measurements I

This method is used if only measurements are available, but access to Assessment Manual Volume 2, Tables 3.6.A, B, and C is required. The method assumes a ground level release, no rain, constant wind speed, constant direction, and constant release rate.

First, estimate the stability class using Table 3.6.A and Table 3.6.B.

Then use the following equation:

$$\frac{DF_p}{DF_m} \times I_m = I_p$$

$$\left(\frac{m^{-2}}{m^{-2}} \right) \times (\quad \text{unit}) = (\quad \text{unit})$$

Where

I_m = Intensity (exposure, dose, or concentration) at measured location.

I_p = Intensity (exposure, dose, or concentration) at projected location.

$DF_m (m^{-2})$ = Dilution factor from Table 3.6.C at measured location.

$DF_p (m^{-2})$ = Dilution factor from Table 3.6.C at projected location.

Method M.3.5.D – Extrapolation from Measurements II

This method is used only if the others are impractical, such as when in the field. This method is within a factor of 10 for ground level releases for a wide range of stability classes and wind speeds. The method assumes a ground-level release, no rain, constant wind speed, constant direction, and constant release rate.

Only proportions of the measurements and their downwind distance to the release point are required. Use the following equation:

$$\frac{Dis_m}{Dis_p} \times I_m = I_p$$

$$\left[\frac{\text{miles}(km)}{\text{miles}(km)} \right] \times (\quad \text{unit}) = (\quad \text{unit})$$

Where

Dis_m (miles, km) = Distance from the source to the measured location.

Dis_p (miles, km) = Distance from the source to the projected location.

I_m = Intensity (exposure, dose, or concentration) at measured location.

I_p = Intensity (exposure, dose, or concentration) at projected location.

METHOD M.3.6 DOSE REDUCTION DUE TO SHELTERING

Purpose: This method is used to estimate the dose reduction resulting from sheltering.

Discussion: If sheltering is critical to a protective action decision, the shielding factors (SF) should be confirmed by monitoring. Sheltering from inhalation and shielding from external exposure are treated separately. It is impossible to accurately estimate the reduction in inhalation dose due to sheltering because of the great variations associated with the type of release, release duration, structure tightness, and actions of the sheltered people. After plume passage, the inhalation dose inside a structure may be higher than the outside dose due to radionuclides trapped in the structure.

Steps: Use one of the following methods.

- Method M.3.6.A – Inhalation Dose Reduction Due to Sheltering
- Method M.3.6.B – Exposure or Dose Rate Considering Shielding

Method M.3.6.A. Estimate the inhalation dose reduction due to sheltering. A general rule is to assume a 50 percent reduction in the inhalation dose if the structure is “closed-up” (windows shut and ventilation off), and if the plume envelops the structure for only a short time (*e.g.*, less than 30 minutes).

Method M.3.6.B. Estimate the exposure or external dose rate considering shielding. These estimates are for external exposure only and do not consider contamination in the structure.

$$I_{w/o\ shielding} \times SF = I_{with\ shielding}$$

$$\left(\quad mrem/hr \right) \times \left(\quad \right) = \left(\quad mrem/hr \right)$$

Where

$I_{w/o\ shielding}$ = exposure or external dose rate (intensity) in mR/hr or mrem/hr without shielding.

$I_{with\ shielding}$ = projected exposure or external dose rate in mR/hr or mrem/hr with shielding.

SF = Shielding Factor from Table 3.7 or Table 3.8.

METHOD M.3.7 FUTURE EXPOSURE (OR DOSE) RATES FROM DEPOSITION

Purpose: This method is used for estimating future exposure.

Discussion: Decay and ingrowth have been considered.

Steps: Use one of the following methods.

- Method M.3.7.A – For an LWR core damage accident. Use precalculated curves for LWR accidents. These curves consider decay and ingrowth.
- Method M.3.7.B – For an LWR core damage accident or a fission weapon detonation. These power functions are based on field measurements and therefore consider the effects of decay, ingrowth, and weathering.

Method M.3.7.A. Calculate the future exposure rate (dose) from deposition from an LWR accident. This method uses the curves in Chart V3.2.1. The method should be valid (plus or minus 10 percent) for a range of core-damage accidents involving reactors that have operated for a year or more. Weathering was not considered because it is assumed to have a minor effect during the first year.

$$I_{T1} \times \frac{f_{T2}}{f_{T1}} = I_{T2}$$

$$\left(\quad mR, mrem/hr \right) \times \left(\frac{\quad}{\quad} \right) = \left(\quad mR, mrem/hr \right)$$

Where

I_{T1} = Exposure or dose rate (intensity) at day or month T1 after reactor shutdown.

f_{T2} = Fraction of the first-day exposure rate from the Y axis of Chart V3.2.1 on day or month T2 after shutdown.

f_{T1} = Fraction of the first-day exposure rate from the Y axis of Chart V3.2.1 on day or month T1 after shutdown.

I_{T2} = Exposure or dose rate (intensity) for day or month T₂ after reactor shutdown.

Method M.3.7.B. Calculate the exposure rate (dose) from deposition, the dose can be approximated, within a factor of 2, for the first year as follows:

$$I_{T_1} \times \left(\frac{T_1}{T_2} \right)^\theta = I_{T_2}$$

Where

- I_{T_1} = Exposure or dose rate (intensity) at time T_1 days after reactor shutdown.
- I_{T_2} = Exposure or dose rate (intensity) at time T_2 days after reactor shutdown.
- θ = Power factor as indicated below for specific scenarios:
 - 0.8 LWR accidents (based on Chernobyl data),
 - 0.6 LWR accidents (based on calculations for the default LWR scenario described in Section 2 of Volume 3), or
 - 1.2 Exposure from fission weapon detonation (G177).

METHOD M.3.8 RESUSPENSION FACTORS BASED ON SAMPLES

Purpose: This method is used to calculate resuspension based on air and deposition samples. It should be used if resuspension is an important source of dose (e.g., plutonium contamination). For LWR accidents, resuspension dose is not considered important during the Early Phase.

Discussion: The amount of radioactivity in air may be an important component of determining the risk to people breathing that air. Ideally, there would be enough air samplers/monitors available to comprehensively characterize the air breathed by the public. However, this would rarely be the case. Therefore, concentrations of radioactivity in air are usually estimated by multiplying the ground deposition by a resuspension factor.

Default values of resuspension factors (R_S) are used to estimate air concentrations and related inhalation doses in several sections of this Manual (e.g., Table 3.5, Methods M.3.2, and M.4.5). The default resuspension factor varies with time: R_S starts as $1 \times 10^{-6} \text{ (m}^{-1}\text{)}$ for times less than one day, changes to $(1 \times 10^{-6})/t$ for the first 1000 days after deposition, then changes to a constant $1 \times 10^{-9} \text{ (m}^{-1}\text{)}$ for longer times. (See Charts 4.1 for curves of resuspension factors for various conditions.) However, substantially different resuspension factors may actually exist, and resuspension factors may change dramatically due to various factors (wind, rain, etc.). (For example, resuspension factors as high as $1 \times 10^{-2} \text{ m}^{-1}$ have been observed for short periods near dusty roads.)

Accordingly, when responding to an actual event where dose from resuspension may be an important factor (e.g., following dispersal of alpha-emitting material), it is prudent to **measure** the actual resuspension factor and to use the measured values when estimating air concentrations based on ground deposition.

Note: The placement of air samplers/monitors used to determine resuspension factors might NOT be the same locations that one would select to conduct air monitoring for the purpose of determining personnel exposures.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Collect air samples
- Step 2 Determine the amount of ground deposition.
- Step 3 Calculate resuspension factors.
- Step 4 Recalculate DCFs if necessary.

Step 1. Collect air samples

Placement of Air Samplers/Monitors

In contrast to direct measurements of air concentration (usually made at occupied locations), air and ground measurements used for determining resuspension factors must be made at or near source locations – i.e., areas of contaminated ground from which activity is being resuspended *into* occupied areas. Although it is possible that such source areas may be near (or may be the same as) occupied areas, it is also possible that the source contamination area is some distance away from the occupied area of interest. Therefore, the location of resuspension measurements must take into account the geography and weather factors that affect the transfer of activity from the ground to the air that will end up in the occupied areas of interest.

In general, resuspension measurements should be made at locations in contaminated areas that are upwind (or may be expected to be upwind) of the occupied areas of interest. Note also that, within reason, resuspension measurements in areas of higher ground contamination may be more accurate (and may be obtained more quickly) than measurements taken in areas of very low or near-background activity). See Figure 3.1 below.

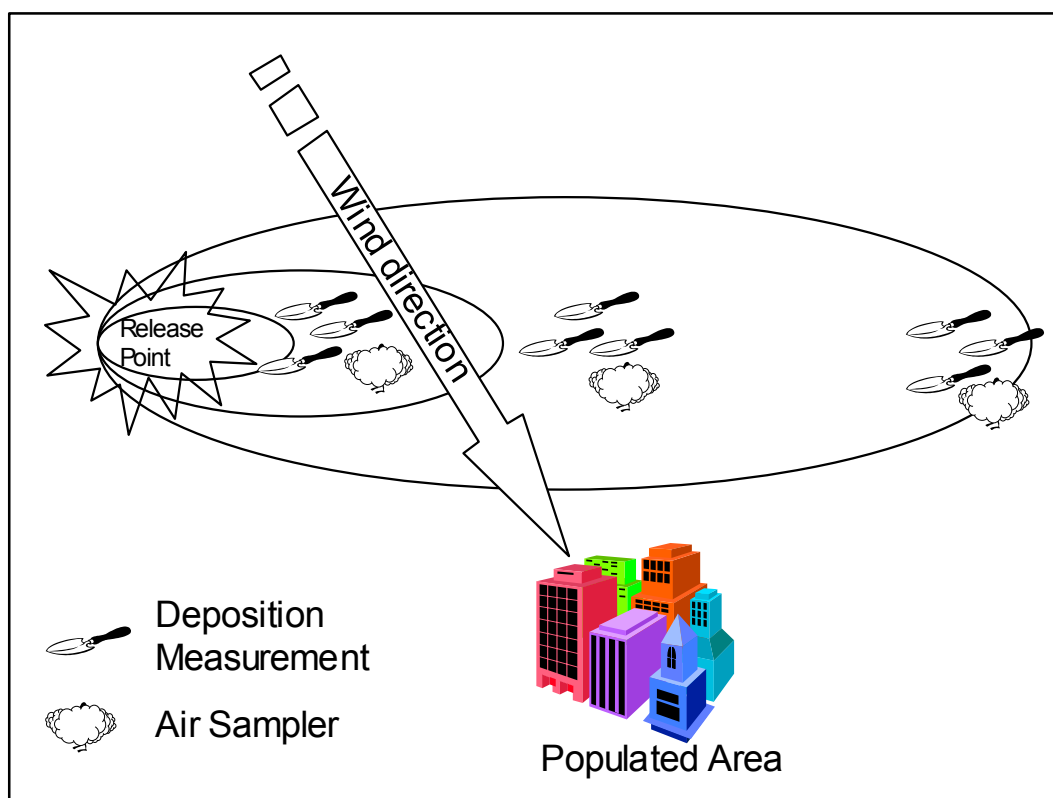


Figure 3.1. Relative Placement of Deposition Measurements and Air Samplers

Following an accident, the majority of air samplers will be deployed in occupied areas such as towns where people are sheltered and at relocation centers, and the number of air samplers that can be used for resuspension measurements may be quite limited. Initially, two or three strategically placed air samplers (as shown in Figure 3.1) can provide highly useful information.

Additional air samplers will be necessary if there is very different terrain within a given contamination area. For example, given the same level of activity and the same weather conditions, resuspension may be quite different in an open grassy field than in a downtown area that has lots of buildings.

Place air samplers/monitors about 4-5 feet above the ground, in open areas, away from structures such as walls or buildings. Avoid areas that are likely to produce localized areas of elevated resuspension (e.g., on the side of a busy road).

Change air sampler filter papers periodically; the frequency of change is dictated by a variety of factors, such as:

- The time that the information is needed in and the type of information needed (e.g., general resuspension factors, variations in resuspension factors with time of day, changing weather conditions, or application of fixative).
- The general level of dust loading in the air. A filter that is caked with dust cannot be accurately counted for alpha activity.
- Weather changes. If a significant change in the weather occurs (e.g., it rains or snows or there is a major wind storm), consider changing the filter paper so that the effect of the weather change on resuspension can be evaluated. Often, such weather-related phenomenon are an expected part of the daily weather pattern; coordinate the timing of filter changes to take best advantage of the anticipated weather.
- The desired level of sensitivity and the amount of activity on the ground and in the air. The greater the amount of resuspended radioactivity, the less time the sampler needs to run to produce a given level of sensitivity.

As a general rule, filters used for resuspension measurements should probably be changed every 4 hours during the first day or so of the response so that health and safety related decisions can be made in a timely manner. Once the area has been characterized, less frequent filter changes (e.g., once per shift, daily, or weekly) that normalize resuspension variations may be more appropriate.

Step 2. Obtain ground measurements

The purpose of these measurements is to obtain the general level of ground activity for comparison to the measured activity on the air filter. Upwind of the air sampler/monitor, obtain approximately 6 ground measurements, preferably using a FIDLER. If only direct alpha measurements are available, obtain a dozen or so measurements. Whichever ground measurement method is used, the result of the ground measurement must be converted to $\mu\text{Ci}/\text{m}^2$ prior to determining the resuspension factor. Measurements should be taken 10-30 feet upwind of the air sampler/monitor.

Step 3. Calculate resuspension factors

Calculate the resuspension factors R_S as follows:

$$\frac{C_{ai}}{C_{gi}} = R_S$$

$$\left(\frac{\mu\text{Ci}/\text{m}^3}{\mu\text{Ci}/\text{m}^2} \right) = (\quad \text{m}^{-1})$$

Where

C_{ai} ($\mu\text{Ci}/\text{m}^3$) = Air concentration of radionuclide i.

C_{gi} ($\mu\text{Ci}/\text{m}^2$) = Average deposition level of radionuclide i.

R_S (m^{-1}) = Resuspension factor.

CAUTION: The air sample and ground measurements must be taken within the plume of contamination or very misleading resuspension factors may be calculated. For example, if there is a strong wind as shown in Figure 3.1 and ‘resuspension’ is measured in the town area (which is outside the plume), a significant level of radioactivity may be detected on the air sampler as a result of contamination resuspended from the plume area. However, a GROUND measurement in the town may indicate non-detectable levels of contamination (because it is outside the plume area). In such a case, absurdly high (and erroneous) resuspension factors would be calculated.

Step 4. Recalculate DCFs if necessary

If R_S is a factor of 5 different than those assumed in the development of the Early Phase DCFs, use Method M.3.4 to recalculate the Early Phase Deposition DCF (DCF_{EPg}).

METHOD M.3.9 RELEASE RATES BASED ON AIRBORNE CONCENTRATIONS

Purpose: This method is used to estimate the isotopic release rate based on airborne isotopic concentrations measured in the environment.

Discussion: This method is valid only if (1) the release rate, wind direction, and speed are constant; (2) the meteorological and terrain conditions are simple; (3) the release height is ground level; (4) the samples are taken more than two miles from the release source; (5) the samples are taken for 30 minutes; (6) it is not raining, and (7) one has a single release point.

Steps: Calculate release rate as follows:

$$\frac{\chi_i \times \bar{U}}{DF_m} = Q_i$$

$$\frac{\left(\frac{\mu Ci}{m^3} \right) \times \left(\frac{m}{s} \right)}{\left(m^{-2} \right)} = \left(\frac{\mu Ci}{s} \right)$$

Where

$\chi_i (\mu Ci/m^3)$ = Air concentration of radionuclide i.

$\bar{U} (m/s)$ = Average wind speed.

$DF_m (m^{-2})$ = Dilution factor, $\chi\bar{U}/Q$, from Table 3.6.C for downwind distance from release point along plume centerline.

$Q_i (\mu Ci/s)$ = Release rate of radionuclide i.

Alternatively, this method can be performed using ARAC (Su93), SHARC, or another suitable model to predict the χ/Q value, from which the release rate may be determined.

METHOD M.3.10 AIR SUBMERSION, GROUND SHINE, INHALATION DOSE CONVERSION FACTORS, AND EXPOSURE CONVERSION FACTORS

Purpose: This method is used to calculate the air submersion (DCF_a), ground shine (DCF_g), and inhalation ($DCF_{T(\text{thyroid}),50}$, $DCF_{e,50}$) Dose Conversion Factors, early absorbed dose conversion factors [$DCF_{T(\text{Organ}),E}$], and Exposure Conversion Factor (ECF) for radionuclides not listed in Table 3.3 or Table 3.4.

Discussion: The DCFs in Table 3.3 and Table 3.4 are calculated for about 100 radionuclides. The inhalation DCFs are for an adult performing light activity. This method allows DCFs to be calculated for radionuclides not listed in the tables or allows factors such as breathing rate, lung clearance class, or ground-roughness correction to be adjusted.

The inhalation dose conversion factors used in this manual are based on the dose coefficients for the lung clearance class having the highest effective dose coefficient. This provides conservative values for CEDE calculations, but may not provide conservative values for committed thyroid or early organ doses. If lung clearance classes of nuclides in a release are known, or if the nuclide mix is such that organ doses are expected to be controlling, then dose coefficients for other lung clearance classes may be taken from the appropriate references (EPA88 or Ec01).

Steps: Calculate factors using one of the following methods.

- Method M.3.10.A Inhalation Dose Conversion Factors
- Method M.3.10.B External Dose Factors (Air Submersion and Ground Shine)
- Method M.3.10.C Exposure Rate Factors

Method M.3.10.A – Inhalation Dose Conversion Factors. The inhalation DCFs for committed doses used in the methods must be in terms of (mrem/hr)/($\mu\text{Ci}/\text{m}^3$). The inhalation DCFs in Table 3.3 are for a breathing rate of an adult performing light activity ($1.2 \text{ m}^3/\text{hr}$) as recommended by EPA88. The inhalation DCFs used in the manual are for the adult. The early organ DCFs are for absorbed dose for 30 days after the radionuclide has been inhaled. CEDE ($DCF_{e,50}$) is the committed dose for 50 years. The thyroid DCF is the committed dose for 50 years.

Calculate the inhalation doses based on the factors from the basic references as follows:

CEDE Inhalation Dose Conversion Factor ($DCF_{e,50}$):

$$DCF_{e,50} = EDCF_{e,50} \times BR \times CF$$

Thyroid Inhalation Dose Conversion Factor [$DCF_{T(\text{thyroid}),50}$]:

$$DCF_{T(\text{thyroid}),50} = EDCF_T \times BR \times CF$$

Early Tissue Inhalation Dose Conversion Factor [$DCF_{T(Organ),E}$] for red bone marrow, small intestine, or thyroid:

$$DCF_{T(organ),E} = [EAD_{Organ(H)} + EAD_{Organ(L)}] \times BR \times CF$$

Early Lung Inhalation Dose Conversion Factor [$DCF_{T(lung),E}$]:

$$DCF_{T(lung),E} = [EAD_{Lung(H)} \times RBE + EAD_{Lung(L)}] \times BR \times CF$$

Where

$DCF_{e,50} (mrem/hr)/(\mu Ci/m^3)$ = CEDE adult inhalation Dose Conversion Factors.

$EDCF_{e,50} (Sv/Bq)$ = Exposure-to-Dose Conversion Factors for inhalation from EPA88, Table 2.1, “Effective” column.

$BR (m^3/hr)$ = This manual assumes a breathing rate for an adult performing light activity, from EPA88, page 10 ($0.020 m^3/min \times 60 m/hr = 1.2 m^3/hr$), as recommended by the EPA. For a 24-hour period, this is conservative. See Table 3.10 for breathing rates for reference man (ICRP74).

CF = Conversion Factor for units (Sv, Bq, μCi , and mrem are shown below, the conversion for Gy and mrad is numerically equal).

$$1 \frac{Sv}{Bq} \times \frac{1.0E + 05 mrem}{Sv} \times \frac{Bq}{2.7E - 05 \mu Ci} = \frac{3.7E + 09 mrem}{\mu Ci}$$

$DCF_{T(thyroid),50,i} [(mrem/hr)/(\mu Ci/m^3)]$ = adult organ (CDE thyroid) inhalation Dose Conversion Factor for radionuclide i from Table 3.3, or Method M.3.10

$DCF_{T(organ),E,i} [(mrad/hr)/(\mu Ci/m^3)]$ = adult organ (early bone marrow, early small intestine, early lung, or early thyroid) inhalation Dose Conversion Factor for radionuclide i from Table 3.3, or Method M.3.10

$EDCF_T (Sv/Bq)$ = Exposure-to-Dose Conversion Factor (for inhalation) for the thyroid, from EPA88, Table 2.1, “Thyroid” column.

$EAD_{Organ(H or L)} (Gy/Bq)$ = Early Organ Absorbed Dose (High or Low LET) from inhalation for 30 days following an inhalation for red bone marrow, small intestine, lung, or thyroid in Gy/Bq from Ec01. The most conservative lung clearance class (based on “effective” DCF from EPA88) is used.

RBE = Relative Biological Effectiveness. The absorbed dose to the lung was computed using an RBE of 10 for high LET radiation to better represent the early dose.

Method M.3.10.B – External Dose Factors (Air Submersion and Ground Shine). The ground shine Dose Conversion Factor (DCF_g) in Table 3.4 is the EDE for a 1-hour exposure at 1 m AGL from a $1 \mu\text{Ci}/\text{m}^2$ deposition of radionuclide *i*, corrected for ground roughness. The external dose from progeny expected to be in equilibrium is included where noted (e.g., ^{137}Cs plus $^{137\text{m}}\text{Ba}$). The DCF from air submersion (DCF_a) is the EDE for a 1-hour exposure to a semi-infinite cloud of constant concentration.

Use the following equations to calculate external DCFs for radionuclides not listed in Table 3.4 or to use different assumptions.

Dose Conversion Factor ground shine (DCF_g):

$$DCF_g = DCECGS \times SICF \times GRCF$$

Dose Conversion Factor air submersion (DCF_a):

$$DCF_a = DCAS \times SICF$$

Where

$DCECGS [(Sv/s)/(Bq/m^2)]$ = Dose coefficients for exposure to contaminated ground-surface, smooth plane from EPA93, Table III.3.

$SICF$ = SI unit conversion factor. See following equation.

$GRCF$ = Ground roughness correction factor of 0.7 to convert the dose projected for a smooth plane to typical ground surface.

$DCAS [(Sv/s)/(Bq/m^3)]$ = Dose coefficients for air submersion (DCAS) from EPA93, Table III.1.

$$1 \frac{Sv/s}{Bq/m^2} \times \frac{3.6E+03 s}{hr} \times \frac{1E+05 mrem}{Sv} \times \frac{Bq}{2.7E-05 \mu Ci} = \frac{1.33E+13 mrem/hr}{\mu Ci/m^2}$$

Method M.3.10.C – Exposure Rate Factors. The Exposure Rate Conversion Factor (ECF) is the exposure rate from $1 \mu\text{Ci}/\text{m}^2$ deposition at 1 m AGL or $1 \mu\text{Ci}/\text{m}^3$ air concentration for 1 hour. The effective dose equivalent (EDE) DCF (DCF_a , DCF_g) was divided by the dose to exposure conversion factor (DEXP), 0.7 mrem/mR, to estimate external exposure rate as recommended by EPA (EPA92, Sections 7.3.1 and B.2.1.1).

Exposure rate from deposition (ECF_g):

$$ECF_g \cong DCF_g \div DEXP$$

Exposure rate from air submersion (ECF_a):

$$ECF_a \cong DCF_a \div DEXP$$

Where

$DCF_g [(mrem/hr)/(\mu Ci/m^2)]$ = Dose Conversion Factor Ground Shine calculated above.

$DCF_a [(mrem/hr)/(\mu Ci/m^3)]$ = Dose Conversion Factor Air Submersion calculated above.

DEXP = Conversion Factor to convert exposure to dose,
0.7 mrem/mR.

METHOD M.3.11 DECAy CORRECTION OF EXPOSURE RATE DATA

Purpose: Adjustment of exposure rate measurements to account for radioactive decay and weathering, when it is necessary to make quantitative comparisons between measurements performed at significantly different times. Key examples include construction of PAG Zone maps and Current Radiological Conditions map.

Discussion: Exposure rate can decline strongly due to radioactive decay, particularly during the first few days (see Charts V.3.2.1a and V.3.2.1b for LWR example). Mapping exposure rate measurements over several days can be problematic, because the data set will be internally inconsistent unless radioactive decay (and weathering) is taken into account. This makes comparison of measurements to a single DRL uncertain. Apparent discrepancies may be observed between measurements at a single or nearby location, which were acquired at different times. This method only decays “old” data to the current date/time.

Utilization of this method is necessary only if both these conditions exist:

- It is necessary to agglomerate several days of exposure rate data into a single internally consistent data set for comparison or plotting.
- The half-lives of significant exposure generating nuclides and their parents are comparable to the time period over which measurements were acquired.

Presently, the decay correction is not automated in the DCENT database. The Assessor must give the correction factor for each point to the Data Center operator. DCENT will then create a “corrected” value field.

Steps: Review the characteristics and requirements of each approach and select the best choice for the situation from the following methods.

- Method 3.11.A – Correction factors are derived from direct observations. This is the preferred method, and should be used whenever possible.
- Method 3.11.B – Correction factors are derived from computations.

Method 3.11.A – Empirical Correction Factors

Empirical determination is the preferred method, because it considers the entire radionuclide mix and implicitly accounts for weathering. However, it requires acquisition of time series of measurements at designated reference locations.

Step A.1. Task Monitoring and Sampling with ongoing monitoring of reference locations as soon as possible, because corrections can only be applied to data obtained after characterization begins. Request exposure rate measurements from at least three locations in the footprint once per shift. Locations should be chosen to optimize sensitivity to spatial variations of the mix. All

measurements should be performed with the same instrument at exactly the same location. Acquisition twice per shift during the first day is useful.

Step A.2. Obtain the measurements each shift and record with the previous measurements. Keep the data for each reference location separate.

Step A.3. Plot the decay curve with time linearly on the x-axis and exposure rate on the y-axis. Use of a logarithmic axis for exposure rate is advised. Plot data for each reference location uniquely on the same plot.

Step A.4. If all the decay curves are roughly parallel, then select just one curve for all corrections. If the decay curves for different reference locations are not parallel, then the mix may not be uniform. If this occurs, use a separate decay curves in each region of the footprint.

Step A.5. Fill in Worksheet 3.3 with header information. Complete the first three columns of shift information (start, end & midpoint). Compute the elapsed time relative to the first measurement. Use a 24-hour format and add 24 hours for each full day.

Step A.6. Complete Column A for each shift by inspection of the decay curve. The value to be recorded is the exposure rate at the shift midpoint time, which is estimated by inspection from the decay curve.

Step A.7. Write the exposure rate and measurement time of the last point on the decay curve in the box labeled “Last Value.”

Step A.8. Complete Column B by dividing the last measured exposure rate by the exposure rate at each of shift midpoint times. This is the Decay Correction Factor ($DF(t)$).

Step A.9. Ask the Data Center to create a corrected value field in the database using the Decay Correction Factors. The Data Center must manually insert the Decay Correction Factor that corresponds to the time of each measurement. The corrected exposure rate is simply:

$$E_{g (now)} = DF(t) \times E_{g (old)}$$

Method 3.11.B – Computed Correction Factors

Computational determination can be used, if the prerequisite reference measurements are not available for the direct measurement approach (Method 3.11.A). Computation requires comprehensive knowledge of the isotopic mix. This can be obtained from any gamma spectroscopic measurement, e.g., stack monitor, material assay, field gamma spectroscopy or sample analysis. This method should only be used when there is a high confidence in knowledge of the mix and repeated reference measurements are not available.

Step B.1. Obtain the radionuclide mix from field or plant gamma spectroscopic measurements.

Step B.2. Setup computational tool that estimates exposure rate for a particular mix and permits decay of that mix. The tool should include in-growth. DEPDOSE (Be91) is recommended, because it is well established and supports several features that are convenient for this operation. Selection of source for exposure rate or dose conversion factors is not important, because only ratios are used.

DEPDOSE is a DOS-based program developed by FRMAC to compute external dose from exposure rate measurements. The “full report” option includes the estimated current exposure rate and the exposure rate at the end of the “initial decay period.” Use this value for construction of the decay curve.

Step B.3. Input the mix to the decay tool. If the mix is not uniform throughout the footprint, then several separate curves must be computed for each region of the footprint.

Step B.4. Fill in Worksheet 3.3 with header information. Complete the first three columns of shift information (start, end & midpoint). Compute the elapsed time relative to the first measurement. Use a 24-hour format and add 24 hours for each full day.

Step B.5. Complete Column A for each shift by calculation of the exposure rate at that time using the decay tool. The decay period is the time since the first shift. The value to be recorded is the exposure rate at each shift midpoint time reported by the tool.

Step B.6. Write the estimated exposure rate and midpoint time of the last shift in the box labeled “Last Value.”

Step B.7. Complete Column B by dividing the Last Value exposure rate by the exposure rate estimated for each of shift midpoint time. This is the Decay Correction Factor ($DF(t)$).

Step B.8. Ask the Data Center to create a corrected value field in the database using the Decay Correction Factors. The Data Center must manually insert the Decay Correction Factor that corresponds to the time of each measurement. The corrected exposure rate is simply:

$$E_{g(\text{now})} = DF(t) \times E_{g(\text{old})}$$

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**SECTION 4. RELOCATION ASSESSMENT FOR DEPOSITED MATERIAL -
INTERMEDIATE PHASE**

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METHOD M.4.0 GENERAL METHOD

Purpose: This method provides means for developing DRLs and projecting doses to relate values measured in the field to EPA Intermediate Phase Relocation PAGs (EPA92).

Discussion: The Intermediate Phase begins after the source of a major release is under control. However, for some accidents (*e.g.*, a reactor core-damage accident) there may be ongoing small releases even after the threat of a major release has passed. These small releases should not prevent assessments concerning the Intermediate Phase.

There are two pathways of primary concern during the Intermediate Phase: (1) exposure to deposited material (direct exposure and inhalation from resuspension) and (2) ingestion. EPA has published PAGs and Long-Term Objectives dealing with deposited material. These PAGs and Long-Term Objectives will be referred to as the Relocation PAG and Relocation Long-Term Objectives. This section provides methods to relate field measurement values to the Relocation PAGs and Long-Term Objectives (EPA92).

To protect the public from deposited material, action should be taken as follows:

- Establish the Relocation Zone where relocation is warranted because the projected doses exceed the Relocation PAGs (Table 4.1) in the first year.
- Adjust the Relocation Zone to Meet the Long-Term Objective in the second year and over 50 years (Table 4.1).

The Relocation PAG is 2,000 mrem TEDE in the first year. The Long-Term Objectives are 500 mrem the second year and 5,000 mrem over 50 years (including the first and second years). The external dose and the resuspension inhalation dose for an individual remaining in the contaminated area are considered. Table 4.1 summarizes the Relocation PAGs and Long-Term Objectives.

For LWR accidents, the EPA Relocation PAG for the first year (2,000 mrem) is expected to meet the Long-Term Objectives through decay, weathering, and part-time occupancy (EPA92). For accidents involving predominantly long-lived radionuclides or in accidents in which resuspension may be important, the Long-Term Objectives may not be met using the EPA Relocation PAGs.

Different States may use different PAGs and Long-Term Objectives. If so, the State levels should be used in the assessment.

Identifying the relocation zone can be difficult due to resuspension and drifting into occupied areas or potential unidentified hot spots. Therefore, the zone as defined should include a buffer zone until the situation is evaluated and dose projections are confirmed. In addition, the mixture of the deposition may change temporally (decay and ingrowth) and spatially. Therefore, samples should be taken and analyzed from a wide area to ensure the DRL is representative of the entire area.

State or local officials may adjust the relocation zone to correspond with local terrain and landmarks. Therefore, local terrain and landmarks should be used to define the boundaries of surveys.

In this section:

- External dose from deposition has been corrected for ground roughness, includes progeny only where noted (e.g., ^{137}Cs plus $^{137\text{m}}\text{Ba}$), and is based on the DCFs in Federal Guidance Report No. 12 (EPA93).
- Inhalation dose factors, which include progeny, are calculated for an adult performing light activity. The time of exposure is an input to the calculation and is situation specific. The dose factors for the solubility classification giving the highest dose (except UF_6 where noted) are provided. The CEDE and thyroid CDE inhalation DCFs are from Federal Guidance Report No.11 (EPA88).
- Decay and weathering are considered. Weathering is included in the resuspension recommendation from NCRP 129 (NCRP99) that is used in this manual (see Chart 3.1).

Steps: Gather and assess environmental data to identify where the Relocation PAGs and Long-Term Objectives may be exceeded from deposition by performing the prioritized tasks shown in Table 4.0.

Table V1.4.1. Relocation Assessment Prioritized Tasks

Purpose: This table lists a series of prioritized tasks and the necessary information to complete the task and indicates which Section 4 method to use.

Crucial Tasks	Necessary Information	Method
For LWR and other accidents where inhalation is not important, identify where there are relocation concerns.	Exposure rates (mR/hr) at 1 m AGL.	M.V3.2.2 Evaluate Deposition Exposure Rates for Light Water Reactor Accidents.
For accidents where inhalation may be important and with gamma emitters, identify where there are relocation concerns.	Isotopic mix (relative abundance) based on <i>in situ</i> measurements, references, or information provided by the operator. <i>and</i> <u>Based On Accident Type, Choose 1 or 2:</u> 1. Accidents where exposure rates identify the area of concern - maximum exposure rates (mR/hr) at 1 m AGL. 2. Accidents where resuspension is a concern and exposure rates are insufficient to identify the area of concern. Deposition of a gamma-emitting marker radionuclide easily identified in the field or lab.	M.4.1 Evaluate Deposition Level.
For accidents where resuspension is critical, recalculate or confirm DRLs or dose based on measured (versus assumed) resuspension factors.	Resuspension air concentrations relative to deposition levels ($\mu\text{Ci}/\text{m}^3$)/($\mu\text{Ci}/\text{m}^2$).	M.4.7 Resuspension Factors Based on Samples.
For accidents where inhalation is important and with no discernable gamma emitter in the deposition, identify where there are relocation concerns.	Air concentrations in populated areas. <i>and</i> Comprehensive isotopic analysis of deposition.	M.4.5 Dose from Deposition.

Table V1.4.1. Relocation Assessment Prioritized Tasks (Continued)

Support Task	Necessary Information	Method
Consider radionuclides not listed in the tables or consider different resuspension factors.	Resuspension air concentrations relative to deposition levels ($\mu\text{Ci}/\text{m}^3$)/($\mu\text{Ci}/\text{m}^2$). <i>and</i> Deposition levels.	M.4.2 Dose Conversion Factors for Deposition.
Estimate future deposition mix to calculate DRL curves as a function of time.	Isotopic concentration (relative abundance) based on <i>in-situ</i> measurements, references, or information provided by operator.	M.4.3 Future Isotopic Activity.
Estimate dose reduction due to partial occupancy and decontamination.	Maximum exposure rates (mR/hr, at 1 m AGL).	M.4.4 Dose Reduction Due to Partial Occupancy and Decontamination.
Calculate Intermediate Phase dose from deposited material. This method should not be used for general assessment of environmental data; DRLs should be used (Method 4.1).	Isotopic concentration (relative abundance) based on <i>in situ</i> measurements, references, or information provided by the operator. <i>and</i> <u>Based On Accident Type, Choose 1 or 2:</u> 1. Accidents where exposure rates identify the area of concern - maximum exposure rates (mR/hr at 1 m AGL). 2. Accidents where resuspension is a concern and exposure rates are insufficient to identify the area of concern. • Deposition of a gamma-emitting marker radionuclide easily identified in the field or lab. <i>or</i> • When no gamma emitter is detectable, perform comprehensive isotopic analysis of deposition.	M.4.5 Dose from Deposition.
For accidents involving large amounts of yttrium and strontium, estimate the skin dose to determine if it exceeds the Relocation PAGs.	Deposition based on <i>in situ</i> measurements, references, or information provided by the operator.	M.4.6 Skin Dose from Resuspended Deposition.

METHOD M.4.1 EVALUATE DEPOSITION LEVEL

Purpose: This method is used once the isotopic mix is estimated or known. This method is used to calculate DRLs and then used to promptly assess deposition to identify where the Relocation PAG (1st year) and Long-Term Objectives (2nd year and 50 years) may be exceeded from direct exposure and resuspension (inhalation).

Two different derived response levels (DRL_{Rg}) can be calculated:

- DRLs based on exposure rate (mR/hr) are used when the exposure rate from the deposition is high enough to identify where the Relocation PAGs and Long-Term Objectives may be exceeded.
- DRLs based on marker-radionuclide level ($\mu\text{Ci}/\text{m}^2$) are used if the exposure rate is not high enough to identify the area of concern.

Discussion: Over time the mixture of deposition may change temporally (decay and ingrowth) and spatially. Therefore, samples should be taken and analyzed from a wide area to ensure the DRL is representative of the entire area. DRLs based on samples should be plotted as a function of time if decay is important. These curves are used to assess field data promptly without performing a complete spectral analysis on each sample. The method considers external dose and inhalation dose from resuspension as recommended by EPA (EPA92). The isotopic mix of the deposition must be known.

Other Accidents Where Inhalation is Not Important. For other accidents where inhalation is not important, an exposure rate of 0.2 mR/hr [approximately (2,000 mrem)/(8,760 hr/yr)] from deposition provides a conservative basis (because decay and weathering are not considered) for the exposure rate from deposition, indicating where the Relocation PAG will be exceeded (DRL_{Rg}).

Steps: The steps performed in this method are summarized in the box below.

Step 1	Obtain the isotopic mix of representative deposition samples.
Step 2	
Option A	Calculate the exposure rate DRL from deposition (DRL_{Rg}) where the Relocation PAGs or Long-Term Objectives are exceeded.
Option B	Calculate the isotopic level DRL (if exposure rates cannot identify the area of concern) of a radionuclide k where the Relocation PAGs or Long-Term Objectives are exceeded.
Step 3	Plot DRLs

Step 1. Obtain the isotopic mix of representative deposition samples.

Table V3.2.6 has estimates of the isotopic ratios for LWR accidents, and Table V3.4 has isotopic mix for typical weapons-grade plutonium. Ensure that samples are taken to assess the impact of changes as a function of time (decay and ingrowth) and deposition patterns.

Step 2, Option A – Calculate the exposure rate DRL

Using Worksheet 4.1, calculate the exposure rate DRL_{Rg} (mR/hr) that indicates where doses exceeding the State’s Relocation PAG or Long-Term Objectives are possible from deposition by performing Steps 2.1 through 2.6 (see below for derivation). This calculation can be performed using RASCAL (NRC94), SHARC, or other appropriate computer model.

$$DRL_{Rg} = P_R \times \frac{\sum_i^n (C_{gi} \times ECF_{gi})}{\sum_i^n (C_{gi} \times DCF_{Rgi})}$$

$$(mR/hr) = (mrem) \times \frac{\sum \left[(\mu Ci / m^2) \times \left(\frac{mR/hr}{\mu Ci / m^2} \right) \right]}{\sum \left[(\mu Ci / m^2) \times \left(\frac{mrem}{\mu Ci / m^2} \right) \right]}$$

Where

DRL_{Rg} (mR/hr) = Deposition Exposure Rate Derived Response Level, exposure rate indicating that Relocation PAG or Long-Term Objectives may be exceeded.

P_R (mrem) = State or EPA Relocation PAG or Long-Term Objectives for the period of interest. The EPA recommendations (Table 4.1) are shown in the following table.

Period	P_R (EPA)	Definition
1 st year	2,000 mrem	PAG
2 nd year	500 mrem	Long-Term Objective
50 years	5,000 mrem	Long-Term Objective

C_{gi} ($\mu Ci/m^2$) = Deposition level of radionuclide i.

ECF_{gi} [(mR/hr)/($\mu Ci/m^2$)] = Deposition Exposure Conversion Factor from Table 3.4 for deposition for radionuclide i.

DCF_{Rgi} [(mrem)/($\mu Ci/m^2$)] = Relocation Dose Conversion Factor for deposition (external exposure and resuspension) for the period of interest from Table 4.2 or Method M.4.2.

Step 2.A.1. Record in Column A of Worksheet 4.1 the deposition levels (C_{gi} , $\mu\text{Ci}/\text{m}^2$) of the principal radionuclides identified in Step 1.

Step 2.A.2. Fill in Column B of Worksheet 4.1 with the Deposition Exposure Rate Conversion Factor [ECF_{gi} , $(\text{mR}/\text{hr})/(\mu\text{Ci}/\text{m}^2)$] from Table 3.4.

Step 2.A.3. Fill in Column C of Worksheet 4.1 with the Relocation Dose Conversion Factors for the 1st-, 2nd-, or 50-year period. Use only one period per worksheet $\{\text{DCF}_{Rg}$, $[(\text{mrem})/(\mu\text{Ci}/\text{m}^2)]\}$ from Table 4.2. For radionuclides not listed in Table 4.2 or for different resuspension factors, use Method M.4.2 to calculate the DCF.

Step 2.A.4. For each radionuclide, multiply Columns A and B on Worksheet 4.1 and record the answer in Column D. Sum Column D.

Step 2.A.5. For each radionuclide, multiply Columns A and C on Worksheet 4.1 and record the answer in Column E. Sum Column E.

Step 2.A.6. Calculate the Relocation Exposure Rate DRL (DRL_{Rg} mR/hr) as follows;

$$P_R \times \frac{\sum \text{Column D (See Step 2.A.4)}}{\sum \text{Column E (See Step 2.A.5)}} = \text{DRL}_{Rg}$$

$$\left(\text{mrem} \right) \times \left(\frac{\text{mR/hr}}{\text{mrem}} \right) = \left(\text{mR/hr} \right)$$

Where

P_R (mrem) = State or EPA Relocation PAG or Long-Term Objectives for the period of interest.

NOTE: If the exposure rate DRL is not detectable, go to Step 2, Option B.

Step 2, Option B – Calculate isotopic deposition DRL

Perform the steps below if the exposure rate DRL (mR/hr) calculated in Step 2.A.6 is **NOT** detectable (e.g., greater than two times background) and there are gamma emitters in the deposition that can be detected in the field. If there are no gamma emitters, calculate the dose from resuspension based on air samples or comprehensive analysis or deposition using Method M.4.5. For accidents involving weapons-grade plutonium, ^{241}Am is usually used as the marker radionuclide. Alpha activity can also be used with the alpha DRL equal to 8.69 times ^{241}Am DRL (see Table V3.3.4).

Calculate the deposition-level DRL for marker-radionuclide k that will indicate the Relocation PAG or Long-Term Objectives may be exceeded by performing Steps 2.B.1 and 2.B.2 (see below for derivation).

$$DRL_{Rgk} = P_R \times \frac{C_{gk}}{\sum_i^n (C_{gi} \times DCF_{Rgi})}$$

$$(\mu Ci / m^2) = (mrem) \times \frac{(\mu Ci / m^2)}{\sum \left[(\mu Ci / m^2) \times \left(\frac{mrem}{\mu Ci / m^2} \right) \right]}$$

Where

$DRL_{Rgk} (\mu Ci / m^2)$ = Deposition level of marker-radionuclide k . Derived Response Level, which indicates where the Relocation PAG or Long-Term Objectives may be exceeded.

$P_R (mrem)$ = State or EPA Relocation PAG or Long-Term Objective. The EPA recommendations are shown in Table 4.1 as well as previously in this Method.

$C_{gk} (\mu Ci / m^2)$ = deposition level of the marker-radionuclide k .

$C_{gi} (\mu Ci / m^2)$ = Deposition level of radionuclide i .

$DCF_{Rgi} [(mrem) / (\mu Ci / m^2)]$ = Relocation Dose Conversion Factor (external exposure and resuspension) for the period of interest from Table 4.2 or Method M.4.2.

Step 2.B.1. Select one of the radionuclides in the deposition as marker-radionuclide k with a photopeak that is discernable in the field.

Step 2.B.2. Calculate the deposition Derived Response Level [$DRL_{Rg} (\mu Ci / m^2)$] for a marker-radionuclide k as follows:

$$P_R \times \frac{C_{gk}}{\sum \text{Column E (See Step 2.A.5)}} = DRL_{Rgk}$$

$$\left(mrem \right) \times \left(\frac{\mu Ci / m^2}{mrem} \right) = \left(\mu Ci / m^2 \right)$$

Where

$\sum \text{Column E}$ = sum of Worksheet 4.1 Column E, calculated in Step 2.A.5.

P_R (*mrem*) = State or EPA Relocation PAG or Long-Term Objective for the period of interest. The EPA recommendations are shown in Table 4.1, as well as previously in this Method.

Step 3. Plot the DRLs

Plot the DRLs calculated in Step 2 as a function of time after the release. Develop curves (using Method M.4.3 to project activity as a function of time) if short-lived radionuclides are present.

Conduct environmental monitoring to locate where the DRL is exceeded, thus indicating that the Relocation PAG or Long-Term Objectives may be exceeded.

METHOD M.4.2 DOSE CONVERSION FACTOR FOR DEPOSITION

Purpose: This method is used to calculate the Relocation Dose Conversion Factor. This method should be used to calculate the Relocation Dose Conversion Factor for radionuclides not listed in Table 4.2 or to consider different resuspension factors (R_S). Table 4.2 lists DCF_{Rgi} for specific radionuclides using a resuspension factor, R_S , of $(1 \times 10^{-6})/t$ in m^{-1} , where t is time in days after deposition (see specific conditions below).

Discussion: The DCF_{Rgi} is an estimate of the external dose from the deposition and CEDE from inhalation of resuspended material for an individual remaining in the contaminated area for one year. This method presents the calculations performed to assess the dose in the first year. Calculations for the second year and for fifty years are similar, but the integration limits change accordingly.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Calculate DCFs for inhalation of resuspended material.
 Step 2 Calculate DCFs for external exposure.
 Step 3 Sum the DCF for resuspension and external exposure.
 Step 4 Calculate the Relocation Deposition DRL.

Step 1. Calculate DCFs for inhalation of resuspended material.

Calculate the contribution to the first-year dose from inhalation of resuspended quantities of radionuclide i [$DCF_{Rgi(\text{resuspension})}$] as follows:

For the first year following a radiological release, and assuming a constant R_S :

$$T_{IPeepi} \times DCF_{e,50i} \times R_S = DCF_{Rgi(\text{resuspension})}$$

$$\left(\text{hr} \right) \times \left(\frac{\text{mrem} / \text{hr}}{\mu\text{Ci} / \text{m}^3} \right) \times \left(\text{m}^{-1} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci} / \text{m}^2} \right)$$

For any time period, and a varying R_S :

$$\int_{t_1}^{t_2} DCF_{e,50i} \times e^{-\lambda t} \times R_S \times dt = DCF_{e,50i} \int_{t_1}^{t_2} e^{-\lambda t} \frac{10^{-6}}{t} dt = DCF_{Rgi(\text{resuspension})}^*$$

* For the default resuspension factor, this integral may be evaluated numerically in an appropriately constructed spreadsheet.

Where

T_{IPeepi} (Eff. hr) = Intermediate Phase Effective Exposure Period; effective hours in one year for radionuclide i from Table 4.6.

$DCF_{e,50i}$ [(mrem/hr)/($\mu\text{Ci}/\text{m}^3$)] = CEDE Dose Conversion Factor from Table 3.3 or Method M.3.10.

R_S (m^{-1}) = Resuspension factor from Method M.4.7 or Chart 4.1.
The default value is $10^{-6}/t$, where t is time in days, for times from 1 day to 1000 days; 10^{-6} for times less than 1 day; and 10^{-9} for times greater than 1000 days.

Step 2. Calculate DCFs for external exposure.

Calculate the contribution to the first-year dose from external exposure from the deposition of radionuclide i [$DCF_{Rgi(\text{External})}$] as follows:

$$T_{IPeepi} \times DCF_{gi} = DCF_{Rgi(\text{External})}$$

$$\left(\text{hr} \right) \times \left(\frac{\text{mrem/hr}}{\mu\text{Ci}/\text{m}^2} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci}/\text{m}^2} \right)$$

Where

T_{IPeepi} (Eff. hr) = Intermediate Phase Effective Exposure Period; effective hours in the first year for radionuclide i from Table 4.6 or

$$T_{IPeepi} = \int_0^{8760} e^{-\lambda t} dt = \frac{1}{\lambda} (1 - e^{-\lambda \times 8760}).$$

DCF_g [(mrem/hr)/($\mu\text{Ci}/\text{m}^2$)] = External EDE ground shine Dose Conversion Factor from Table 3.4 or Method M.3.10.

Step 3. Sum the DCF for resuspension and external exposure.

Sum the inhalation and external exposure components to calculate the first-year relocation DCF (DCF_{Rgi}) for deposition of radionuclide i as follows:

$$DCF_{Rgi(\text{Resuspension})} + DCF_{Rgi(\text{External})} = DCF_{Rgi}$$

$$\left(\frac{\text{mrem}}{\mu\text{Ci}/\text{m}^2} \right) + \left(\frac{\text{mrem}}{\mu\text{Ci}/\text{m}^2} \right) = \left(\frac{\text{mrem}}{\mu\text{Ci}/\text{m}^2} \right)$$

Step 4. Calculate the Relocation Deposition DRL.

Calculate the Intermediate Phase Relocation Deposition DRL (DRL_{Rgi}) from the Relocation Deposition DCF and the PAG as follows:

$$\frac{P_R}{DCF_{Rgi}} = DRL_{Rgi}$$

$$\left(\frac{mrem}{\mu Ci / m^2} \right) = \left(\frac{mrem}{\mu Ci / m^2} \right) (\mu Ci / m^2)$$

Where

P_R (mrem) = State Intermediate Phase Relocation PAG or EPA PAG of 2,000 mrem from remaining on deposition for the first year, 500 mrem from remaining on deposition for the second year, or 5,000 mrem from remaining on deposition for the first 50 years (Table 4.1).

METHOD M.4.3 FUTURE ISOTOPIC ACTIVITY

Purpose: This method is used to project future isotopic activity. In addition to this procedure, there are several computer programs available (*e.g.*, RASCAL [NRC94], SHARC).

Steps: Use one of the following two methods.

- Method M.4.3, Option A – Consider effects of decay and ingrowth: This uses a table of radionuclides that represent the principal contributors to Intermediate Phase dose for reactor accidents. Decay and ingrowth were considered.
- Method M.4.3, Option B – Consider effects of decay alone

Method M.4.3, Option A – Consider effects of decay and ingrowth. Estimate activity based on Table V3.2.6, which considers decay and ingrowth as follows:

$$A_{it_0} \times \frac{IR_{it_1}}{IR_{it_0}} = A_{it_1}$$

$$\left(\mu Ci \right) \times \left(\frac{\quad}{\quad} \right) = \left(\mu Ci \right)$$

Where:

A_{it_0} = Activity at time t_0 (measured).

IR_{it_1} = Radionuclide i to marker nuclide ratio at time t_1 .

IR_{it_0} = Radionuclide i to marker nuclide ratio at time t_0 .

A_{it_1} = Activity at time t_1 .

Method M.4.3, Option B – Consider effects of decay alone. Estimate activity considering decay alone as follows:

$$A_{it_0} \times e^{-\lambda t} = A_{it_1}$$

$$\left(\mu Ci \right) \times e^{(\frac{1}{h})(h)} = \left(\mu Ci \right)$$

Where:

λ = Radioactive decay constant.

t = Time interval from t_0 to t_1 .

METHOD M.4.4 DOSE REDUCTION DUE TO PARTIAL OCCUPANCY AND DECONTAMINATION

Purpose: This method is used to estimate the dose reduction by two mechanisms:

- Dose reduction from shielding during partial occupancy.
- Effectiveness of decontamination.

Discussion: According to the EPA guidance (EPA92), decontamination may be required to meet the Long-Term Objectives.

Step 1. Estimate dose considering the fraction of time an individual is shielded in a structure.

The doses from inhalation or from contamination in the structure are not addressed. These estimates should be confirmed by field monitoring. This calculation can also be performed using a computer model (e.g., RASCAL).

$$Dose_{Unshielded} \times [(SF \times OF) + (1 - OF)] = Dose_{W/PO}$$

$$(\quad mrem) \times \{[(\quad) \times (\quad)] + [1 - (\quad)]\} = (\quad mrem)$$

Where:

$Dose_{Unshielded}$ (mrem) = Dose unshielded.

$Dose_{W/PO}$ (mrem) = Dose with partial occupancy.

SF = Shielding Factors from Tables 3.7 and 3.8.

OF = Occupancy Fraction. Fraction of time in an area with this shielding factor.

Estimate the impact of decontamination. Table V3.2.7 provides estimates of the impact of decontamination in an urban environment for deposition from a reactor accident. Tables V3.3.12a, V3.3.12b, and V3.3.12c provide decontamination estimates for deposition from a weapon detonation. The much lower effectiveness for reactor accidents is due to the small size and chemical composition of the reactor accident deposition.

These tables **DO NOT** consider the potential dose to the individual performing the decontamination. Decontamination efforts could result in an increase to the total population (public plus workers) dose. Therefore, carefully consider the potentially high dose received by workers performing decontamination prior to its recommendation.

The effectiveness of the decontamination techniques and the dose to workers should be confirmed by tests before widespread application.

Step 2. Confirm dose reduction by monitoring.

METHOD M.4.5 DOSE FROM DEPOSITION

Purpose: This method is used to calculate dose from remaining deposition for the 1st-year, 2nd-year, and the 50-year period following the accident. This method should not be used to determine if the deposition in an area might exceed the Relocation PAGs. DRLs developed using Method M.4.1 should be used instead.

Discussion: Except for Method.4.5.D, $TEDE_{IP}$ is calculated and this includes the dose from external exposure and inhalation of resuspended activity. Decay has been considered.

Steps: Calculate the dose using one of the following methods.

- Method M.4.5.A Based on Comprehensive Isotopic Levels of Deposition.
- Method M.4.5.B Based on Exposure Rates.
- Method M.4.5.C Based on the Deposition Levels of Radionuclide k .
- Method M.4.5.D Based on Airborne Concentration of Resuspended Material.
- Method M.4.5.E Based on Derived Response Levels.

Method M.4.5.A – Based on Comprehensive Isotopic Levels of Deposition. Using Worksheet 4.2, calculate the dose based on the isotopic levels of the deposition by performing Steps A.1 through A.3 (see below for derivation). This calculation can also be performed using an appropriate computer code (e.g., RASCAL [NRC94]).

$$TEDE_{IP} = \sum_i^n (C_{gi} \times DCF_{Rgi})$$

$$(mrem) = \sum \left[(\mu Ci / m^2) \times \left(\frac{mrem}{\mu Ci / m^2} \right) \right]$$

Where

$TEDE_{IP} (mrem)$ = Intermediate Phase Total Effective Dose Equivalent - EDE from 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension.

$C_{gi} (\mu Ci/m^2)$ = Deposition level of radionuclide i .

$DCF_{Rgi} [(mrem)/(\mu Ci/m^2)]$ = Relocation Dose Conversion Factor for deposition for the period of interest from Table 4.2 or Method M.4.2.

Step A.1. Record in Column A of Worksheet 4.2 the deposition level (C_{gi} , $\mu Ci/m^2$) of the principal radionuclides.

Step A.2. Record in Column B of Worksheet 4.2 the Relocation Dose Conversion Factors for the 1st-, 2nd-, or 50-year periods, DCF_{Rgi} , $(mrem)/(\mu Ci/m^2)$. DCFs that consider resuspension can

be found in Table 4.2. Use Method M.4.2 for radionuclides not listed in Table 4.2 or to consider different resuspension factors.

Step A.3. Using Worksheet 4.2, calculate the $TEDE_{IP}$ by multiplying Columns A and B and record the answer in Column C. Sum Column C to estimate the dose for the assumed period. The $TEDE_{IP}$ includes the dose from external exposure and resuspension.

Method M.4.5.B – Based on Exposure Rates. This method is used to calculate the Intermediate Phase Exposure-to-Dose Conversion Factor ($EDCF_{IP}$) that can be used to relate an exposure rate from deposition to dose over the Intermediate Phase. Once calculated, this factor is used to calculate dose based on exposure rates over a wide area.

Using Worksheet 4.3, calculate the dose based on exposure rates from deposition by performing Steps B.1 through B.7 (see below for derivation). This calculation can also be performed using the RASCAL (NRC94) or other applicable computer codes.

$$TEDE_{IP} = E_g \times \frac{\sum_i^n (C_{gi} \times DCF_{Rgi})}{\sum_i^n (C_{gi} \times ECF_{gi})}$$

Where

$TEDE_{IP}$ (mrem)	= Intermediate Phase Total Effective Dose Equivalent TEDE from 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension.
C_{gi} ($\mu\text{Ci}/\text{m}^2$)	= Deposition level of radionuclide i.
DCF_{Rgi} [(mrem)/($\mu\text{Ci}/\text{m}^2$)]	= Relocation Dose Conversion Factor for deposition in the period of interest from Table 4.2 or Method M.4.2.
ECF_{gi} [(mR/hr)/($\mu\text{Ci}/\text{m}^2$)]	= Deposition Exposure Conversion Factor from Table 3.4 or Method M.3.10.
E_g (mR/hr)	= Exposure rate at 1 m AGL from deposition.

Step B.1. Record in Column A of Worksheet 4.3 the deposition level, C_{gi} ($\mu\text{Ci}/\text{m}^2$), from a representative sample of the deposition.

Step B.2. Record in Column B of Worksheet 4.3 the Relocation Dose Conversion Factors for the 1st-, 2nd-, or 50-year periods [DCF_{Rgi} , (mrem)/($\mu\text{Ci}/\text{m}^2$)]. DCFs that consider resuspension can be found in Table 4.2. Use Method M.4.2 for radionuclides not listed in Table 4.2 or to consider different resuspension factors.

Step B.3. Fill in Column C of Worksheet 4.3 with the Deposition Exposure Rate Conversion Factor, ECF_{gi} , (mR/hr)/($\mu\text{Ci}/\text{m}^2$), from Table 3.4 or Method M.3.10.

Step B.4. For each radionuclide, multiply Columns A and B on Worksheet 4.3 and record the answer in Column D. Sum Column D.

Step B.5. For each radionuclide, multiply Columns A and C on Worksheet 4.3 and record the answer in Column E. Sum Column E.

Step B.6. Calculate the Intermediate Phase Exposure-to-Dose Conversion Factors ($EDCF_{IP}$) for the representative sample as follows:

$$\frac{\sum \text{Column D (See Step B.4)}}{\sum \text{Column E (See Step B.5)}} = EDCF_{IP}$$

$$\left(\frac{mrem}{mR/hr} \right) = \left(\frac{mrem}{mR/hr} \right)$$

Step B.7. Calculate the $TEDE_{IP}$ by multiplying the measured exposure rates by the $EDCF_{IP}$ calculated in Step B.6. $TEDE_{IP}$ includes the dose from external exposure and resuspension.

$$TEDE_{IP} = EDCF_{IP} \times E_g$$

$$\left(mrem \right) = \left(\frac{mrem}{mR/hr} \right) \times \left(mR/hr \right)$$

Where

- $TEDE_{IP} (mrem)$ = Intermediate Phase Total Effective Dose Equivalent - EDE from the 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension
- $E_g (mR/hr)$ = Exposure rate at 1 m AGL from deposition.
- $EDCF_{IP} [(mrem)/(mR/hr)]$ = Intermediate Phase Exposure-to-Dose Conversion Factor for the period of interest from Step B.6.

Method M.4.5.C – Based on the Deposition Level of Radionuclide k . This method is used to calculate the Intermediate Phase Deposition Level-to-Dose Conversion Factor ($LDCF_{IP}$) that can be used to relate the deposition level of a marker-radionuclide k to dose over the Intermediate Phase. Once calculated, this factor is used to calculate dose based on the levels of the marker radionuclide over a wide area.

Using Worksheet 4.4, calculate the dose based on the deposition level of radionuclide k by performing Steps C.1 through C.5 (see below for derivation).

$$TEDE_{IP} = C_{gk, sample} \times \frac{\sum_i^n (C_{gi, repr.} \times DCF_{Rgi})}{C_{gk, repr.}}$$

$$(mrem) = (\mu Ci / m^2) \times \frac{\sum \left[(\mu Ci / m^2) \times \left(\frac{mrem}{\mu Ci / m^2} \right) \right]}{(\mu Ci / m^2)}$$

Where

$TEDE_{IP} (mrem)$	=	Intermediate Phase Total Effective Dose Equivalent - EDE from the 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension.
$C_{gk, sample} (\mu Ci / m^2)$	=	Deposition level of marker-radionuclide k in sample.
$C_{gk, repr.} (\mu Ci / m^2)$	=	Representative (baseline) deposition level of marker-radionuclide k .
$DCF_{Rgi} [(mrem) / (\mu Ci / m^2)]$	=	Relocation Dose Conversion Factor for deposition for the period of interest from Table 4.2 or Method M.4.2.

Step C.1. Record in Column A of Worksheet 4.4 the deposition level, C_{gi} ($\mu Ci / m^2$), from a representative sample of the deposition.

Step C.2. Record in Column B of Worksheet 4.4 the Relocation Dose Conversion Factors for the 1st-, 2nd-, or 50-year periods [DCF_{Rgi} , $(mrem) / (\mu Ci / m^2)$]. DCFs that consider resuspension can be found in Table 4.2. Use Method M.4.2 for radionuclides not listed in Table 4.2 or to consider different resuspension factors.

Step C.3. For each radionuclide, multiply Columns A and B on Worksheet 4.4 and record the answer in Column C. Sum Column C.

Step C.4. Calculate the Intermediate Phase Deposition Level-to-Dose Conversion Factors ($LDCF_{IP}$) for a representative sample by dividing the sum of Column C from Worksheet 4.4 by the level of radionuclide k as shown in the following sample.

$$\frac{\sum \text{Column } C \text{ (See Step C.4)}}{C_{gi}} = LDCF_{IP}$$

$$\left(\frac{mrem}{\mu Ci / m^2} \right) = \left(\frac{mrem}{\mu Ci / m^2} \right)$$

Step C.5. Calculate the $TEDE_{IP}$ by multiplying the measured level of radionuclide k in samples by the Level-to-Dose Conversion Factor calculated in Step C.4. The $TEDE_{IP}$ includes the dose from external exposure and inhalation dose from resuspension.

$$TEDE_{IP} = LDCF_{IP} \times C_{gk, sample}$$

$$\left(mrem \right) = \left(\frac{mrem}{\mu Ci / m^2} \right) \times \left(\mu Ci / m^2 \right)$$

Where

$TEDE_{IP} (mrem)$ = Intermediate Phase Total Effective Dose Equivalent – EDE from the 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension.

$C_{gk, sample} (\mu Ci / m^2)$ = Deposition level of marker-radionuclide k in sample.

$LDCF_{IP} [(mrem) / (\mu Ci / m^2)]$ = Intermediate Phase Deposition Level-to-Dose Conversion Factor for the period of interest from Step C.4.

Method M.4.5.D – Based on Airborne Concentration of Resuspended Material. Using Worksheet 4.5, calculate the inhalation dose during the first year based on an air concentration by performing Steps D.1 and D.2 (see below for derivation). This calculation can also be performed using the RASCAL (NRC94) code. If the dose from external exposure is significant, it should be added.

$$H_{e,50(IP)} = \sum_i^n (C_{ai} \times DCF_{Rai})$$

$$\left(mrem \right) = \sum \left[\left(\mu Ci / m^3 \right) \times \left(\frac{mrem}{\mu Ci / m^3} \right) \right]$$

Where

$H_{e,50(IP)} (mrem)$ = CEDE from first year of resuspension.

$C_{ai} (\mu Ci / m^3)$ = Air concentration of radionuclide i .

$DCF_{Rai} [(mrem) / (\mu Ci / m^3)]$ = Relocation Dose Conversion Factor for the first year of resuspension from Table 4.3.

Step D.1. Record in Column A of Worksheet 4.5 the airborne concentration representative of the concentration at the beginning of a year (C_{ai} , $\mu\text{Ci}/\text{m}^3$) of the principal radionuclides (see Table V3.2.4 for a list of the principal radionuclides for an LWR accident).

Step D.2. Record in Column B of Worksheet 4.5 the Intermediate Phase air concentration Dose Conversion Factors (DCF_{Rai}) in Table 4.4.

Step D.3. Using Worksheet 4.5, calculate the inhalation dose by multiplying Columns A and B and recording the answer in Column C. Sum Column C to estimate the dose from inhalation only for the first year.

Step D.4. Add any dose from ground shine as appropriate. Compare the dose calculated with the Relocation PAG (see Table 4.1).

Method M.4.5.E – Based on Derived Response Levels: The DRLs for the Relocation PAGs are exposure rates or levels of a marker radionuclide measurable in the field that indicate the Relocation PAG at that location will be exceeded. Therefore, the TEDE_{IP} for the period assumed in calculating the DRL can be estimated as follows:

$$\text{TEDE}_{\text{IP}} = \frac{\text{Field Measurement}}{\text{DRL}_R} \times P_R$$

Where

TEDE_{IP} (mrem) = Intermediate Phase Total Effective Dose Equivalent – EDE for the 1st-, 2nd-, or 50-year periods of ground shine and CEDE from resuspension.

Field Measurement (unit) = Value measured in the field at location where the dose is estimated (same unit as DRL).

DRL_R (unit) = DRL that indicates that the Relocation PAG or Long-Term Objective will be exceeded (Method M.4.1).

P_R (mrem) = State or EPA Relocation PAG or Long-Term Objective. The EPA recommendations (Table 4.1) are shown in the table below.

Period	P_R (EPA)	Definition
1st year	2,000 mrem	PAG
2nd year	500 mrem	Long-Term Objective
50 years	5,000 mrem	Long-Term Objective

METHOD M.4.6 SKIN DOSE FROM RESUSPENDED DEPOSITION

Purpose: This method is used to estimate the skin dose from resuspended material during the first year.

Discussion: Skin dose appears to be critical only in accidents dominated by strontium and yttrium. Skin dose is very difficult to measure directly; it should be estimated based on deposition levels (EPA92). Skin dose from resuspension will not be critical for a reactor accident. The method does not address direct deposition of radioactive material on the skin.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Conduct deposition sampling.
Step 2 Project skin dose.

Step 1. Conduct deposition sampling.

Obtain the sampling results of the deposition in populated areas at the boundary of the area where the Relocation PAGs may be exceeded (outside the Relocation Zone).

Step 2. Project skin dose.

Project skin dose by multiplying deposition levels ($\mu\text{Ci}/\text{m}^2$) of the principal beta emitters by the skin beta Dose Conversion Factors (DCF_{skin}) from Table 4.5. The State may want to adjust the boundary of the Relocation Zone to ensure that skin dose is below 50 times the Relocation PAGs outside the zone.

METHOD M.4.7 RESUSPENSION FACTORS BASED ON SAMPLES

Purpose: This method is used for accidents where resuspension is an important source of dose (e.g., plutonium contamination) during the Intermediate Phase.

Discussion: The Relocation Dose Conversion Factors in Table 4.2 are calculated for a resuspension factor (R_S) that varies with time: it starts as $1 \times 10^{-6}/t$ (m^{-1}) for days 1 to 1000 after deposition, then changes to a constant 1×10^{-9} (m^{-1}) for longer times. However, substantially different resuspension factors have been observed. For mechanical resuspension, R_S as high as $1 \times 10^{-2} m^{-1}$ have been observed for short periods near dusty roads. For wind resuspension, R_S in the range of 1×10^{-8} or $1 \times 10^{-9} m^{-1}$ have been measured after rain or for old (weathered) contamination. Chart 4.1 shows curves of resuspension factors that consider weathering.

For reactor accidents, the dose from ground shine appears to be far more important than the inhalation dose from resuspension. This must be confirmed by air sampling.

Resuspension rates may vary greatly depending on the type of deposition (dry or wet), nature of the contaminated surface, weather conditions, and time after deposition.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Conduct air and ground sampling.
- Step 2 Calculate resuspension factors.
- Step 3 Recalculate DCFs if necessary.

Step 1. Conduct air and ground sampling.

Obtain the results of air and ground sampling in populated areas outside the boundary projected to exceed Early Phase PAGs. Select areas where dose from resuspension is expected to be high (e.g., contaminated dry/dusty areas and populated locations). The samples will help identify hot spots and redefine the boundary, if necessary. For the Intermediate Phase, the samples should be taken for 24 hours and at a frequency to account for the seasonal variation.

Step 2. Calculate resuspension factors.

Calculate the resuspension factor, R_S , as shown in Method M.3.8 Step 3.

Step 3. Recalculate DCFs if necessary.

If R_S is a factor of 5 higher than those assumed in the development of the Intermediate Phase DCFs (i.e., $R_S = 1 \times 10^{-6}/t$ where R_S is in units of m^{-1} and t is time in days), use Method M.4.2 to recalculate the DCF for the Intermediate Phase.

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SECTION 5. INGESTION ASSESSMENT

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METHOD M.5.0 GENERAL METHOD

Purpose: This method is used to relate environmental measurement values to the Food and Drug Administration (FDA) Derived Intervention Levels (DILs) for radioactive contamination in food (FDA 98). The FDA Ingestion PAG is presented in Table 5.1, and the DILs are presented in Table 5.2.

Discussion: Ingestion may be a problem as soon as there is a release and could be a concern to great distances. The FDA guidance is based on a PAG that restricts the Committed Effective Dose Equivalent (CEDE) to 0.5 rem (5 mSv) or the Committed Dose Equivalent (CDE) to any specific organ to 5 rem (50 mSv), whichever is most limiting. The PAG is then expressed in term of limits on the concentration of radioactive contamination in food, referred to as DILs. A DIL corresponds to the concentration of radioactivity in food, which could lead to an individual in the most sensitive population receiving a dose equal to the PAG if no intervention were taken for the year.

The DILs were computed with respect to the most sensitive population for five types of nuclear accidents (reactor, fuel reprocessing, waste, weapons, and spacecraft). Analysis of these scenarios led to the identification of nine radionuclides that essentially control dose. These nine radionuclides are divided into five groups having similar characteristics: ^{90}Sr , ^{131}I , $^{134}\text{Cs} + ^{137}\text{Cs}$, $^{103}\text{Ru} + ^{106}\text{Ru}$, and $^{238}\text{Pu} + ^{239}\text{Pu} + ^{241}\text{Am}$. The DILs for these five groups are those that are principally utilized for assessment (also called principal radionuclides in FDA guidance). In addition, the FDA has provided DILs for 15 other nuclides found in the core inventory of a nuclear reactor. Since there are possible accident scenarios for which none of these 24 nuclides may be the controlling factor for ingestion dose, the FDA guidance also provides the method used to calculate DILs for other potentially significant radionuclides.

The five principal DILs are applied separately, not summed. Similarly, the 15 additional (secondary) DILs (and any others calculated for a specific scenario) are applied separately. If any one DIL is met or exceeded, then consumption of the food has the potential to cause a dose that meets or exceeds the PAG.

Projected doses from ingestion of contaminated food are assessed in a manner compatible with the FDA guidance used for developing DILs. Dose calculations assume radionuclide concentrations are for foods prepared for consumption, raw foods get no credit for potential contamination reduction measures, and ingestion is assumed to take place for a period of one year (or less for short-lived nuclides).

Steps: Gather data and perform assessments to determine if deposition, food, water, or milk concentrations may result in doses greater than or equal to the Ingestion PAG by performing the prioritized tasks listed in Table 5.0. These tasks fit into the basic process for ingestion assessment, which is time-phased and proceeds in five steps:

- a. Assess model predictions and early exposure-rate data to suggest where the PAG may be met or exceeded. This assessment will be useful in the first day following the accident to convey the potential magnitude of the incident.

- b. Assess soil samples and field gamma spectroscopy to refine the estimate of where the PAG may be met or exceeded. This assessment will be useful for the first few days when few, if any, food sample analyses are available.
- c. Assess food samples in broad classes (human food, milk, forage). This approach will suffice for the first week or so until enough data are available to visualize a more detailed picture, which addresses specific foods.
- d. Evaluate secondary radionuclides and determine controlling radionuclides. This evaluation should be done by the seventh day.
- e. Assess individual lots of food. This is a later-term consideration to support controls that have been implemented.

Table V1.5.1. Ingestion Assessment Prioritized Tasks

Purpose: This table lists a series of prioritized tasks and the necessary information to complete each task and indicates which Section 5 (or Volume 3) method to use.

Crucial Tasks	Necessary Information	Method
For a LWR accident, evaluate exposure rate to determine where the Ingestion PAG may be met or exceeded.	Exposure rates ($\mu\text{R/hr}$) at 1 m AGL.	M.V3.2.3 Evaluating Exposure Rates (Ingestion DRL) from Light Water Reactor Accidents.
For accidents with gamma emitters, develop DRLs for deposition marker-radionuclide levels to determine where the Ingestion PAG may be met or exceeded.	Isotopic mix (relative abundance) based on samples, references, or information provided by the operator. <i>and</i> Deposition levels of the marker radionuclide.	M.5.1 Computing Surrogate-Radionuclide Derived Response Levels for Depositions.
For accidents with no gamma emitters, evaluate entire isotopic mix of the deposition to determine where the Ingestion PAGs may be met or exceeded.	Isotopic concentration (relative abundance) based on samples, references, or information provided by the operator. <i>and</i> Comprehensive isotopic analysis of deposition.	M.5.2 Assessing Deposition Measurements.
Assess food concentrations to confirm where the PAGs may be met or exceeded.	Isotopic analyses of milk, drinking water, meat, eggs, fish, and fresh produce.	M.5.3 Assessing Food, Milk, and Water Product Samples.
Support Tasks	Necessary Information	Method
Estimate the dose from ingestion of surface contamination (dirt).	Isotopic levels of deposition.	M.5.11 Computing Dose from Ingestion of Contaminated Dirt (Surface Contamination).

Assess the forage and water fed to milk-producing animals to determine if their milk may cause doses that meet or exceed the PAG.	Isotopic analysis of cow forage and drinking water.	M.5.4 Assessing Cow/Goat Forage and Water for Milk Pathway.
Assess milk from animals on stored feed in areas where other pathways may result in milk contamination.	Isotopic analysis of milk samples.	M.5.5 Evaluating Milk Contamination from Cows or Goats on Stored Feed.
Develop food, water, and milk concentration DILs for radionuclides not listed in Table 5.2 or use different assumptions (<i>e.g.</i> , consider processes to reduce contamination or different PAG levels).		M.5.6 Computing Food Concentration Derived Intervention Levels.
Develop DRLs for cow forage and water for radionuclides not listed in Table 5.10 or use different assumptions.		M.5.7 Computing Cow/Goat Forage and Water Concentration Derived Response Levels.
Develop DRLs for deposition that may be an ingestion concern for radionuclides not listed in Table 5.4 or use different assumptions.		M.5.8 Recomputing Deposition Derived Response Levels.
Estimate the potential peak concentration in milk.	Isotopic analysis of cow's milk samples.	M.5.9 Estimating Concentration in Cow's Milk after Intake.
Calculate the dose from ingestion of contaminated food.	Isotopic analysis of food, milk, and water samples.	M.5.10 Computing Ingestion Dose for Food, Milk, or Water Concentrations.
Develop DCFs for radionuclides not listed in Table 5.7 or use different assumptions.		M.5.12 Recomputing Ingestion Dose Conversion Factors.

METHOD M.5.1 USING SURROGATES IN LIEU OF DIFFICULT MEASUREMENTS

Purpose: Encourage and overview the use of easily performed measurements as surrogates for difficult to perform measurements.

Discussion: Often quantities required for decisions or reporting cannot be measured easily, if at all. Substitution of easily measured quantities named “markers” or “surrogates” for these problematic quantities is both acceptable and encouraged. Surrogates, called marker radionuclides, are widely used by the Assessment Manual. Specifically, the manual has used both exposure rate and a user-selected radionuclide as markers. The quantities, which must be measured to assess ingestion pathway concerns, are often quite difficult to measure. The difficulty usually arises because sophisticated fixed-laboratory analyses are required. Therefore, adaptation of the ingestion assessment methods to surrogate measurements is strongly encouraged. Particulars of the adaptation depend upon the details of the problem at hand. The scenario-specific assessments found in Volume 3 utilize surrogates when appropriate.

Steps: The basic method for using surrogates is described in the steps below. Opportunities for variations to optimize measurement design should be explored and exploited. Judgment and experience are vital allies.

Step 1. Understand the surrogate concept. The basic concept of measurement via surrogate is captured in the equation below:

$$Q_x = S_{m,x} \times Q_m$$

Where:

Q_m = easily measured surrogate quantity (exposure rate, gross alpha, ^{137}Cs , ^{241}Am ...)

Q_x = estimate of the difficult to measure quantity (doses, ^{90}Sr , ^{239}Pu ...)

$S_{m,x}$ = the average ratio of the difficult to easily measured quantities (Q_x / Q_m)

Step 2. Select a surrogate. The key to utilizing surrogates is prudent selection of the surrogate. Seek the following attributes:

- Easy to measure: 1) simple instrumentation, 2) few steps to measure, and 3) signature easily recognized
- Highly detectable: 1) not prone to interference or aliasing, and 2) low background competition (natural or fallout)
- Reliable surrogate ratio ($S_{m,x}$): 1) not temporally or spatially variable, and 2) not technique or instrument dependent
- Common surrogates (markers) are exposure rate (gross γ), gross α activity, gross β activity, ^{241}Am , ^{137}Cs .

Step 3. Determine the surrogate ratio.

The surrogate ratio ($S_{m,x}$) is defined as:

$$S_{m,x} = \frac{\text{Quantity to be estimated } (Q_x)}{\text{Easily measured quantity } (Q_m)} \text{ for a specific radionuclide mix}$$

The ratio can be computed, measured or determined from a combination of both. That is, both numerator and denominator may be calculated, or one can be calculated and the other measured or both could be measured.

If the quantity to be estimated (Q_x) is a dose, then the amount of dose must be computed as the sum of contributions from each radionuclide in the mix. Likewise, if either Q_x or Q_m is exposure rate, then it is the sum of contributions from each radionuclide in the mix. In all cases assure that the assumptions implicit to the conversion factors are consistent with the situation. If not, recompute the conversion factors.

If measured values are to be used, assure that the selected value is both representative and statistically reliable. This will require evaluation and averaging of an ensemble of high quality measurements. Generally, empirical determination is superior to calculation, because it implicitly accounts for subtle effects.

Step 4. Compute the decision level in terms of the surrogate.

The basic concept of using a surrogate measurement to indicate exceedance of a decision level is captured in the equation below:

$$\text{Decision Level} = \frac{PAG}{S_{m,x}}$$

The Decision Level may have a variety of names. FRMAC has the term Derived Response Levels (DRL) and Derived Intervention Levels (DIL). Another term used by the IAEA for the same concept is Operational Intervention Level (OIL). Similarly, this approach is extended to Decontamination and Decommissioning work, where the term Derived Concentration Guide Line (DCGL) is used.

Step 5. Estimate the desired quantity from the surrogate.

Simply apply the definition from above:

$$Q_x = S_{m,x} \times Q_m$$

METHOD M.5.2 ASSESSING DEPOSITION MEASUREMENTS/SAMPLES FOR THE FDA PRINCIPAL RADIONUCLIDES

Purpose: This method considers the deposition levels of the FDA principal radionuclides to determine if consumption of produce grown in an area would lead to a dose that equals or exceeds the PAG.

Discussion: This method applies to immediate consumption of directly contaminated produce grown in an area with this level of deposition. Use Worksheet 5.1 (Deposition Concentration Ingestion Analysis) to evaluate deposition of the five groups of radionuclides of primary interest. The worksheet contains deposition DRLs that were computed from the FDA DILs assuming 2 kg/m² productivity and a retention factor of 1.0 for iodine and 0.2 for all other radionuclides. The worksheet comprises four tests. If any one test fails, then the food from the area may exceed the FDA guidelines. This procedure addresses only the principal radionuclides.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Obtain the measured isotopic level of deposition.
Step 2 Calculate measured level to ingestion DRL ratios.
Step 3 Use ratios to assess sample/measurement.

Step 1. Obtain the measured isotopic level of deposition.

Obtain isotopic mix of the deposition using spectral analysis.

Step 2. Calculate ingestion DRL to sample level ratios.

Using Worksheet 5.1 (Deposition Concentration Ingestion Analysis), evaluate the isotopic deposition level, to determine if the FDA DILs (and therefore, the HHS PAG) may be met or exceeded, by completing the following steps. In the steps below letters in parentheses indicate columns.

The derived response levels (DRL_{Ingg}) in Table 5.4 (and Worksheet 5.1) are the deposition levels of a single radionuclide (or radionuclide group) capable of producing food concentrations equal to FDA DILs. Therefore, if one or more of these DRLs is met or exceeded, ingestion of contaminated produce from the area may result in doses that meet or exceed the ingestion PAG.

Step 2.1. ⁹⁰Sr and ¹³¹I Tests

1. Enter the deposition concentration for ⁹⁰Sr and ¹³¹I, in Column A.
2. Note units of deposition measurement; select DRL with matching units from Column B.
3. Determine ratios for both nuclides by dividing concentration (A) by DRL (B) selected above; enter in Column C.

-
4. If the ratio for either ^{90}Sr or ^{131}I (C) is greater than or equal to 1.0, mark such in Column D with an **X**.

Step 2.2. $^{134}\text{Cs} + ^{137}\text{Cs}$ Test

1. Enter the deposition concentration for ^{134}Cs and ^{137}Cs , in Column A.
2. Sum the concentrations and enter at the bottom of Column A as “Sum Σ A.”
3. Note units of deposition measurement; select DRL with matching units from Column B.
4. Determine ratio by dividing “Sum Σ A” (A bottom row) by proper DRL (B); enter ratio in Column C.
5. If the ratio (C) is greater than or equal to 1.0, mark Column D with an **X**.

Step 2.3. $^{238}\text{Pu} + ^{239}\text{Pu} + ^{241}\text{Am}$ Test

1. Enter the deposition concentrations for ^{238}Pu , ^{239}Pu , ^{241}Am , in Column A.
2. Sum the concentrations and enter at the bottom of Column A as “Sum Σ A.”
3. Note units of deposition measurement; select DRL with matching units from Column B.
4. Determine ratio by dividing “Sum Σ A” (A bottom row) by proper DRL (B); enter ratio in Column C.
5. If the ratio (C) is greater than or equal to 1.0, mark Column D with an **X**.

Step 2.4. $^{103}\text{Ru} + ^{106}\text{Ru}$ Test

1. Enter the deposition concentrations for ^{103}Ru and ^{106}Ru , in Column A.
2. Note units of deposition measurement; select DRL with matching units from Column B for both radionuclides.
3. Determine ratio for each by dividing concentration (A) by proper DRL (B); enter in Column C.
4. Sum the ratios at the bottom of Column C as “Sum Σ A.”
5. If either the ratio or the ratio sum (C) is greater than or equal to 1.0, mark Column D with an **X**.

Step 3. Use ratios to assess sample.

Determine if consumption of produce at the location of the deposition mix will meet or exceed the Ingestion PAG.

Review Column D. If marked with an **X** for any test (meaning the ratio in Column C is greater than or equal to 1.0), then the sample meets or exceeds the PAG. Mark the box **This Sample Exceeds PAG**. If no test is flagged with an **X** in Column D (meaning all test ratios are less than 1.0), then the sample is acceptable. Mark the box **This Sample is OK**.

METHOD M.5.3 ASSESSING FOOD, MILK, AND WATER PRODUCT SAMPLES

Purpose: This method is used to determine if contamination levels found in food (including milk) or drinking water will result in doses that equal or exceed the HHS Ingestion PAG.

Discussion: This method uses the FDA DILs. These DILs can be obtained from tables or methods found in the manual. If the State(s) has developed DRLs that are compatible with Federal guidance, they should be used.

Remember to apply the following application guidelines: (a) tests are valid for food as prepared for consumption, (b) raw foods get no credit for potential contamination reduction measures, and (c) spices should be compared to 10 times the DIL. For concentrates, notes to Table 2 in FDA98 indicate that they should be evaluated as reconstituted. This is assuming that the reconstitution water was not contaminated.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Obtain the measured radionuclide concentrations in the sample.
Step 2 Complete Worksheets 5.2 and 5.3.
Step 3 Assess whether the sample exceeds the PAG.

Step 1. Obtain the measured radionuclide concentrations in the sample.

Obtain the concentration of the principal radionuclides in the water, milk, or the fresh weight of the food. The principal radionuclides contributing to ingestion dose for an LWR accident are listed in Table V3.2.4.

Note: If dry weight is used, multiply it by the appropriate factor from Table 5.5 to estimate the fresh weight.

Step 2. Food Contamination Analysis**Step 2.1. Principal Radionuclide Analysis**

This is the principal means of assessment for ingestion concerns. Use Worksheet 5.2 (Food Contamination Analysis – Principal Radionuclides) to assess human foods for the FDA principal radionuclides. The procedure is nearly identical to the procedure for deposition analysis but makes no assumptions about deposition details. Only the five groups of radionuclides of primary interest are addressed here. The secondary radionuclides for which FDA has provided DILs are discussed below. The worksheet comprises four tests. If any one test fails for a food sample, then that food exceeds the FDA guidelines. In the steps below, letters in parentheses indicate columns.

Step 2.1.1. ⁹⁰Sr and ¹³¹I Tests

1. Enter the food concentration for ⁹⁰Sr and ¹³¹I, in Column A.

2. Note units of concentration measurement; select DIL with matching units from Column B.
3. Determine ratios for both nuclides by dividing concentration (A) by proper DIL (B); enter in Column C.
4. If the ratio for either ^{90}Sr or ^{131}I (C) equals or exceeds 1.0, mark such in Column D with an **X**.

Step 2.1.2. $^{134}\text{Cs} + ^{137}\text{Cs}$ Test

1. Enter the food concentration for ^{134}Cs and ^{137}Cs , in Column A.
2. Sum the concentrations and enter at the bottom of Column A as "Sum ΣA ."
3. Note units of concentration measurement; select DIL with matching units from Column B.
4. Determine ratio by dividing "Sum ΣA " (A bottom row) by proper DIL (B); enter ratio in Column C.
5. If the ratio (C) equals or exceeds 1.0, mark Column D with an **X**.

Step 2.1.3. $^{238}\text{Pu} + ^{239}\text{Pu} + ^{241}\text{Am}$ Test

1. Enter the food concentrations for ^{238}Pu , ^{239}Pu , ^{241}Am , respectively, in Column A.
2. Sum the concentrations and enter at the bottom of Column A as "Sum ΣA ."
3. Note units of concentration measurement, select DIL with matching units from Column B.
4. Determine ratio by dividing "Sum ΣA " (A bottom row) by proper DIL (B); enter ratio in Column C.
5. If the ratio (C) equals or exceeds 1.0, mark Column D with an **X**.

Step 2.1.4. $^{103}\text{Ru} + ^{106}\text{Ru}$ Test

1. Enter the food concentrations for ^{103}Ru and ^{106}Ru , in Column A.
2. Note units of concentration measurement; select DIL with matching units from Column B for both radionuclides.
3. Determine ratio for each by dividing concentration (A) by proper DIL (B); enter in Column C.
4. Sum the ratios at the bottom of Column C as "Sum ΣC ."
5. If either the ratio or the ratio sum (C) equals or exceeds 1.0, mark Column D with an **X**.

Finally, review Column D. If marked with an **X** for any test (meaning the ratio in Column C equals or exceeds 1.0), then the sample exceeds PAG. Mark the box **This Sample Exceeds PAG**. If no test is flagged with an **X** in Column D (meaning all test ratios are less than 1.0), then the sample is acceptable. Mark the box **No Principal Radionuclide \geq DIL**.

Step 2.2. Secondary Radionuclide Analysis

This procedure assesses the contribution of the secondary radionuclides and identifies the radionuclides that control the assessment outcome for human foods. The FDA methodology identified nine radionuclides as those most likely to dominate assessment results (^{90}Sr , ^{131}I , ^{134}Cs , ^{137}Cs , ^{103}Ru , ^{106}Ru , ^{238}Pu , ^{239}Pu , and ^{241}Am). For the nuclear reactor, nuclear weapons, and radionuclide thermoelectric generator/radioisotope heater unit (RTG/RHU) spacecraft accident scenarios, these will generally suffice. However, there exist circumstances, particularly involving fuel reprocessing, waste and certain reactor accidents, where contributions by radionuclides other than those nine will be important or controlling. Therefore, 15 additional DILs are provided in the FDA guidance for those radionuclides next most likely to be of significance. The following procedure evaluates those radionuclides and establishes the dominant radionuclides.

Use Worksheet 5.3, “Food Contamination Analysis – Secondary Radionuclides,” to assess the significance of the 15 remaining nuclides and identify the dominant species. Assess the 15 secondary radionuclides by ratio of food concentration to the respective DIL (Step 2.2.1). If any one test fails (ratio ≥ 1.0), then that food exceeds the FDA guidelines. Define the group of dominant radionuclides (Step 2.2.2). Rank order the ratios of the secondary radionuclides with those obtained from Worksheet 5.2 for the nine principal radionuclides. All radionuclides with a ratio greater than 1/5 of the most dominant radionuclide or with a ratio greater than or equal to 1.0, are defined as dominant radionuclides. Part 1 of Worksheet 5.3 serves as the supplement to Worksheet 5.2 to complete the “Food Contamination Analysis” and document whether the secondary radionuclides need to be included in the food analysis.

If any secondary radionuclides are among the set of dominant radionuclides, then they must be included in future assessments of foods. If a consistent set of radionuclides can be demonstrated as dominant, then assessment need only be performed for those radionuclides. Be aware that the list of dominant radionuclides may change with time, because of decay.

In the steps below letters in parentheses indicate columns.

Step 2.2.1. Assess Secondary Radionuclides

1. Enter the food concentrations for each radionuclide in Column A.
2. Note units of concentration measurement; select DIL with matching units from Column B.
3. Determine ratios for both nuclides by dividing concentration (A) by proper DIL (B); enter ratio in Column C.
4. If the ratio in any row of Column C equals or exceeds 1.0, then the sample exceeds the PAG. Mark the box **This Sample Exceeds PAG**. If the ratios in all rows of Column C are less than 1.0, then the sample is acceptable. Mark the box **This Sample is OK**. Ignore Columns D and E for now.

Step 2.2.2. Determine Dominant Radionuclides

1. Complete Worksheet 5.2, “Food Contamination Ingestion Analysis – Principal Radionuclides,” if that has not already been done
2. Transcribe results of the four tests from Column C of Worksheet 5.2 to Column C of Part 2 of Worksheet 5.3.
3. In Column D, rank order ratios of both Part 1 and Part 2 results with **1** being the greatest ratio.
4. In Column E, mark with an **X** all radionuclides whose ratios (Column C) meet one of the following criteria:
 - a. the ratio equals or exceeds 1.0 or
 - b. the ratio is greater than 1/5 of the most dominant (largest) radionuclide ratio.
5. These are the dominant radionuclides. Attach Worksheet 5.3 to Worksheet 5.2 as part of the Food Sample Analysis.

Step 3. Assess the sample.

Determine if concentrations in the food or water may meet or exceed the PAG.

If the ratio of the concentration in the food sample to the FDA DIL is greater than or equal to 1.0 for any of the tests, the PAG may be exceeded by consumption of the food or water.

Alternatively, the calculation may be done specifically for goats, if goat-specific DRLs are calculated using method m.5.8. If this were done, the comparison value would be 1 instead of 0.25.

METHOD M.5.3B ASSESSING POTABLE WATER SAMPLES

Reserved for EPA drinking water assessment method.

FRMAC Assessment has elected to treat drinking water as food until EPA issues specific guidance.

METHOD M.5.4 ASSESSING COW/GOAT FORAGE AND WATER FOR MILK PATHWAY

Purpose: This method is used to determine if the consumption of contaminated forage or water by a cow or goat produces milk in excess of the Ingestion PAGs as expressed by the DILs.

Discussion: This method uses DRLs. These DRLs can be obtained from tables or methods found in the manual. However, if the State(s) has developed DRLs that are compatible with Federal guidance, they should be used.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Obtain the measured isotopic concentration in the sample.
Step 2 Calculate the DRL-to-sample concentration ratios.
Step 3 Assess the sample.

Step 1. Obtain the measured isotopic concentration in the sample.

Obtain the concentration in the fresh forage or water consumed by the cow or goat. If fresh forage results are reported on a dry weight basis, estimate fresh weight as follows (Table 5.5 – adapted from Table 5.16 in NRC83):

$$\begin{aligned} \text{Dry Weight} \times 4.5 &= \text{Fresh Weight} \\ (\quad \text{kg}) \times 4.5 &= (\quad \text{kg}) \end{aligned}$$

Step 2. Calculate the DRL-to-sample concentration ratios.

Using Worksheet 5.4, determine if the contamination in cow or goat forage or water produces doses in excess of the PAG by reviewing the ratios of the measured concentrations to cow forage concentration DRLs by completing Steps 2.1 through 2.4 (The derivation is presented below.).

Step 2.1. Record in Column A of Worksheet 5.4 the isotopic concentration ($\mu\text{Ci}/\text{kg}$ fresh weight or $\mu\text{Ci}/\text{L}$) in the sample.

Step 2.2. Record in Column B of Worksheet 5.4 the cow/goat forage or water concentration $\text{DRL}_{\text{Ing,cow}}$ levels ($\mu\text{Ci}/\text{kg}$ or $\mu\text{Ci}/\text{L}$) from State(s) or Table 5.10 or by using Method M.5.7. Use Method M.5.7 for radionuclides that are not listed in Table 5.10 or to consider different assumptions (e.g., different PAG levels).

Step 2.3. For each radionuclide on Worksheet 5.4, divide Column A by Column B and record the answer in Column C.

Step 3. Assess the sample.

Determine if the cow or goat forage or water concentrations may result in milk that exceeds the HHS PAG.

If any of the values in Column C (from Step 2.3) is –

For cows:

- Greater than or equal to 1, this indicates that the milk may result in doses in excess of PAG.

For goats:

- Greater than or equal to 0.25, this indicates that the milk may result in doses in excess of PAG.

Method M.5.4 – Derivation of Cow/Goat Forage Assessment Criteria

The cow forage concentration Derived Response Levels ($DRL_{Ing,cow}$) in Table 5.10 are the forage or cow drinking water concentrations of a single radionuclide capable of producing milk ingestion dose equal to PAG in the limiting age group. Therefore, the milk may produce doses in excess of the Ingestion PAG if any of the ratios of the measured concentrations to DRL concentrations is greater than or equal to 1 as shown below.

$$\frac{C_{cow,i}}{DRL_{Ing,cow,i}} \geq 1$$

$$\frac{(\mu Ci/kg, \mu Ci/L)}{(\mu Ci/kg, \mu Ci/L)} \geq 1$$

Where

- $C_{cow,i}$ ($\mu Ci/kg$ or $\mu Ci/L$) = Cow forage or water concentration of radionuclide i.
 $DRL_{Ing,cow,i}$ ($\mu Ci/kg$ or $\mu Ci/L$) = Cow forage or water concentration DRL for radionuclide i from State(s) or Table 5.10 or by using Method M.5.7.

METHOD M.5.5 EVALUATING MILK CONTAMINATION FROM COWS OR GOATS ON STORED FEED

Purpose: This method provides guidance for assessing the potential for contamination in milk produced by animals on stored feed.

Discussion: Most milk-producing animals are raised on stored feed. However, they may be allowed to graze outdoors and thus be exposed to contaminated grass, water, etc. In addition, inhalation may be raised as a concern even though inhalation of contaminated air is not an important milk contamination pathway.

The area where consumption of contaminated forage may produce milk that exceeds DILs will bound the area where other pathways (*e.g.*, inhalation) may be a concern. Milk samples should be taken from cows and goats on stored feed in the area where exposure rates (Method V3.2.3 for reactor accidents) or ground concentrations (Methods M.5.1 or M.5.2) indicate that animals not on stored feed could produce milk exceeding the FDA DILs.

Evaluate the sample concentrations using Method M.5.3.

METHOD M.5.6 COMPUTING FOOD CONCENTRATION DERIVED INTERVENTION LEVELS

Purpose: This method describes the process for calculating food, milk, and water concentration DILs for radionuclides not contained in Table 5.2 or using different assumptions. Use Method M.5.3 to evaluate food, milk, and drinking water samples.

Discussion: Food concentration DILs are concentrations of radionuclides in human food, milk, and water capable of producing a dose exceeding the HHS Ingestion PAG. The FDA DILs are found in Table 5.2. Table 5.2 is (1) based on HHS PAG levels, (2) for 1 year consumption, (3) for average consumption rates, and (4) without any actions to reduce the dose (*e.g.*, filtration, allowing decay, washing). Use this method to calculate food, milk, and water concentration DILs for radionuclides not contained in Table 5.2 or using different assumptions.

Steps: The steps performed in this method are summarized in the box below.

- Step 1 Calculate food concentration DILs.
Step 2 Evaluate food, milk, and water sample concentrations.

Step 1. Calculate food concentration DILs.

Calculate the concentration for a radionuclide i (DIL_i in $\mu\text{Ci}/\text{kg}$, or other appropriate units of activity) that is capable of exceeding the Ingestion PAGs by substituting the corresponding dose conversion factor in the following equation:

$$\frac{P_{Ing}}{f \times U_f \times DCF_{Ingi}} = DIL_i$$

$$\frac{(\quad mrem)}{(\quad) \times (\quad kg) \times (\quad mrem / \mu Ci)} = (\quad \mu Ci / kg)$$

Where

P_{Ing} = Ingestion PAG is the projected dose from consuming contaminated food that warrants taking protective actions. HHS recommends a PAG of 500 mrem (5 mSv) CEDE, or 5 rem (50 mSv) CDE to individual tissues and organs, whichever is more limiting.

U_f = Food intake (kg) for the period of intake by the population of interest. The annual food-consumption values used in this manual are listed in Table 5.7 and are the same as those used in FDA98. The period of intake is one year, except for very short-lived radionuclides. For a short-lived nuclide (half-life less than 54 days), the period of intake (DI_i) is the nearest (rounded up) whole number of days required for the nuclide to decay to less than 1% of its initial activity. The food

intake for each short-lived nuclide is adjusted by the ratio of the period of intake to one year, as follows

$$\frac{DI_i}{365} \times \text{Annual Intake} = \text{Calculated Intake}$$

Where

DI_i = Period of intake is the nearest (rounded up) whole number of days required for the nuclide to decay to less than 1% of its initial activity.

$$\frac{-\ln(0.01)}{\lambda_i} = DI_i$$

Where

$$\lambda_i = \text{Radiological decay constant} = (\ln(2)) / T_{1/2}$$

$$T_{1/2} = \text{Radiological half-life.}$$

DCF_{Ingi} = Ingestion Dose Conversion Factors are the dose equivalent (mrem/ μ Ci, or other appropriate units of activity, applying the corresponding unit conversion factor(s) to calculate the DIL in the desired units) to the tissue and population being considered. These are the same as the dose coefficients described in FDA98.

The age groups used, the choice of DCF_{Ingi} for each age group, and the consumption values for each age group are discussed in Appendix E of FDA98. Follow the guidance given there to calculate DILs for radionuclides not provided in FDA98.

Step 2. Evaluate food, milk, and water sample concentrations.

Use the process described in Method M.5.3 to evaluate food, water, or milk using the DILs calculated in this method.

METHOD M.5.7 COMPUTING COW/GOAT FORAGE AND WATER CONCENTRATION DERIVED RESPONSE LEVELS

Purpose: This method is used to calculate animal forage and water concentration DRLs for radionuclides not contained in Table 5.10 or to use different assumptions. Use Method M.5.4 to evaluate animal forage and water samples.

Discussion: The cow forage or water concentrations Derived Response Levels ($DRL_{Ing-Cow}$) are concentrations of radionuclides in cow forage or drinking water capable of producing a concentration in milk exceeding FDA DILs. The fresh forage and water concentration DRLs for radionuclides included in FDA98 are found in Table 5.10. Table 5.10 assumes (1) milk concentrations are at the level of the FDA DILs, (2) the primary source of the cows' food or water is directly contaminated, (3) nothing is done to reduce contamination, (4) the milk is consumed immediately by an infant, and (5) 30 days of intake. Use this information to calculate DRLs for radionuclides not contained in Table 5.10 or to use different assumptions.

Steps: This method includes the following step. The derivation is presented following the step.

Step 1. Calculate the $DRL_{Ing,cow,i}$ for radionuclide i for forage or water consumed by milk cows as follows:

$$\frac{DIL_i \times CF}{U_{cow} \times f_{mi} \times CF} = DRL_{Ing,cow,i}$$

$$\frac{\left(\frac{pCi/kg}{kg/d} \right) \times \left(\frac{\mu Ci/pCi}{d/L} \right)}{\left(\frac{kg/d}{kg/d} \right) \times \left(\frac{\mu Ci/L}{L/kg} \right)} = \left(\frac{\mu Ci}{kg} \right)$$

Where

DIL_i = FDA DIL (pCi/kg) is the concentration of radionuclide i in milk (or other food) capable of producing doses in excess of the PAG, from Table 5.2 or calculated using Method M.5.6.

U_{cow} = Ingestion rate of fresh forage or water by cows. This manual assumes 50 kg/d for fresh forage and 60 L/d for water (Table 5.9).

f_{mi} = Transfer factors ($\mu Ci/L$)/($\mu Ci/day$) for radionuclide i for cow's milk from Table 5.6.

CF = Conversion factor to convert mass to volume or pCi to μCi .

$DRL_{Ing,cow,i}$ = Cow forage and water concentration Derived Response Level ($\mu Ci/kg$ or $\mu Ci/L$) for radionuclide i.

Method M.5.7. Derivation of Cow Forage Concentration DRL

Starting with the concentration in the cow's forage (C_{cow}), the concentration in milk is estimated as follows:

$$C_{Milk,i} = C_{cow,i} \times U_{cow} \times f_{mi} \times CF$$

$$\frac{\mu Ci}{kg} = \left(\frac{\mu Ci}{kg} \right) \times \left(\frac{kg}{d} \right) \times \left(\frac{\mu Ci / L}{\mu Ci / d} \right) \times \left(\frac{L}{kg} \right) \quad (1)$$

Substituting the FDA DIL for milk concentration in Equation 1, solve for the concentration in a cow's forage (or water) (C_{cow}) that will result in a concentration in milk equal to the DIL, as shown in Equation 2. This is the forage concentration Derived Response Level ($DRL_{Ing,cow,i}$).

$$DRL_{Ing,cow,i} = \frac{DIL_i \times CF}{U_{cow} \times f_{mi} \times CF}$$

$$\frac{\mu Ci}{kg} = \frac{\left(\frac{pCi}{kg} \right) \times \left(\frac{\mu Ci}{pCi} \right)}{\left(\frac{kg}{d} \right) \times \left(\frac{\mu Ci / L}{\mu Ci / d} \right) \times \left(\frac{L}{kg} \right)} \quad (2)$$

Where

- DIL_i = Ingestion Derived Intervention Level for radionuclide i.
- $C_{milk,i}$ = Concentration in milk.
- $C_{cow,i}$ = Concentration in cow's forage (or water).
- CF = Conversion Factors needed to convert between units (e.g., 10^{-6} $\mu Ci/pCi$; 1 L/kg for milk, assuming the same density as water (assumed to be equal to the density of water though this may introduce an error or 4% as mil has a density range of 1027 to 1033 kg/m^3 at 20°C).
- U_{cow} = Cow's ingestion rate of fresh forage or water.
- f_{mi} = Transfer factors ($\mu Ci/L$)/($\mu Ci/d$).
- $DRL_{Ing,cow,i}$ = Forage (or water) concentration DRL.

METHOD M.5.8 RECOMPUTING DEPOSITION DERIVED RESPONSE LEVELS

Purpose: This method is used to calculate DRLs for deposition for radionuclides not contained in Table 5.4 or to use different assumptions. These Derived Response Levels (DRL_{Ingg}) are levels of a radionuclide on the ground where fresh produce or milk-cow forage has been directly contaminated at a level capable of producing a concentration in food meeting or exceeding the DIL and thereby, a dose exceeding HHS Ingestion PAG. Use Method M.5.2 to evaluate deposition levels.

Discussion: The deposition DRLs for the radionuclides contained in FDA98 are found in Table 5.4. The DRLs in Table 5.4 assume (1) FDA DILs, (2) the food is directly contaminated, and (3) food is consumed for 1 year. This method is used to calculate DRLs for radionuclides not contained in Table 5.4 or using different assumptions.

Steps: This method consists of the following step. The derivation follows.

Step 1. Calculate the ingestion deposition DRL_{Ingg} ($\mu\text{Ci}/\text{m}^2$) for directly contaminated produce as follows:

$$\frac{DIL_i \times Y}{r \times CF} = DRL_{Ingg}$$

$$\left(\frac{p\text{Ci} / \text{kg}}{\quad} \right) \times \left(\frac{\text{kg} / \text{m}^2}{\quad} \right) = \left(\quad \mu\text{Ci} / \text{m}^2 \right)$$

Where

DIL_i = Food concentration DIL is the concentration of radionuclide i in food (pCi/kg) that will produce an ingestion dose in excess of the PAG. The value is taken from Table 5.2 (based on FDA98) or calculated using Method M.5.6

Y = Productivity (kg/m^2) is the fresh weight of the food produced per square meter (kg/m^2). A value of $2 \text{ kg}/\text{m}^2$ is assumed (see Table 5.9).

r = Fraction of deposition that is retained on the crop. For fresh produce, 0.2 is used for particulates and 1.0 for iodines, as recommended by NRC77 (see Table 5.9).

CF = Conversion factor as needed (e.g., to convert pCi to μCi).

$DRL_{Ingg,i}$ = Deposition Derived Response Level ($\mu\text{Ci}/\text{m}^2$) for ingestion of radionuclide i .

Step 2. Calculate the ingestion deposition DRL_{Ingg} ($\mu\text{Ci}/\text{m}^2$) for milk-cow forage.

Step 2, Option A. Calculate the ingestion deposition DRL_{Ingg} ($\mu\text{Ci}/\text{m}^2$) for milk-cow forage using the cow's ingestion rate of fresh forage expressed in terms of mass.

$$\frac{DIL_i \times Y \times \rho_{milk}}{r \times f_{mi} \times U_{cow} \times CF \times e^{-\lambda_i t_f}} = DRL_{Ingg,i}$$

$$\frac{(\text{ pCi / kg}) \times (\text{ kg / m}^2) \times (\text{ kg / L})}{(\text{ }) \times \left(\frac{\mu\text{Ci / L}}{\mu\text{Ci / day}} \right) \times (\text{ kg / day}) \times (\text{ pCi / } \mu\text{Ci}) \times (\text{ })} = (\text{ } \mu\text{Ci / m}^2)$$

Step 2, Option B. Calculate the ingestion deposition DRL_{Ingg} ($\mu\text{Ci}/\text{m}^2$) for milk-cow forage using the cow's ingestion rate of fresh forage expressed in terms of grazing area.

$$\frac{DIL_i \times \rho_{milk}}{r \times f_{mi} \times UAF \times CF \times e^{-\lambda_i t_f}} = DRL_{Ingg,i}$$

$$\frac{(\text{ pCi / kg}) \times (\text{ kg / L})}{(\text{ }) \times \left(\frac{\mu\text{Ci / L}}{\mu\text{Ci / day}} \right) \times (\text{ m}^2 / \text{ day}) \times (\text{ pCi / } \mu\text{Ci}) \times (\text{ })} = (\text{ } \mu\text{Ci / m}^2)$$

Where

- DIL_i = Food concentration DIL is the concentration of radionuclide i in food (pCi/kg) that will produce an ingestion dose in excess of the PAG. The value is taken from Table 5.2 (based on FDA98) or calculated using Method M.5.6.
- Y = Productivity (kg/m^2) is the fresh weight of the food produced per square meter (kg/m^2). A value of $2 \text{ kg}/\text{m}^2$ is assumed (see Table 5.9).
- r = Fraction of deposition that is retained on the crop. For pasture, 0.5 is used as recommended by NRC77 (see Table 5.9).
- CF = Conversion factor as needed (e.g., to convert pCi to μCi).
- f_{mi} = Transfer factor for radionuclide i in cow's milk (see Table 5.6).
- ρ_{milk} = Density of milk (assumed to be equal to the density of water though this may introduce an error or 4% as milk has a density range of 1027 to $1033 \text{ kg}/\text{m}^3$ at 20°C).
- U_{cow} = Cow's ingestion rate of fresh forage (see Table 5.9).
- λ_i = Radioactive decay constant for radionuclide i.
- t_f = Time to market, a time factor (2 days, NRC77) to account for the time to get from activity on the pasture to milk ready for the receptor.
- UAF = Utilized area factor (effective area grazed by a cow in a day).
- $DRL_{Ingg,i}$ = Deposition Derived Response Level ($\mu\text{Ci}/\text{m}^2$) for ingestion of radionuclide i.

Method M.5.8, Step 1. Derivation of Ingestion Deposition DRLs for Directly Contaminated Produce

The concentration of radioactivity in produce contaminated by direct deposition can be estimated as shown in Equation 1.

$$C_{food}(pCi/kg) = \frac{C_g(\mu Ci/m^2) \times r \times CF(pCi/\mu Ci)}{Y(kg/m^2)} \quad (1)$$

Substituting the FDA DIL for food concentration in Equation 1, solve for the deposition level (C_g) resulting in a food concentration equal to the DIL as shown in Equation 2. This is the ingestion deposition derived response level (DRL_{Ingg}).

$$DRL_{Ingg,i}(\mu Ci/m^2) = \frac{DIL_i(pCi/kg) \times Y(kg/m^2)}{r \times CF(pCi/\mu Ci)} \quad (2)$$

Where

C_g = Concentration of deposited activity on terrain.

r = Fraction of deposition that is retained on the crop.

Y = Agricultural productivity — food produced per square meter.

CF = Conversion factor as needed (e.g., to convert pCi to μCi).

DIL_i = FDA Derived Intervention Level.

$DRL_{Ingg,i}$ = Deposition Derived Response Level ($\mu Ci/m^2$) for ingestion of radionuclide i .

Method M.5.8, Step 2. Derivation of Ingestion Deposition DRLs for Milk-Cow Forage

Option A. The concentration of radioactivity in milk produced by cattle grazing on pastures contaminated by direct deposition can be estimated as shown in Equation 1.

$$C_{milk} (pCi / kg) = \frac{C_g (\mu Ci / m^2) \times r \times f_{mi} \left(\frac{\mu Ci / L}{\mu Ci / day} \right) \times U_{cow} (kg / day) \times CF (pCi / \mu Ci) \times e^{-\lambda_i t_f}}{Y (kg / m^2) \times \rho_{milk} (kg / L)} \quad (1)$$

Substituting the FDA DIL for milk concentration in Equation 1, solve for the deposition level (C_g) resulting in a milk concentration equal to the DIL as shown in Equation 2. This is the ingestion deposition derived response level ($DRL_{Ingg,i}$) for the milk pathway.

$$DRL_{Ingg,i} (\mu Ci / m^2) = \frac{DIL_i (pCi / kg) \times Y (kg / m^2) \times \rho_{milk} (kg / L)}{r \times f_{mi} \left(\frac{\mu Ci / L}{\mu Ci / day} \right) \times U_{cow} (kg / day) \times CF (pCi / \mu Ci) \times e^{-\lambda_i t_f}} \quad (2)$$

Option B. An alternative method for specifying the cow's intake is the utilized area factor (UAF). This is the effective area grazed by a cow in a day. Using this approach, the concentration of radioactivity in milk produced by cattle grazing on pastures contaminated by direct deposition can be estimated as shown in Equation 3.

$$C_{milk} (pCi / kg) = \frac{C_g (\mu Ci / m^2) \times r \times f_{mi} \left(\frac{\mu Ci / L}{\mu Ci / day} \right) \times UAF (m^2 / day) \times CF (pCi / \mu Ci) \times e^{-\lambda_i t_f}}{\rho_{milk} (kg / L)} \quad (3)$$

This approach progresses similarly to the method illustrated above. Substituting the FDA DIL for milk concentration in Equation 3, solve for the deposition level (C_g) resulting in a milk concentration equal to the DIL as shown in Equation 4. This is the ingestion deposition derived response level ($DRL_{Ingg,i}$) for the milk pathway.

$$DRL_{Ingg,i} (\mu Ci / m^2) = \frac{DIL_i (pCi / kg) \times \rho_{milk} (kg / L)}{r \times f_{mi} \left(\frac{\mu Ci / L}{\mu Ci / day} \right) \times UAF (m^2 / day) \times CF (pCi / \mu Ci) \times e^{-\lambda_i t_f}} \quad (4)$$

Where

- f_{mi} = Transfer factor for radionuclide i in cow's milk.
- ρ_{milk} = Density of milk (assumed to be equal to the density of water).
- λ_i = Radioactive decay constant for radionuclide i.
- t_f = Time to market, a time factor (2 days, NRC77) to account for the time to get from activity on the pasture to milk ready for the receptor.
- UAF = Utilized area factor (effective area grazed by a cow in a day).

Other parameters are as previously defined.

METHOD M.5.9 ESTIMATING CONCENTRATION IN COW'S MILK AFTER INTAKE

Purpose: This method is used to estimate the iodine, cesium, and strontium concentrations in milk after a cow has consumed contaminated feed. Use Method M.5.3 to evaluate milk samples.

Discussion: The assessment is based on Charts 5.1, 5.2, and 5.3 (adapted from FEMA87 and Ng77). These curves are for a single contaminating event with the cattle continuing to graze on the contaminated area. The curves, therefore, show the reduction due to decay. Experience shows there to be a considerable variation in the time where the peak concentration may appear.

Step 1. Estimate the cow's milk concentrations as follows:

$$C_{m, t_0} \times \frac{C_{chart, t_1}}{C_{chart, t_0}} = C_{p, t_1}$$

$$\left(\mu Ci / L \right) \times \left(\frac{\mu Ci / L}{\mu Ci / L} \right) = \left(\mu Ci / L \right)$$

Where

C_{m, t_0} = Measured milk concentration at time t_0 after consuming contaminated feed.

C_{chart, t_1} = Concentration from Chart 5.1, 5.2, or 5.3 for time t_1 after consuming contaminated feed.

C_{chart, t_0} = Concentration from Chart 5.1, 5.2, or 5.3 for time t_0 after consuming contaminated feed.

C_{p, t_1} = Projected milk concentration at time t_1 after consuming contaminated feed.

METHOD M.5.10 COMPUTING INGESTION DOSE FOR FOOD, MILK, OR WATER CONCENTRATIONS

Purpose: This method is used to calculate the dose from consumption of contaminated food based on measured concentrations in food, milk, or water ($\mu\text{Ci}/\text{kg}$ or $\mu\text{Ci}/\text{L}$). Use DRLs or Method M.5.3 to determine if food, milk, or water samples may meet or exceed the DILs.

Discussion: The FDA guidance on accidental radioactive contamination (FDA98) provides intervention levels at which protective actions should be taken, but does not specifically address calculating the dose from ingesting a particular food. This method presents the process for performing a dose calculation for a food. There is no specific guidance on the period to use for the ingestion dose calculation. That depends on the food being considered and the length of time it will be available for consumption. The length of time a food is available for consumption can vary greatly. As an example, consider fresh produce. In some cases, the produce may be only eaten fresh and have a relatively short local growing and availability season (e.g., lettuce). However, in other cases the produce may be eaten both fresh and processed. This may be the case with items such as snow peas or berries, which may be eaten fresh, frozen, canned, or otherwise preserved. Thus, the period of time over which the food may be ingested depends on the food being considered and the use to which it will be put. Once this period is determined, it may be modified based on the half-life of the radionuclide being considered.

Steps: This method consists of the following step.

Step 1. Calculate the dose from consumption of contaminated food as follows:

$$\sum_i^n (C_{fi} \times U_f \times DI_i \times DCF_{Ingi}) \times \prod RF = D_{Ing}$$

$$\left(\mu\text{Ci} / \text{kg} \right) \times \left(\text{kg} / \text{d} \right) \times \left(\text{d} \right) \times \left(\text{mrem} / \mu\text{Ci} \right) \times \prod () = \left(\text{mrem} \right)$$

Where

D_{Ing} = Dose from ingestion.

C_{fi} = Contamination of radionuclide i in food f ($\mu\text{Ci}/\text{kg}$ or $\mu\text{Ci}/\text{L}$).

U_f = Amount of a food f (kg or L, as appropriate) consumed per day by the population of interest. The average consumption values used in this manual are listed in Table 5.7 (derived from EPA84) and have the same basis as those used in FDA98 (i.e., EPA84).

DI_i = Days of Intake is the period of time (whole days) over which the food is assumed to be consumed. This value is then limited by the shorter of one year or the time it takes the radionuclide to decay to less than 1% of its original activity. Thus, DI_i for a food with a short availability period, will be limited by the availability period or the decay time, while DI_i for a food with a long (e.g., continuous) availability period will be limited by one year or the decay time.

The limiting value of the period of intake is the nearest (rounded up) whole number of days required for the nuclide to decay to less than 1% of its initial activity.

$$\frac{-\ln(0.01)}{\lambda_i} = DI_i$$

Where

$$\lambda_i = \text{Radiological decay constant} = (\ln(2)) / T_{1/2}$$

$$T_{1/2} = \text{Radiological half-life.}$$

DCF_{Ingi} = Ingestion Dose Conversion Factors are the dose equivalent (mrem/ μ Ci) to the tissue and population receiving the highest dose from radionuclide *i*. Table 5.8 lists Ingestion DCFs used in this manual and their bases. Use Method M.5.12 for radionuclides not listed in Table 5.8 or to use different assumptions.

RF = Reduction Factor is the fraction of the contamination remaining after decay and any other process that is used to reduce the contamination before food is released for consumption. No credit is given in this manual to processes used to reduce the amount of contamination. The RF can be estimated as follows:

Decay. There is a period of decay that occurs before the period of intake begins.

$$e^{-\lambda T_d} = RF$$

Where

$$\lambda = \text{Radiological decay constant} = (\ln(2)) / T_{1/2}. \text{ Table 1.1 lists } \lambda.$$

$$T_{1/2} = \text{Radiological half-life. Table 1.1 lists } T_{1/2}.$$

$$T_d = \text{Time food is held up before consumption.}$$

Processing/filtering. A process such as filtering water, washing produce, or other treatment designed to remove contamination. The RF should be based on tests conducted before and after the process.

$$\frac{C_{After}}{C_{Before}} = RF$$

$$\left(\frac{\mu\text{Ci} / \text{kg}, L}{\mu\text{Ci} / \text{kg}, L} \right) = (\quad)$$

METHOD M.5.11 ESTIMATING DOSE FROM INGESTION OF CONTAMINATED SOIL (SURFACE CONTAMINATION)

Purpose: This method is used to calculate the dose from consuming contaminated dirt.

Discussion: Ingestion of contaminated dirt can occur when surface contamination is transferred from a surface to hands, toys, cigarettes, etc. Estimating dose from ingestion of contaminated dirt (surface contamination) discussion: "The dose from this pathway may be considered in the calculation of the dose for comparison with the relocation PAG.

Generally the contribution of this pathway is minor and it was therefore, not considered in the Relocation PAG. However, this pathway can become significant and even dominant in certain special cases. One such case is for long-term residence or outdoor work in areas contaminated with aged plutonium in surface soil (e.g., Rocky Flats).

The EPA *Exposure Factors Handbook* contains recommended values for soil ingestion. They are 50 mg/day for adults and 100 mg/day for children (EPA97a, section 4.7 and Table 4-23). The handbook additionally states that a conservative value of 200 mg/day may be used for children. Soil ingestion values may be presented in terms of area by application of an assumed soil density and mixing depth. These calculations use 1.6 g/cm³ for soil density, 0.1 mm for the layer of dust over pavement, and 1 mm for the surface layer of contaminated soil (EPA89, Chapter 1).

Human Ingestion Rate of Contaminated Soil				
Surface	Adult		Child	
	mg/day	m ² /day	mg/day	m ² /day
Pavement	50	3 × 10 ⁻⁴	100	6 × 10 ⁻⁴
Ground	50	3 × 10 ⁻⁵	100	6 × 10 ⁻⁵

Sources: EPA97a and EPA89

Based on the ingestion values recommended by EPA (EPA97a), this manual assumes an ingestion rate of 6.0 × 10⁻⁴ m²/d for the public.

Steps: This method consists of the following step.

Step 1. Calculate the dose from ingesting dirt contaminated with radionuclide i as follows:

$$\sum_i^n (C_{gi} \times U_{Dirt} \times DI_i \times DCF_{Ingi}) = D_{Ing}$$

$$\left(\mu\text{Ci} / \text{m}^2 \right) \times \left(\text{m}^2 / \text{d} \right) \times \left(\text{d} \right) \times \left(\text{mrem} / \mu\text{Ci} \right) = \left(\text{mrem} \right)$$

Where

DCF_{Ingi} = Ingestion Dose Conversion Factor -- the dose equivalent (mrem/ μ Ci) from radionuclide i to the tissue and population for which the calculation is being done. Table 5.8 lists the Ingestion DCFs. Use Method M.5.12 for radionuclides not listed in Table 5.8 or to use different assumptions.

C_{gi} = Deposition contamination of radionuclide i (μ Ci/ m^2).

U_{Dirt} = Human ingestion rate for surface contamination (dirt) in m^2/d . Assume $6 \times 10^{-4} m^2/d$.

DI_i = Days of Intake is the period that people are expected to remain on contaminated ground, corrected for radioactive decay. The default assumption for this Method is to use a one-year exposure period. Therefore, days of intake is equal to the Intermediate Phase Effective exposure period, which is calculated as follows, except that it is expressed in days instead of hours:

$$\begin{aligned} T_{Ipeepi} &= \int_0^{8760} e^{-\lambda t} dt \\ &= \frac{1}{\lambda} (1 - e^{-\lambda \times 8760}), \end{aligned}$$

Where

t = time in hours (8760 is the number of hours in one year) and

λ = radioactive decay constant ($(\ln 2)/T_{1/2}$)

The Days of Intake is then calculated as follows:

$$DI_i = T_{Ipeepi} / 24$$

METHOD M.5.12 RECOMPUTING INGESTION DOSE CONVERSION FACTORS

Purpose: This method is used to calculate Ingestion Dose Conversion Factors (DCF_{Ingi}) for radionuclides not listed in Table 5.8 or to use different assumptions.

Discussion: FDA DILs are calculated for the most limiting tissue and component of the population (those receiving the highest dose) for each radionuclide considered (FDA98). For milk ingestion, the infant is expected to be limiting. Considering ingestion rates and dose factors, the child was considered a conservative representation of the general population. The DCFs in Table 5.8 are for the infant and the child (10-years-old). The Ingestion DCFs used in this manual are from ICRP-56 (ICRP89), where available, and from NRPB87 for radionuclides not contained in ICRP-56. The Ingestion DCFs in the EPA Federal Guidance Report No. 11 (EPA88) were not used because they were for the adult. This method is used to calculate Ingestion Dose Conversion Factors (DCF_{Ingi}) for radionuclides not listed in Table 5.8 or to use different assumptions.

Steps: This method consists of the following step.

Step 1. Calculate the Ingestion Dose Conversion Factor (DCF_{Ingi}) as follows:

$$DCF_{Ingi} = RDCF_i \times SICF$$

$$\left(\frac{mrem}{\mu Ci} \right) = \left(\frac{Sv}{Bq} \right) \times \left(3.7E + 09 \frac{mrem / \mu Ci}{Sv / Bq} \right)$$

Where:

$RDCF_i (Sv/Bq)$ = Ingestion DCF from the reference for an organ or CEDE from ingestion. ICRP89 provides age-dependent ingestion DCFs for the public for selected radionuclides. NRPB87 provides age-dependent ingestion DCFs based on ICRP30 (for workers). EPA88 provides DCFs for the adult based on ICRP30.

$SICF$ = SI unit conversion factor:

$$SICF = 3.7E + 09 \frac{mrem / \mu Ci}{Sv / Bq}$$

METHOD M.5.13 ASSESSING FOOD CROPS AND FIELDS

Purpose: This method is used to determine if food crops in the field will be acceptable for human consumption after harvest.

Discussion: If cropland is contaminated, it will be necessary to determine if crops growing on the land will be acceptable for human consumption after harvest. If the food will not be acceptable for consumption, further effort and expense to cultivate the crops is not worthwhile. Thus, farmers must know quickly whether to continue cultivating crops that have been contaminated. They cannot wait until after the crops have been harvested to determine if the food is likely to be fit for human consumption.

This method uses the Derived Intervention Levels (DILs) for food established by the FDA. The method modifies the MARSSIM sampling method developed for decommissioning to develop a method for the sampling of cropland. The method works both for crops that are already growing and for crops that have not yet been planted.

Step 1. Establish radiation action level concentrations

Establish the radiation action level concentration for ground concentration that will result in crops that exceed the DIL established by the FDA. The equation (whose derivation is shown in the Appendix) for the radiation action level concentration, ALc, is:

$$ALc = \frac{DIL}{e^{-\lambda t} \left[\frac{(F_F \times F_H)}{Y} + \frac{(Cps \times F_2)}{d \times D} \right]}$$

Where:

- ALc = action level ground concentration at which the crop is not likely to meet the DIL at harvest time in units of activity/ m²
- DIL = derived intervention level established by the FDA in units of activity/kg
- $e^{-\lambda t}$ = radiological decay factor (which will be ~1 for long-lived radionuclides)
- t = time between the sampling and the harvest
- F_F = fraction of the activity deposited that is on the food
- F_H = fraction of the radioactivity deposited on the crop that will remain at the time of harvest
- Cps = the concentration factor of the plant relative to the concentration in the soil (from the Table 4)
- F_2 = fraction of the crop's mass that will be added during the remainder of the growing season

$$d = \text{effective root depth (for decommissioning)} = 15 \text{ cm}$$

$$D = \text{soil density in units of kg/m}^3$$

Step 2. Characterize areas with respect to potential concentrations

Areas are first classified as impacted or non-impacted. Impacted areas are areas where the plume may have deposited radioactive materials. Non-impacted areas are areas where no radioactive materials have been deposited. No measurements are made in non-impacted areas.

For impacted areas whose concentrations are expected to be below the radiation action level, three levels of classification are established.

Class 1 Areas are impacted areas that may have concentrations of radioactivity from the accident that exceed the DIL at some locations.

Class 2 Areas are impacted areas that are not expected to have concentrations of radioactivity from the accident that exceed the DIL at any location.

Class 3 Areas are impacted areas that have a low probability of containing radioactivity from the accident that exceed 10% of the DIL at any location.

Impacted areas that are believed to significantly exceed the DIL may need a few measurements to justify compensation for lost crops or land use.

Step 3. Select survey units

The impacted area should be divided into survey units based on the three classification criteria previously defined. A survey unit is a sector of land that is to be surveyed and evaluated as a single unit. Survey units should be areas with similar potential for radioactivity from the accident. The areas suggested below give a reasonable sampling density considering average farm sizes and the relative homogeneity of plume deposition.

Table V1.5.2 Suggested Survey Unit Areas for Agricultural Land

Class	Land
1	Up to 100,000 m ² (<0.1 sq mile)
2	100,000 m ² to 2 × 10 ⁶ m ² (0.1 to 1 sq. mile)
3	> 2 × 10 ⁶ m ² (> 1 sq. mile)

Step 4. Determine Minimum Detectable Concentration (MDC)

The minimum detectable concentration (MDC) must be determined for the instruments that will be used to survey the impacted areas. The MDC is the concentration that a specific instrument can be expected to detect 95% of the time under actual conditions of use. Instruments used to survey the impacted area should have an MDC less than 50% of the ALc. After surveys are taken, it is necessary to determine whether or not the result can be distinguished from the instrument background. The detection sensitivities for samples are:

Critical Level (L_c)

Detection Limit (L_D)

Minimum Detectable Concentration (MDC)

L_c is the net response level that is considered above background.

L_D is the net response level expected to be detected with a fixed level of certainty.

Step 5. Select decision errors

In MARSSIM, the statistical tests that can be used are the Wilcoxon Rank Sum (WRS) Test when background is considered or the Sign Test when background is not considered. Since backgrounds are small relative the action level, the Sign Test is appropriate.

In surveys of crops, two types of decision errors should be considered. A Type I error (or false positive) occurs when a detector considers the sample above background when only background radioactivity is present. A Type II error (or false negative) occurs when a detector considers a sample at background when it is above background. The initial default decision errors are 0.05. If the sampling cost would exceed the value of the crops, the decision errors should be increased.

Once the number of samples has been determined, it is important to compare the cost of sampling against the crop value. This non-technical method is used to condemn food in the field prior to the expenditure of resources. A simple evaluation involves the cost of 1) crop value during an average season, and 2) cost of analysis for each sample.

Food in the field should be evaluated based on the following equations:

$$Cost_{CV} \geq Cost_S \text{ (Proceed with sampling and analysis.)}$$

Where $Cost_{CV}$ = monetary crop value

$Cost_S$ = monetary cost of analyzing all samples

The crop value must be significantly greater than the monetary cost of sampling the previously determined number of samples.

If:

$$Cost_S > Cost_{CV},$$

then, do not collect any samples. Condemn the crop.

Step 6. Determine sample numbers

The following equation is used to determine the number of samples (N) needed in a survey unit using the Sign Test [EPA 97b (MARSSIM, equation 52, page 5-23)]:

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

Where

- N = number of samples needed in a survey unit
- $Z_{1-\alpha}$ = percentile represented by the decision error α
- $Z_{1-\beta}$ = percentile represented by the decision error β
- $\text{Sign } p$ = estimated probability that the random measurement of the survey unit will be less than the DIL when the survey unit median concentration is actually at the lower bound gray region (LBGR). The LBGR is also known as the shift.

The values of $Z_{1-\alpha}$, $Z_{1-\beta}$ and $\text{Sign } p$ are tabulated in MARSSIM.

Table V1.5.3. Number of Samples Needed for Sign Test when α and $\beta = 0.05$

Relative Shift Δ/σ	N
1.0	29
1.4	20
1.6	17
2.0	15
3.0	14

(from MARSSIM Table 5.5 EPA97b)

The relative shift (Δ/σ) is defined as the ratio involving the concentration to be measured relative to the variability in the concentration where the variability is the standard deviation (σ) of the

measured values in the survey unit. The judicious choice of decision error keeps the number of samples reasonable while maintaining statistical significance without covering the entire impacted area. When $\alpha = 0.05$ the relative shift is large (3 or greater.) In this work, the relative shift will be assumed to have a value of 3, which is a reasonable default when actual data is not available. If decision errors α and $\beta = 0.1$, nine samples would be required for $\Delta/\sigma = 3$

Step 7. Determine Sample Location

A reference coordinate system should be established for the impacted areas. The reference coordinate system is a set of intersecting lines referenced to a fixed site location or benchmark. Reference coordinate systems are established so that locations of any point in the survey unit can be identified by coordinate numbers. A reference coordinate system does not establish the number of sample points or determine where the samples will be taken.

In Class 1 and 2 areas, the sampling locations are established in a regular pattern, either square or triangular. After the number of samples needed in a survey unit has been determined and the decision to use a square or triangular grid, sample spacings are determined from the equations below:

$$L = \sqrt{\frac{A}{0.866N}} \quad \text{for a triangular grid}$$

$$L = \sqrt{\frac{A}{N}} \quad \text{for a square grid}$$

Where

L = spacing between sample locations

A = the survey unit area

N = the number of samples needed

The calculated value of L is then often rounded downward to a shorter distance that is easily measured in the field.

A random starting point is identified for the survey pattern. The coordinate location of the random starting point is a set of two random numbers, one representing the x-axis and the other the y-axis. The random numbers can be generated by computer, hand held calculator or from a published table of random numbers. Each random number should be multiplied by the appropriate survey unit dimension to provide a coordinate relative to the origin of the survey unit reference coordinate system.

Beginning at the random starting point, a row of points should be identified parallel to the x-axis at intervals of L . For a square grid, the additional rows should be parallel to the first row at a distance of L from the first row. For a triangular grid, the distance between rows should be $0.866L$, and the sample locations in the adjacent rows should be midway on the x-axis between

the sample locations in the first row. The sample locations selected in this manner that do not fall within the survey unit area or that cannot be surveyed because of the site conditions should be replaced with other sample locations. Additional locations are determined using the same random selection process that was used to select the starting point.

In the Class 3 survey units all samples should be taken at random locations. Each sample location is a set of two random numbers, one representing the x-axis and the other y-axis. Each set of random numbers multiplied by the appropriate survey unit dimension to provide coordinates relative to the reference coordinate system. Coordinates identified in this manner, which do not fall within the survey unit area or can not be surveyed due to access or hazard, are replaced with other sample locations determined using the same procedure.

Step 8. Determination of Compliance (Pass or Condemn)

Compare the analysis of the samples collected with the classification levels. If the analysis indicates that areas have been improperly classified, the areas should be reclassified and a new number of samples determined. If all areas are improperly classified the plume projection parameters should be reevaluated and the classification process started again. When all areas are properly classified, the samples should be evaluated based on the following criteria:

Table V1.5.4. Interpretation of Sample Analysis When No Reference Area Is Used

Measurement Results	Conclusion
All concentrations from a survey unit are less than the ALc	Pass (Food from survey unit may be consumed)
Some concentrations from a survey unit are greater than the ALc but the average concentration is less than the ALc	Conduct the Sign Test
The average concentration is greater than the ALc	Fail (Food may not be consumed)

Appendix 5.13.1 Derivation of the Action Level Equation

Prior to designing a sampling plan, it is necessary to know the radiation concentration limit that the sampling must detect. Without knowing this in advance, it is not possible to select instruments of proper sensitivity, to understand how to characterize areas, and to determine how many samples will be necessary. It is a common mistake to design a sampling plan without first knowing the levels that are sought.

The radiation concentration limits for food ready to be consumed or entered into commerce are the Derived Intervention Levels (DILs). The DILs are the officially accepted concentrations for food established by the Food and Drug Administration. Food that meets or exceeds the DIL means the PAG is met which is not recommended for consumption. It is of great value to have

the DILs established and accepted prior to an accident. Without them, a rational sampling plan could not be designed, and it would be difficult to gain public acceptance of any just-developed values in the intense controversy likely to follow a significant accident.

The DILs apply to food that shall be consumed or entered into commerce. However, if a release occurs during in the growing season, the farmer will want to know whether the crops will be consumable after harvest. If they will not be consumable, there is no reason to invest effort and expense in their continued cultivation. Therefore, it is necessary to estimate concentrations at the time of sampling that will result in a concentration equal to the DILs at the time the food will enter commerce.

Several factors will affect the concentration at the time of harvest or consumption. Radioactive decay would reduce the concentration in food before harvesting or consumption, and thus the concentration on crops in the field at the time of sampling could be higher than the DILs but the food would still be consumable later. In addition, root uptake of radionuclides will occur during the growing season. Thus, the concentrations on crops could increase during the growing season. In this case the concentration on the ground may be more important than the concentrations in the crops themselves. A third factor is the radioactivity deposited on the crop will be removed by rain and wind during the growing season. At this point, it is necessary to derive an equation that relates measurable values taken at the time of sampling to radiation concentration in the crops at the time of harvest. The total crop concentration at the time of harvest, Ch_T , will have two components: radioactivity deposited directly on the food by the plume, Ch_o and radioactivity taken up by roots from radioactivity deposited on the ground, Ch_R . The total concentration at the time of harvest, Ch_T

$$Ch_T = Ch_o + Ch_R$$

The radioactivity deposited on the food will take the form:

$$Ch_o = C_g \times F_F \times F_H \times e^{-\lambda t} / Y$$

Where

Ch_o = concentration on crops at the time of harvest in units of activity/kg

C_g = concentration deposited per unit area of ground by the plume in units of activity/m²

F_F = fraction of the activity deposited that is on the food (may be approximated as the surface area of the food divided by the surface area of the ground)

F_H = fraction of the radioactivity deposited on the crop that will remain at the time of harvest

$e^{-\lambda t}$ = radiological decay factor (which will be ~1 for long-lived radionuclides)

$$Y = \text{crop yield in units of kg/m}^2$$

Similarly, the crop radioactivity from root uptake will take the form:

$$Ch_R = \{C_g \times Cps \times F_2 \times e^{-\lambda t}\} / d \times D$$

Where

Ch_R = concentration from root uptake in units of activity/kg

C_g = concentration deposited in the unit area directly by the plume in units of activity/m²

Cps = concentration factor of the plant relative to the concentration in the soil (from the Table V1.5.5 below)++

F_2 = fraction of the crop's mass that will be added during the remainder of the growing season

$e^{-\lambda t}$ = radiological decay factor (which will be ~1 for long-lived radionuclides)

d = effective root depth (for decommissioning = 15 cm)

D = soil density in units of kg/m³

The *Handbook of Soil Science* provides the average density of silt loam soil as approximately 2,650 kg/m³. ANL/EAD/LD-2 provides default plant/soil concentration factors for root uptake for the radionuclides expected after a radiological release.

Table V1.5.5. Plant/Soil Concentration Factors for Root Uptake (Cps)

Element	Default Plant/soil concentration factors for root uptake
I	0.02
Cs	0.04
Sr	0.3
Ru	0.03
Pu	0.001
Am	0.001

Source: ANL/EAD/LD-2

The total radioactive concentration at the time of harvest Ch_T , can be simplified to obtain the following expression:

$$\begin{aligned} Ch_T &= Ch_o + Ch_R \\ &= (C_g \times F_F \times F_H \times e^{-\lambda t} / Y) + (C_g \times Cps \times F_2 \times e^{-\lambda t} \times) / d \times D \\ &= C_g \times e^{-\lambda t} [(F_F \times F_H) / Y + (Cps \times F_2) / d \times D] \end{aligned}$$

Finally,

$$Ch_T = C_g \times e^{-\lambda t} [(F_F \times F_H) / Y + (Cps \times F_2) / d \times D]$$

If the concentration at the time of harvest, Ch_T , exceeds the DIL, then the food is not consumable. It is necessary to know what ground concentration, C_g , will cause Ch_T to exceed the DIL. The value is the action level concentration, ALc.

$$ALc = \frac{DIL}{e^{-\lambda t} \left[\frac{(F_F \times F_H)}{Y} + \frac{(Cps \times F_2)}{d \times D} \right]}$$

Where:

ALc = action level ground concentration at which the crop is not likely to meet the DIL at harvest time in units of activity/ m²

DIL = derived intervention level established by the FDA in units of activity/kg

$e^{-\lambda t}$ = radiological decay factor (which will be ~1 for long-lived radionuclides)

t = time between the sampling and the harvest

F_F = fraction of the activity deposited that is on the food

F_H = fraction of the radioactivity deposited on the crop that will remain at the time of harvest

Y = crop yield in units of kg/m²

Cps = concentration factor of the plant relative to the concentration in the soil (from the Table VI.5.5)

F_2 = fraction of the crop's mass that will be added during the remainder of the growing season

d = effective root depth (for decommissioning) = 15 cm

D = soil density in units of kg/m³

The ALc is the ground concentration that the aerial and ground-based surveys must detect to identify foods that will exceed the DIL.

The criteria to evaluate food are as follows

Measurement Results	Conclusion
$Ch_T > DIL$	Food not consumable
$C_g > ALc$	Food will not be consumable

The following two examples are provided to illustrate the use of the equations.

Example 1: Determine the ALc for ^{137}Cs on a mature tomato crop. At the time of contamination, a mature crop would not have root uptake contamination.

$$ALc = \frac{DIL}{e^{-\lambda t} \left[\frac{(F_F \times F_H)}{Y} + \frac{(Cps \times F_2)}{d \times D} \right]}$$

DIL for ^{137}Cs = 1360 Bq/kg

F_H = fraction of the radioactivity deposited on the crop that will remain at the time of harvest = 1

F_F = fraction of the activity deposited that is on the food = 0.1

F_2 = fraction of the crop's mass that will be added during the remainder of the growing season = 0 (this is a mature crop)

$e^{-\lambda t}$ = radiological decay factor = 1 no decay has occurred

Y = crop yield in units of $\text{kg}/\text{m}^2 = 25 \text{ kg}/\text{m}^2$

$$ALc = \frac{1360 \text{ Bq}/\text{kg}}{1 \left[\frac{0.1 \times 1}{25 \text{ kg}/\text{m}^2} + 0 \right]} = 340,000 \text{ Bq}/\text{m}^2$$

ALc = 340,000 Bq/ m^2 (9 $\mu\text{Ci}/\text{m}^2$)

Example 2: Determine the ALc for ^{137}Cs on wheat crop that has not germinated.

$$ALc = \frac{DIL}{e^{-\lambda t} \left[\frac{(F_F \times F_H)}{Y} + \frac{(Cps \times F_2)}{d \times D} \right]}$$

DIL for ^{137}Cs = 1360 Bq/kg

$e^{-\lambda t}$ = the radiological decay factor = 1 (^{137}Cs half-life = 37 years)

F_H = the fraction of the radioactivity deposited on the crop that will remain at the time of harvest = 0 (crop not germinated)

Cps = the concentration factor of the plant relative to the concentration in the soil (from the Table VI.5.5) = 0.04

F_2 = the fraction of the crop's mass that will be added during the remainder of the growing season = 1 (all of crop's mass will be added)

d = the effective root depth (for decommissioning) = 15 cm = 0.15 m

D = soil density in units of kg/m^3 = 2650 kg/m^3

$$ALc = \frac{1360 \text{ Bq/kg}}{\left[\frac{10 + 0.04 \times 1}{0.15 \text{ m} \times 2650 \text{ kg/m}^3} \right]}$$

$$ALc = \frac{1360 \text{ Bq/kg}}{1 \times 10^{-4} \text{ m}^2/\text{kg}} = 1.36 \times 10^7 \text{ Bq/m}^2$$

$$ALc = 1.36 \times 10^7 \text{ Bq/m}^2 \text{ (370 } \mu\text{Ci/m}^2\text{)}$$

Although we chose to examine wheat, this method would yield the same numerical value for any crop not germinated. The values of the parameters used in these examples are only rough approximations. Additional studies should be performed to establish values that are more accurate.

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SECTION 6. ADMINISTRATION, INTERNAL PROCEDURES, AND TOOLS

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ADMINISTRATION

Administrative activity is kept to a minimum, but a certain degree is necessary to assure performance and continuity. During an event, management consists only of the Assessment manager and the deputies. Because FRMAC does not have an ongoing existence, activities such as planning, training and preparation must be performed by other means. The two key mechanisms are the FRMAC Assessment Working Group and the NNSA Consequence Management Technical Advisory Group.

STAFFING AND RECALL

Staff is drawn from State, Federal, and contractor resources, but the details of selection have changed from that used in the past. Now FRMAC Assessment Working Group members and NNSA/contractor staff have key roles.

Formerly, a FRMAC was to be established within 24 to 36 hours of notification. Ample time was available for NNSA to contact organizations and assemble a team. However, the need for a more immediate response led NNSA to establish a precursor, “Consequence Management” Phase I and Phase II. Phase I, which deploys within 4 hours, covers the first shift and includes 3 pre-identified Assessment team members (1 scientist, 1 GIS & 1 database). Phase II, which deploys in 12 hours, picks up the second shift and is slightly larger with nine Assessment team members (3 scientists, 3 GIS & 3 database). By the end of the second shift, additional staff from the Assessment Working Group should be on scene. Other State or Federal team members may be requested or volunteer themselves. Participation by individuals from the State(s) is strongly encouraged.

NNSA management will contact the management of those agencies expected to participate in the FRMAC to request staffing. First choice for Assessment team members will be the members of the Assessment Working Group.

It must be recognized that the skill level and versatility of individuals will vary greatly. Those involved with Consequence Management and the Assessment Working Group will be the key staff members, because of their experience and training.

A goal of the Federal Emergency Response Community is to reduce the “footprint” of the Federal response. That is, practices will be adopted to reduce the number of people and amount of equipment at the scene. To do this a “Home Team” may be established for Assessment. This Home Team will be assembled and carry out any Assessment activities that can be exported out of the FRMAC. These activities might include computation of conversion factors or preparations of graphic presentation during the off hours. Should a Home Team be established, staff will be drawn as described above. Although the Home Team is part of FRMAC, it is not located at FRMAC headquarters.

DIVISION FUNCTIONS

A general description of each of the six functional components of FRMAC Assessment is found in Section 1, “Overview of Assessment – Assessment Process.” This discussion expands that description with discrete tasks and responsibilities for each functional component. These are the activities expected (order is not significant). If any of these activities are omitted, contact the Assessment Manager.

OVERVIEW

- Identify areas in which there is a potential for early health effects
- Highlight and notify Assessment Manager of any unexpected findings
- Maintain awareness of monitoring and laboratory work underway
- Maintain awareness of Action Requests and their progress
- Review all incoming data, don't get confused by redistribution of copies
- Correlate incoming data with Monitoring Plan and Action Requests, expedite high priority items
- Correlate incoming sample data with Monitoring Plan and Action Requests, expedite high priority items
- Assist Assessment Manager with assignment of priority and detection limits to samples submitted for analysis
- Develop a characterization of the radiological scenario
- Summarize key aspects for presentation to decision-makers
- Produce the PAG Zone Map set at least once per shift
- Use ARAC/SHARC for early PAG Zone Maps
- Assure Monitoring & Sampling Status Map is produced at least twice per shift
- Obtain Posting and Location Identifier maps at least twice per shift
- Prepare maps which integrate several data types on one base for comparison
- Direct application of conversion factors to data sets
- Develop graphical presentations for GIS to produce
- Perform quality reviews of data
- Pursue and resolve quality issues
- Assign Assessment quality “flag” in DCENT
- Prepare QA Cover Sheet for all products
- Approve and release as many Assessment products as possible
- Maintain QA records of Assessment division activity
- Maintain Assessment Library

Data Center

- Log, time/date stamp and index all data received
- Promptly distribute copies of “raw” data to users
- Preserve and control “originals,” distribute copies
- Enter radioed data into the database (DCENT)
- Verify radioed data
- Enter all hardcopy text data into the data base (DCENT)
- Perform initial screening of data for quality. Specifically, check for completeness and constancy of records (times, locations, units, exponents, and instruments...).
- Maintain a secure archive of all data received Link to Laboratory Information Management Systems (LIMS) where possible
- Set QA Flags
- Manipulate data to perform sorts and corrections
- Adapt and enhance software to accommodate special needs
- Prepare data sets for use by GIS
- Prepare canned reports each shift as Assessment Products, which summarize the data

GIS (Geographical Information System)

- Plot data as directed by Overview
- Arbitrate priorities with FRMAC Deputy Director and Assessment Manager
- Always have Overview review GIS product on screen, before printing
- Always use a map projection, assure no Lat/Long plots
- Verify Lat/Long grids, tick marks and labels
- Obtain and plot ARAC and SHARC predictions
- Obtain AMS data and plot
- Obtain GIS coverages and data from other organizations
- Map protective actions, control zones/point and incident site
- Make PAG Zone and Monitoring and Sampling Maps a top priority
- Provide Posting and Location Identifier maps at least twice per shift (large size)
- Work with Overview to identify outliers
- Label all products thoroughly, See Method M.6.3
- Prepare GIS soft products for distribution, complete QA Cover sheet for file
- Prepare GIS hardcopy products for distribution, attach QA Cover sheet to GIS copy
- Segregate “Released” products from those awaiting approval or for internal FRMAC use
- Interface with NNSA’s Emergency Communications Network

Computations

- Perform computations described in Assessment Manual Methods
- Monitor validity of assumptions used by Assessment Manual's methods, DCFs and DRLs
- Consider significance of other dose pathways
- Evaluate potential effectiveness of mitigation measures
- Identify and prioritize measurements needed to refine assessment methods
- Report when conditions warrant revision of DRLS/DILs or conversion factors
- Report when Assessment methods must be adjusted or replaced
- Determine radionuclide mix and evaluate spatial variation
- Determine resuspension factor
- Determine correction factors for data (quality issues, decay...)
- Publish DRLs, DCFs, conversion factors, radionuclide mix and resuspension factor as Assessment Products (issue with QA Cover Sheet)
- Investigate and analyze monitoring or laboratory techniques to resolve a quality issues
- Estimate uncertainty of data and assessments
- Establish and maintain contact with other assessment teams

Predictions

- Seek and obtain source term information
- Review predictions by external groups and understand differences
- Predict deposition, instantaneous air concentration, exposure rate
- Apply DCFs to predictions to estimate doses (critical organ CDE, TEDE) for early and intermediate phase
- Consult with Computations regarding application of DCFs
- Use DRLs a plot levels when practical
- Provide results to GIS (softcopy) and Overview
- Prepares sets of predictions as Assessment Products (distribute with QA Cover sheet)
- Adjust model to fit field measurements (used for interpolation and extrapolation)
- Estimate uncertainty of predictions
- Perform what-if predictions until no release potential exist
- Coordinate with other modeling groups

Meteorology

- Provide on-site meteorological information for transport & dispersion models
- Assemble current and forecast weather information important to field operations
- Brief weather conditions and forecast at shift changes

- Assemble and disseminate aviation weather as required
- Monitor chill and heat stress, notify Health and Safety of concerns

JOB DESCRIPTIONS

FRMAC Assessment employs the same job descriptions used by NNSA Consequence Management (CM). These descriptions are controlled and maintained by the CM Training and Readiness group, which developed job descriptions for every CM/FRMAC role. Those descriptions include duties and responsibilities, line of command, independence limitations, qualifications, physical requirements, working conditions, safety restrictions and Reading File bibliography. The job descriptions are unpublished. Full text is not included here, because they are too voluminous for inclusion in the Assessment Manual. References to operation outside of the United States apply only to CM, not FRMAC.

Below are summaries of those job descriptions relevant to the Assessment division.

Assessment Division Manager

The FRMAC Assessment Division Manager is the on-scene expert on health effects and the environmental impact resulting from exposure to ionizing radiation, dose assessment, Federal PAGs, the International Atomic Energy Agency's (IAEA's) Intervention Levels, and remediation methodologies. The Assessment Manager is responsible for the development of all summarized and assessed FRMAC data products which include data to support the protective action decision making process, dose projections, contamination contours, and contours related to PAGs. The Assessment manager is also responsible for maintaining an effective interface with the Monitoring Division, specifically the monitoring manager and the laboratory analysis manager. The Assessment Manager must continually provide the monitoring manager with input to and feedback on the Implementation Plan to assure Monitoring Plan objectives are achieved. The Assessment manager must assure that all samples submitted to the laboratory have been assigned priorities and detection limits that reflect the goals of both the Monitoring Plan and Action Requests. This review of analysis requests with the laboratory manager can be in person or delegated.

Deputy Assessment Division Manager

The FRMAC Deputy Assessment Division Manager functions as the FRMAC Assessment Division Manager's immediate assistant and will function as the Division Manager in the Division Manager's absence and during the second shift.

Overview Group Supervisor/Scientist

The FRMAC Overview Group Supervisor/Scientist is an expert on health effects and the environmental impact resulting from exposure to ionizing radiation, dose assessment, Federal PAGs, the International Atomic Energy Agency's (IAEA's) Intervention Levels, and remediation

methodologies. The primary responsibilities of the Overview Group are to: 1) develop an overall view of the radiological situation based upon the radiological data prepared by the FRMAC Assessment Division's Analysis Group, 2) assist in the development of strategies to define and collect the required radiological data, and 3) review all FRMAC radiological assessments and data for overall consistency and integrity.

Computations Group Supervisor/Scientist

The FRMAC Computations group Supervisor/Scientist is an expert on health effects and the environmental impact resulting from exposure to ionizing radiation, dose assessment, Federal PAGs, the International Atomic Energy Agency's (IAEA's) Intervention Levels, and remediation methodologies. The Assessment Division Supervisor/Scientist develops summarized and assessed FRMAC data products which include data to support the protective action decision making process, dose projections, contamination contours, and contours related to PAGs. All data products must be presented in a format that is understandable to the FRMAC Director, Lead Federal Agency (LFA), State(s), and when appropriate, the Department of State (DOS), and the host nation.

Predictions Group Supervisor/Scientist

The FRMAC Predictions Group Supervisor/Scientist is responsible for preparing predictions of atmospheric plume dispersion characteristics, ground deposition, resuspension rates, exposure rates, and radiation doses to individuals and populations resulting from releases of radioactive materials to the environment.

Data Center Supervisor

The FRMAC Data Center Supervisor is the database expert responsible for the setup and operation of the deployed Emergency Response Data System (ERDS). The Data Center Supervisor provides data management of all field monitoring and radioanalytically derived data, source-term information, onsite radiological situation information, meteorological data, and other appropriate incident related information. He/she develops requested data and informational reports, and establishes communication interfaces with GIS and other on-scene emergency response organizations. The Data Center Supervisor is responsible for date and time stamping, cataloging, and archiving of all original FRMAC documents relating to the FRMAC response. He/she is also responsible for data, data products and any parameters affecting the quality or integrity of the FRMAC data or data products, and any other related data forms and/or information.

Data Entry Clerk

The FRMAC Data Entry Clerk assists in the setup and operation of the deployed Emergency Response Data System (ERDS). The Data Entry Clerk performs data entry duties of all field monitoring, radioanalytically derived data, and appropriate incident related information into the

ERDS. He/she assists in the development of requested data and informational reports. The Data Entry Clerk assists in date and time stamping, cataloging, and archiving of all original FRMAC documents relating to the FRMAC response. He/she is also responsible for data, data products, any parameters affecting the quality or integrity of the FRMAC data or data products, and any other related data forms, and/or information.

Database Specialist

The FRMAC Database Specialist assists in the setup and operation of the deployed Emergency Response Data System (ERDS). The Database Specialist provides data entry and assists in the data management of all field monitoring, radioanalytically derived data, and appropriate incident related information. He/she assists in developing requested data and informational reports, and establishes communication interfaces with GIS and other on-scene emergency response organizations. The Database Specialist assists in date and time stamping, cataloging, and archiving all original FRMAC documents relating to the FRMAC response. He/she is also responsible for data, data products, any parameters affecting the quality or integrity of the FRMAC data or data products, and any other related data forms, and/or information.

GIS Group Supervisor/Specialist

The FRMAC GIS Group Supervisor/Specialist is responsible for the operation of the Emergency Response GIS equipment, the creation of GIS data products, the importation of Atmospheric Release Advisory Capability (ARAC) predictive models, and the communication of the GIS data products with DOE Headquarters and the other DOE sites via the Emergency Communications Network (ECN).

Meteorology Group Supervisor/Meteorologist

On-scene National Oceanographic and Atmospheric Administration (NOAA) meteorological support is essential to FRMAC operations to provide vital weather observations; to identify potential meteorological threats to personnel, equipment, and aircraft; and to provide credible assessments and proper planning for potential threats to the general public and the environment.

The FRMAC Meteorology Group Supervisor/Meteorologist is the senior meteorologist in the Meteorology Group and is responsible for the coordination of all Meteorology Group's activities. The Meteorology Group Supervisor/Meteorologist is responsible for providing a broad spectrum of weather services; including operation-specific weather forecasts, on-scene surface and upper-air meteorological data, aviation-weather support, meteorological consultation to the FRMAC Director, and post-operation meteorological data summaries. Support also includes providing climate information and current meteorology for predeployment operations and weather related advisories, watches, and warnings.

CHAIN OF COMMAND

The chain of command for Assessment Division Manager is summarized in the diagram below (Figure 6.1). Three key points must be understood:

- The organization collapses with the size of the event. Individuals may serve multiple roles. Often the supervisor is also the scientist. It is possible that one person will serve all roles.
- The Assessment Division Manager takes direction from four managers (FRMAC Director, Deputy Director, Operations Manager and Deputy Operations Manager).
- The Deputy Assessment Division manager is the delegated manager in the absence of the Assessment Division Manager. If both are absent, a delegate will be appointed.

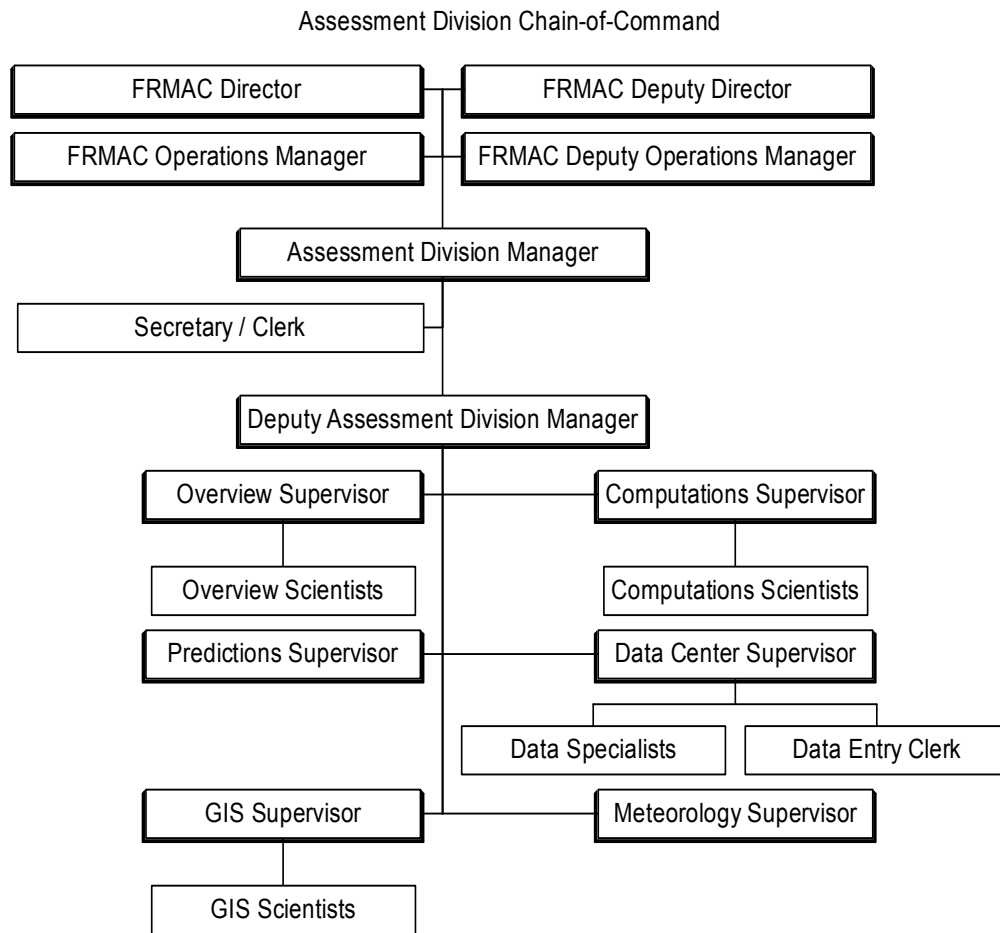


Figure 6.1. Assessment Division Chain of Command

SHIFT CHANGE

Plan on 12-hour swing shifts, because only enough personnel are available to staff two shifts. The day shift will be the most fully staffed, while the night shift may be quite minimally staffed. The Home Team, if activated, may be on a separate shift schedule.

Assessment Managers

Substantial overlap is required between the shifts of the Division Manager and Deputy Manager to assure continuity of workflow and situation awareness. If practical, adhere to the following, unless otherwise directed by management.

- Assessment managers are requested to work each shift one hour longer than the balance of the Assessment staff
- The oncoming manager should arrive at least one hour before shift change to overlap with the last hour of the shift on duty.
- The last hour of the shift should be used to jointly:
 - Prepare the Status Report (outgoing manager prepares, incoming manager reviews)
 - Exchange Assessment journal
 - Review Action Items completed and received that shift
 - Inspect Assessment Products produced that shift
 - Survey all work in progress
 - Discuss priorities
- The outgoing Assessment Manager should present a shift change briefing to the oncoming staff before departure.

Assessment Staff

Communication between outgoing Assessment staff and their replacements is vital to work continuity. If practical, adhere to the following, unless otherwise directed by management.

- Replacements should arrive before their predecessor departs to convey Assessment function specific information.
- Outgoing staff must assure that all taskings, notes and computations are conveyed to the replacement.
- If there is no replacement, make and leave good notes to yourself for the next day prior to departure.
- Highlight any priority items or problems that require prompt attention during the next shift.

DOCUMENTATION AND REPORTING

Certain records and reports are necessary. The balance between this documentation and production of Assessment products must be considered and adjusted often. Initially, it is anticipated that little effort will go into documentation and reporting. But as the volume of data, action requests and especially the FRMAC organization grows, so also the importance of the documentation and reporting grow. If possible, FRMAC Assessment should secure the assistance of a clerk or secretary.

Status Reports

The FRMAC Director must submit status reports at least once per shift. Expect the FRMAC Operations Manager (or Deputy) to request these reports near the end of each shift. Assessment division input to the Status report is mandatory. Address the following items:

- Major Assessment tasks being worked (top priorities)
- Assessment Products released this shift
- Assessment Products to be released (what? and when?)
- Significant problems and shortfalls

Records

The following records must be maintained.

Action Requests

Keep all Action Requests in a single, conspicuous, clearly marked folder. Segregate pending from completed requests.

Data

Data includes predictions, measurements and analyses. Segregate all data at least by the types cited below. Additional breakout may be necessary.

- Radio reports – reconcile with verified data and remove from Radio Reports when verified
- Verified data – includes both monitoring reports and Data Center reports
- Segregate radio reports, verified data, sample acquisition logs and laboratory reports
- Sample acquisition reports – reconcile with laboratory analyses and remove from Sample Acquisition Reports
- Laboratory analyses – bundle reports for splits and aliquots together.

QA Cover Sheets

Assure a QA cover Sheet (Method M.6.1) is prepared for all Assessment products and a copy is kept on file in Assessment.

Assessment Products

Where possible, copies of Assessment products should be retained. Hardcopy products can be placed into a file. However, both the Data Center and GIS must maintain soft copy products for the Assessment file.

Journal

The Assessment Manager should begin a journal that records all transactions of the Assessment Division. This journal should stay with the manager at all times to receive any requests, log agreements and record information. The journal should be exchanged from the outgoing manager to the incoming manager at shift change.

Postings

Post the following prominently:

- Current PAG Zone Map
- Current Monitoring and Sampling Map
- Current DRLs and special conversion factors (Method M.6.2)
- Current resuspension and surrogate ratios

Action Requests

Specific assessments and Assessment products are assigned using the “FRMAC Action Request” form. The Action Request is used by the FRMAC Manager to capture, track and most importantly, prioritize requests made of the FRMAC by the State, LFA or public. It is not used for tasking activity within the FRMAC. Requests will be reviewed and prioritized by the FRMAC Operations Manager (or deputy), then delivered to the Assessment Division manager on duty. The FRMAC Action Request form, Figure 6.2, is a one-piece self-replicating form (pack of 5 copies).

FRMAC ACTION REQUEST

Reference No. _____

Reported By: _____ Priority _____
Organization _____ 1. Emergency
Name _____ 2. Urgent
Date _____ Time _____ 3. Routine
Authorization _____

NATURE OF REQUEST

DO NOT WRITE BELOW THIS LINE — FOR FRMAC USE ONLY

FRMAC Response Action Group(s) _____ FRMAC Priority _____
Organization _____ 1. Emergency
Name _____ 2. Urgent
Date _____ Time _____ 3. Routine
Authorization _____

REPLY/RESOLUTION

Distribution: _____ For Tracking Use Only
Received By _____
Date/Time _____

WHITE (FRMAC RETENTION)

Figure 6.2. FRMAC Action Request

The functions of the five copies are as follows:

- White Originator's request to FRMAC, delivered to FRMAC management team, manager will task appropriate FRMAC division and prioritized. Top copy (white) is retained by manager to track action.
- Yellow Copy retained by originator, indicates reference number, tasking to group and assigned priority. Remaining pack of 3 copies is passed on to the division tasked with action.
- Green Tasking to responsible FRMAC division, write the response to the action request on this page, retain in division's file. Remaining pack of 2 copies returns to FRMAC management.
- Pink FRMAC management file copy closes out action request and records response for future reference.
- Goldenrod Response copy to be delivered to request originator.

Assessment will receive the bottom three copies (green, pink, and goldenrod). Complete the action and write the response or summary in the "Resolution/Reply" field of the top most copy. Remove the top copy (green) and file it in the Assessment Action Request file. Give the remaining two copies (pink & goldenrod) back to the Action Request tracker at the FRMAC management desk. NOTE: The bottom goldenrod copy is often barely legible. Please rewrite portions as needed to assure readability.

TOOLS AND USAGE

The primary tools used by Assessment, besides the Assessment manual, are the DCENT database system, the GIS (Geographical Information System), and various models. Utilization of these tools is described here.

DCENT - DATABASE TOOL

The ERDS DCENT data system is a PC client-server database and is designed to hold information about events or occurrences, which apply to a deployment in an Emergency Response event or exercise.

The Basic level computer skill or Occasional end user is the intended audience for this user guide.

FRMAC Data Center- The DCENT database was developed to collect, track, reduce, and archive field and laboratory data collected during a FRMAC emergency response event. The DCENT data center is the collection point for all FRMAC related data. The data is input, verified, corrected to specifications set by the field scientist, and output to field assessment teams and the GIS system.

Getting Started – Key steps to using DCENT

- Open the ERDS Folder located on the desktop double-click on the DCENT application icon
- A form with a “Not For Public Dissemination” label will appear, click on the **C**ontinue button to proceed
 - A login dialog box will prompt for a username and password, type in **USER** for both the username and password.
 - Click **O**k for a successful login.

Menu Screens

There are 13 menu screens available in DCENT. Certain screens and functions are quite important to assessors and other users, while some are for just for data entry clerks or data specialists (developer/operators). Those that are key to assessors are marked with ★.

★ Main Menu

DCENT’s Main Menu screen is the control center for the entire application. If you want to start browsing for information, the Main Menu is the starting point. If you encounter a problem while browsing through the forms, simply find and click on the button titled ‘Main Menu’. Click on the Exit button to close the application.

Badging System

When a deployment for an Emergency Response event or exercise occurs the Badging System form is used to collect the *deployed personnel* information. This form helps create a list, which will later be used to retrieve personnel names in other DCENT forms.

Teams

The ‘Teams Form’ is used to enter data on the field teams. The team list will be used to retrieve team names in other DCENT forms.

★ Known Locations

The ‘Known Locations Form’ is used to enter locations that have been marked. The information provided will be utilized to facilitate the completion of other DCENT forms by having a list of the locations.

★ Instrumentation

The “Instrumentation Form” is used to enter information on instruments that are used in the event or exercise. The instrument records help create a list, which will be used to retrieve instrument names in other DCENT forms.

Data Acquisition

The Data Acquisition Log is the entry form for all field monitoring data and its associated information. A unique record is created and maintained for each measurement.

★ Samples

This form allows for recording information about each sample, e.g., location, type, time/date, and team identity. The sample number assigned here ties the sample to its analyses. It does not record analysis results, but does include contact radiation measurements of the sample.

Event Log

Used to enter events that require some sort of post action.

Miscellaneous Tables

These are used by Data Center staff to view or enter information directly into a database table.

Data Browser: Event Log Data

This can be used to review FRMAC Action Requests and key events.

★ Data Browser: Field Data

Used to browse through the field data records. The data cannot be edited through the ‘Data Browser: Field Data’ it can only be viewed.

CrossCheck Field Log

Used to verify data entry from the Radio Log as soon as hard copy Field Logs become available.

★ Set Flags Form

Used to set all data quality flags, including “Assessed Flag.” The Assessment Flag is set by exception. The Assessment scientist examines a block of data and identifies outliers to be

flagged as “Hold,” while the balance are flagged as “Assessed”. The Data specialist will set the flags in DCENT, not the Assessment scientist.

Four flag fields can be assigned: 1) Raw/Hold, 2) Verified, 3) Assessed and 4) Released. If the data point is bad, then the Raw/Hold field is set to Hold and Assessed is blank.

★ Reports

A number of predefined reports are available and, if needed, the data specialist can add more. The reports are broken into 3 categories: 1) Field Team, 2) Sample, and 3) Maintenance Reports.

To activate output of one of these predefined reports click on the ‘Reports’ button located on the Main Menu screen. Select a category by clicking on the corresponding tab, then click on the button for the desired report.

Frequently Used Reports

Sample Rpt.

Sample Report (dcent-17.rpt) – is an Air Sample Report that is grouped by location it also includes *sample #, lab sample, collection time, nuclide, measurement, units, and mda.*

Sample Summary (dcent-60L.rpt) – is an Air Sample Report that is grouped by location and contains all of the *lat & long, log numbers, samples, data/time, measurements, and units.*

Final (dcent-117.rpt) – is an Air Sample Report grouped by location and contains the *sample #, collection date/time, analysis type, and measurement units.*

Log Report (dcent-60.rpt) – this report indicated whether the data contains samples and also displays the quality control flags along with the *log number, key, and location description.*

Maintenance Rpt.

Team Report ver2 (dcent-20.rpt) – is a report that displays a list of all the *team names or numbers* along with the *team type, start & end date, radio channel, phone numbers, and vehicles.*

Inst. Type Rpt (dcent-03.rpt) – displays a list of all the instrument types, it also includes *description, meter, probe, detection type, radiation level, and the minimum & maximum values.*

Field Team Rpt.

Uci_m2 Rpt (dcent-07.rpt) – this report only displays the microcuries per square meter units in association with the ‘real data set’—the *bearing & sector, value, team, measurement, distance, and instrument type* are also on the report.

Mr_Hr Rpt (dcent-08.rpt) – this report displays mR per hour units in association with the ‘real data-set’—the *instrument type, team, lat & long, value, distance, bearing & sector, and remarks* are also on the report.

Requesting Custom Reports

The data specialist can craft custom reports for a one-time need or may wish to develop new, additional predefined reports. Only the Assessment Division manager may initiate the request to the Data center manager. Once the request is assigned to a data specialist and given a priority, close interaction between the assessor and data specialist will be required. The report specification must be jointly developed. Information required includes data type, time/date range, instrument, QA flags, teams, layout and other information required for the custom report.

Calculations

There are only three preprogrammed calculations currently supported by the DCENT database. The data specialist can add other calculations, but substantial time to program and validate these will be required. Calculations to correct systematic errors are programmed only as needed. However, template code does exist which can be easily modified. The preprogrammed calculations and form of corrections are briefly reviewed below.

- Normalization – conversion of data from reported units of measure to common units of measure.

$$\text{Value}_{\text{normalized}} = \text{CF}_{\text{units}} \times \text{Value}_{\text{measured}}$$

Where CF_{units} is the requisite conversion factor

- FIDLER – converts raw FIDLER data to a deposition concentration (parameters are instrument specific)

$$\text{Deposition} = \text{CF}_j * (\text{FIDLERmeas}_j - \text{FIDLERbkgrnd}_j)$$

Where CF_j and FIDLERbkgrnd_j are instrument specific factors

- Air Samples – computes air concentration from filter analysis results and air flow/time data

$$\text{AirConc} = \text{CF} * (\text{SampleActivity} - \text{SampleBkgrnd}) \div \text{AirVolume}$$

- Correction – linear adjustment of values to compensate for systematic errors

$$Value_{new} = scale \bullet (Value_{old} - offset)$$

Logging Off of the DCENT application

To exit the DCENT application return to the Main Menu screen from whatever form you are on and then click on the **Exit** button. If you are already on the Main Menu screen then simply click on the **Exit** button.

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Overview of GIS

Within the FRMAC, there is a continuing effort to improve the data management and communication process. GIS is central to this process providing both critical data management and product generation tools. Arc/Info and ArcView GIS software provide an integrated platform for the input, archival, query, and analysis of spatially referenced GIS data. RSL GIS scientists have leveraged on the suite of ESRI products to develop a deployable GIS capability for handling emergency response activities in the FRMAC.

To support FRMAC deployments and field exercises, a geographic data base consisting of transportation, cultural, environmental, business, radiological, aerial photographic, and satellite imagery data is maintained for the United States. Particular attention is paid to areas around commercial nuclear power plants and DOE facilities. To be prepared for a crisis at any location in the country at any time, it is imperative that all data be maintained on-line and be readily available for field deployment and query by emergency managers. Raster imagery is also critical to the RSL GIS for response activities. “A picture is worth a thousand words” is a relevant statement to the need for aerial photos of a facility during a response. Photos provide emergency responders with visual information as to facility layouts, environmental conditions, and facility hazards that are relevant to emergency response activities. Such information may not exist in vector layers in the GIS database. Use of scanned map products can also reduce the map labeling preparation time necessary for GIS staff to create final hardcopy products. Scanned 1:100,000 USGS maps are maintained for the entire country. Scanned 1:24,000 USGS maps are maintained for the major U.S. cities. The library of typical vector and raster base map layers in the RSL GIS includes, but is not limited to, the following data:

<u>Data Layer Theme</u>	<u>Source</u>
Base Map Data:	
State Boundaries	GDT
County and/or Township Boundaries, MSA’s GLOSSARY	GDT
Roads, Highways, etc	GDT

Railroads	GDT
Utility Corridors	GDT, Pennwell MapSearch
Evacuation Routes	NRC Site Plans
Surface Hydrology	GDT

Metropolitan Statistical Area = MSA

Geographic Data Technology <http://www.geographic.com/home/index.cfm>

Emergency Response and Public Facilities Data:

Emergency Operations Centers (EOC)	NRC and DOE Files
Decontamination Centers	NRC and DOE Files
Shelters and Reception Centers	NRC and DOE Files
Emergency Planning Zones (EPZ)	NRC Regulations
Protective Action Sectors (PAS)	NRC Site Plans
TLD Locations	NRC Site Plans
Schools	Business Point File
Police and Fire Stations	Business Point File
Hospitals & Physicians	Business Point File
Nursing Homes	Business Point File
State Institutions	Business Point File
Major Industries	Business Point File
Small & Large Businesses	Business Point File
Recreation Areas	Business Point File, GDT
Infrastructure (electric, pipelines, etc)	Pennwell MapSearch

Demographics Data:

Demographics Data	GDT, ESRI, Business Points
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Radiation Measurements and Derived Data:

Exposure Rates	AMS
Deposition Measurements	AMS / ERDS
Protective Action Recommendations	Assessment Staff
Ingestion Pathways	Assessment Staff

Baseline Radiation Surveys

Historical AMS

Dispersion Model Output Data:

RASCAL

NRC

ARAC

DOE (LLNL)

SHARC

DOE (Sandia)

Imagery:

Satellite Images

Space Imaging, SPOT

Aerial Photographs

DOE, EG&G & BN Surveys

Scanned USGS Maps

SureMaps, LandInfo, other

A variety of source materials (including digital and paper maps, tabular summaries, and imagery) has been collected from Federal, State, and commercial sources. Radiation data is entered from hand-drawn maps or from gamma data acquired with the Aerial Measuring System (AMS).

The RSL GIS is a robust system for the analysis of spatial data for radiological emergency response. Emergencies require rapid processing of base map data to provide most effectively support for emergency response officials. Data layers are preprocessed and maintained on-line for quick implementation during the initial response phase of a crisis. Scenario-dependant information and field measurements are entered into the GIS as data become available in the field. As more information is entered into the GIS database, the power of the system for emergency response and as a decision-making tool is systematically enhanced.

Presentation Options

Assessment products requested from the GIS are available in many formats with varying degrees of complexity and completion times. The three primary presentation formats are interactive mapping, computer displays projected to large screens, and hard copy maps and tabular summaries.

If the requirement is to obtain facts of information contained in the GIS, then the quickest method to retrieve this is through interactive mapping. This type of information can generally be derived directly from the GIS by sitting down at a terminal and querying data interactively on the system. The requestor gets the necessary information, and no other products are required.

Often, FRMAC scientists need to view data for group discussion that might lead to information for the LFA or State to support the generation of protective action recommendations or just to understand the general status of the response. Again, no hardcopy product is necessarily required. To meet this requirement, GIS screen displays can be projected to large format to

guide the group discussion. This is a quick method to disseminate information without time lags associated with hardcopy printing.

Although they require the most effort and processing, hardcopy maps are the most requested GIS products. Hardcopy maps are often necessary for analysis of radiological data conditions, providing radiological status to LFA or other FRMAC organizations, or for dissemination at press briefings, etc. In general, hardcopy products can be generated most rapidly as page-size maps. Page-size maps lend themselves to quick printing and can easily be reproduced on color copiers, or even faxed. Page-size products tend to have more simplified information being presented due to the smaller map area available for printing. These maps are excellent for status or overview products and can be printed on transparencies for use during briefings. D size and E size map products tend to take longer to produce due to increased amounts of information being presented and time necessary to physically print the map on a plotter. Large format, or plotter, products are very useful in the analysis of radiological data by the assessment staff. Hand drawn contours (i.e., PAGs etc) can be drawn directly on top of data plots and turned back over to the GIS staff for input into the database. Often, large format maps are required for press briefings, because these products are superior to video clips, viewgraphs or computer displays. Hardcopy products also represent a snapshot in time, indicating conditions at the time of printing only, and can be easily referenced based on map numbering information.

Map Request Process

Requesting map products from GIS staff can be done in accordance with the procedure appropriate to the scale of the response activity. The process is somewhat different for a small scale CMRT Phase 1 than for a full FRMAC response. The following discussion outlines the GIS support to each size of response and the method for requesting GIS products.

CMRT Phase I

A CMRT Phase I response has one GIS person on staff for the 12-hour shift. The GIS assets include a laptop computer with full GIS capabilities, a computer projector, and a page-size color printer/copier. For this scale response, only page-size hardcopy maps can be requested. Since there is only one GIS person on staff, map requests should be routed through and prioritized by the Assessment Manager. Understand that one GIS person will be very busy, and low priority requests may take a while to complete due to conflicting priorities.

CMRT Phase II

A CMRT Phase II response expands on the Phase I with regard to personnel and equipment. A Phase II has two GIS personnel on staff per 12-hour shift for a 24-hour operation. The available equipment list grows to include a Sun Workstation, 2 plotters, 2 large monitors and video routing equipment, and an 11x17 inch printer. This is in addition to the existing Phase I equipment. Similar to a phase I response, it is anticipated that the two GIS staff members will be extremely busy meeting requests for GIS information. Again, the Assessment Manager will be the point of contact to route all GIS requests through. He/she prioritizes these requests to ensure that high-

priority products are completed in a timely manner. Additionally, requests for maps can be routed through the Overview group and subsequently passed to the Assessment Manager for prioritization.

FRMAC

A Full FRMAC response is the largest planned GIS response. This response includes four GIS staff per 12-hour shift for a 24-hour operation. The equipment associated with a Full FRMAC includes more plotters and computers added to the CMRT Phase II assets. Of the four GIS staff working per shift, two would focus on map production tasks, one person would serve as data manager (focusing on import and documentation of the various data sets into the GIS), and the remaining person would serve as the GIS manager. The GIS manager would be responsible for delegating requests to the GIS staff and ensuring that products are delivered to appropriate customers with the corresponding approvals. The GIS manager works closely with the Assessment Manager to set priorities on requests for map information. Requests for map information originating outside assessment should be funneled through either the Overview group or the Assessment Manager.

Canned & Custom Map Products

Requests for hardcopy map products fall into two general categories namely, canned and custom map products. Keep in mind when requesting a product, that “iterations” or multiple version of a map leading up to a final product causes the production time for a product to increase dramatically. Please consider each “iteration” as a unique map product. A final plot that takes the requestor 4 versions to become final is actually like producing 4 unique maps. For this reason, it is much more efficient to submit the initial map request with as much information as possible to reduce multiple “iterations”. In conjunction with assessment scientists, the GIS staff has spent time defining and automating a set of canned GIS map products. The products are outlined in method M.6.3. Remember that when requesting a canned map product, what you get IS what you get. If the required product is a modification to a canned product or a completely different map, the request is considered a custom map product.

When requesting a custom map product, please indicate clearly the following information:

- Map Title & Sub Title
- Map Scale and size of physical plot
- Specific verbiage for any text blocks on the product.
- Specific list of map themes to be included on the map (remember: more themes make a map harder to read).
- Any necessary label information on the map (complex labeling generally make the map more time consuming to produce).
- Any necessary legend information such as data break points and associated colors and symbology for the data.

- Any necessary logos or graphical auxiliary data.

Time for a map request to be filled is dependant upon the number of competing priorities placed on the GIS staff. Typically, page-size products are generated faster due to being less complex with shorter printing times. Page-size products can be turned around in as quickly as 15 minutes (again depending on the complexity of the request). Large map products take longer due to map complexity, plot-processing time, and finally print speed of the plotter. A good rule of thumb is about 30 minutes for a large format product (5 to 10 minutes of which is plotting time).

As the GIS staff generates map products, each map is compiled with a unique map number placed on it. The map number is of the form Xxyymmddttt.vv where: Xx is the response or project delineation, yy is the year, mm is the month, dd is the day, tttt is the plot time in military, and vv is the version number of the map. If you need to request additional copies of a previously generated product, please refer to the map number. All plots are archived on-line as rtl (plotter format), pdf, and jpeg formats and are named based on the map number. Plot information is also available in the Map Archive Database (MAD). MAD is a database application built on Microsoft Access that stores metadata on each plot generated by the GIS. The database can be queried using map number, title, project and other fields to quickly identify if an existing product meets the user's needs. MAD is currently a developmental system, but has worked well in several recent FRMAC exercises and could prove useful to the Overview group in the future as the system matures.

Release Control

All map products generated by the GIS will be labeled with the appropriate release information on the hardcopy. One of three markings will appear on all FRMAC map products: FRMAC Use Only, Draft, and Releasable. A "FRMAC Use Only" product is a map that is not allowed to leave the FRMAC facility. Such maps might have raw data or other data that has not been assessed or reviewed by the FRMAC director. Map products marked with "Draft" are products that are geared to become releasable but have yet to be approved for release by the FRMAC director. Finally, the FRMAC director approves "Releasable" map products for release to organizations outside the FRMAC. Such releasable map products must go through the standard procedure for information release outside the FRMAC.

Browsing Data

As mentioned above in the presentations options section, the quickest method to get information from available data is to browse interactively in the GIS. This is an effective method by which to quickly assess the validity of data. Data entry or reporting errors in GPS coordinates are quickly found in the GIS by spatially searching for outlying data points. To do this, simply zoom to the extent of the active data point theme or layer in the GIS. As points show up outside the extent of the response field activities, the outlying points need to be queried and reported as questionable or bad to the ERDS data center staff. The data points can also be quickly assessed to look for points with outlier data values. By applying a color lookup based on defined break points in the data, trend anomalies in the data can quickly be identified. These questionable points should again be queried and reported to the ERDS data center to check for data entry

transcription errors or other reporting flaws. Using these methods to assess the field data eliminates the need to make draft hardcopy map products and helps leverage GIS staff time to meet other mapping priorities.

MODELS

Modeling tools are available to assist the FRMAC Assessment Group in predicting the dose from atmospheric releases, estimating DILs, evaluating field measurement data, and calculating dose from skin contamination. Below are brief descriptions of the codes that are used by FRMAC assessment staff.

One of the most extensively used modeling tools is an atmospheric dispersion model. Running models during emergency response requires careful attention to the applicability of input data as well as judgment to make assumptions and simplifications when information is sparse. Results can vary dramatically with different source characteristics, such as height of release, release fraction, or particle size distribution. The quality and quantity of meteorological data as interpreted by model transport code strongly affect the downwind footprint location and extent. To assist decision-making, model inputs need to be representative, the model physics realistic, and the modeler skilled. In addition, having the means to transmit and communicate the model results appropriately and quickly is just as important as making the model run.

Modeling tools range from simple order-of-magnitude estimates with all manual inputs to advanced three-dimensional systems with a high degree of automation. Fast-running models can provide initial guidance while more detailed models are being run. Simpler models include Hotspot and RASCAL. SHARC and HPAC are more complex codes that demand training and maintenance of skill for effective use. ARAC consists of a centralized modeling system with advanced 3-D models technical and scientific support staff, and tools for remote access to automated predictions. Running different models in parallel may provide a useful check when time allows. However, when decisions need to be made operational protocols must be in place so that only one model result goes forward.

ARAC

The Atmospheric Release Advisory Capability (ARAC) provides a centralized modeling service as well as a set of modeling tools with features developed specifically to support FRMAC operations. The central service is located in the National Atmospheric Release Advisory Center (NARAC) at Lawrence Livermore National Laboratory (LLNL) in Livermore, California. There, full-time assessment meteorologists employ an advanced modeling system to simulate three-dimensional atmospheric flows, terrain effects, and dispersion of releases on all scales of interest, from local to global.

The NARAC modeling system uses a continuous representation of the ground surface based on a piecewise bilinear interpolation of grid-point topographical data. Nested grids and a variety of map projections are provided to treat problems at the appropriate spatial scale. Variable vertical resolution allows detailed representation of the meteorological and concentration fields in the critical near-surface region.

The ADAPT model is used to generate realistic three-dimensional meteorological fields. ADAPT assimilates real-time observations worldwide (e.g., surface stations, radiosondes, profilers) and/or weather forecast model results, as well as land-surface data. The ADAPT model uses observed and/or forecasted data to construct meteorological fields (mean winds, pressure, precipitation, temperature, etc.) based on a variety of interpolation methods and atmospheric parameterizations. Turbulence quantities required by the dispersion model are diagnosed using near-surface meteorological variables, surface-layer and boundary-layer similarity-theory scaling relationships, and a surface energy budget method. ADAPT produces non-divergent wind fields using an adjustment procedure based on the variational principle and a finite-element spatial discretization.

NARAC generates mesoscale forecasts using its relocatable version of the Naval Research Laboratory's COAMPS model. COAMPS is a coupled atmospheric data assimilation and weather forecast model. The forecast model is based on non-hydrostatic compressible dynamics, and includes parameterizations for subgrid scale mixing, explicit moist physics, cumulus convection, and radiation.

The dispersion model, LODI, solves the 3-D advection-diffusion equation using a Lagrangian stochastic, Monte Carlo method. LODI simulates the processes of mean wind advection, turbulent diffusion, radioactive decay and production, first-order chemical reactions, spatially varying and aerosol-size-dependent wet and dry deposition (including gravitational settling). The decay and growth of radionuclides in decay chains is calculated dynamically during the simulation. Sources may be specified as continuous or instantaneous emissions from point, line, area, or volume sources. Fires, explosions, and stack emissions with momentum and/or buoyant plume rise can be modeled. For an aerosol source, the mass (or activity) particle size distribution can be specified with the input parameters of a lognormal distribution or from tabular input. Multiple, time-dependent sources can be used in a single simulation. The time-varying emission of radionuclide mixtures and the time-dependent production and decay of daughter products during atmospheric transport is a unique capability.

In real-time, the NARAC system automatically accesses global databases of terrain elevation, geographical data, high-resolution land use/cover data, real-time meteorological observations, and meteorological forecasts. The system also accesses radionuclide decay chain and dose factor databases. NARAC model output options include varying air concentration, ground deposition, air immersion dose, ground exposure dose, or inhalation dose. Dose rates, time-average or time-integrated dose from all these pathways can be calculated. Output can be calculated for individual radionuclides, radionuclide mixtures, or particle size ranges (e.g., respirable particles). In addition, population within affected areas can be estimated.

Built into NARAC databases are default source terms and associated consequence plot types for each of the FRMAC scenarios. Standard FRMAC products include dose (specific organ or bone, CDE, EDE, CEDE, and TEDE contoured with appropriate PAG values), dose rate, deposition, and air concentrations (instantaneous, time-averaged, or time-integrated). Products may be customized to event-specific DRLs/DILs. Products may be adjusted to match a set of field measurements sent electronically from the FRMAC DCENT. ARAC also delivers a Consequence Report with each set of products. This report describes the nature of the release, the assumptions used in the calculations and the predicted effects. A unique feature of the ARAC

support is the extensive quality assurance and error checking by expert assessment meteorologists including graphic visualizations of each modeling step.

The NARAC system is highly automated with electronic transmission of products in the following ways:

1. Directly to the FRMAC GIS Center
2. On a LLNL server for access as World Wide Web pages (NARAC Web)
3. As files delivered to designated users of the NARAC iClient software

The last two Internet- and Web-based tools provide multiple authorized organizations with simultaneous, instant access to the same model products. Authorized organizations are given unique user name and passwords to access the NARAC Web pages for a particular event. In addition, the NARAC iClient software can be installed on standard desktop and laptop computers, and uses Internet technology to receive products via modem or Internet connection. The iClient allows users to enter event information, request NARAC centralized system model predictions, run local models (such as Hotspot) independent of the central system, and display model results with geographical information. Meteorological data for NARAC calculations can be seamlessly and automatically acquired in real time, or the user may manually enter meteorological data. *iClient* users can also run the NARAC models in a totally automated mode without assistance from NARAC meteorologists. The use of the Java platform-independent programming language for the *iClient* means that the software will run on standard desktop or laptop computers.

Request for NARAC *iClient* software is available by contacting ARAC Program Office at 925-422-1801, see <http://narac.llnl.gov>. For NARAC Customer Support call 925-422-9159 or 925-424-ARAC (424-2722) or e-mail narac@llnl.gov.

SHARC

The Sandia Hazard Assessment Response Capability – SHARC (Bo92) consists of field-deployable codes and expert operators to rapidly assess the effects of Weapons of Mass Destruction (WMDs). In many exercises it has been demonstrated that portability of effects prediction expertise is invaluable to key decision-makers. The principal codes implemented in SHARC are:

AIRRAD: Transport of nuclear fallout. Dose rate, integrated dose, and times of arrival and last fallout are predicted. AIRRAD (Wa89) predicts downwind contours for dose rate, integrated dose, time of arrival, and time of last fallout.

ERAD: (Explosive Release Atmospheric Dispersal) is used to calculate atmospheric dispersal for materials released by unmitigated and foam-mitigated high explosive detonation and other release mechanisms. For energetic releases ERAD models the plume rise by integration of the equations of motion for a growing (mass-entraining) sphere representing the released material. This approach offers an advantage over empirically defined initial cloud geometry by explicitly handling the influence of the atmosphere's temperature profile on the vertical rise providing a physical basis for cloud height which can manifest capture by an inversion layer or puncture

through such layers. Solution of the advection equation accounts for turbulent diffusion in the vertical direction characterized by contemporary Monin-Obikov atmospheric scaling for both stable and highly convective atmospheric boundary layers.

NUKE: This code is a collection of predictions of the prompt effects associated with nuclear detonation. Empirical relations are used to characterize the blast overpressure, gamma and neutron radiation, thermal fluence, crater size, and range of EMP influence. Further empiricism is used to characterize the effects of these “bomb outputs” on people and structures. Injury and mortality are considered for people exposed to blast, thermal radiation, and nuclear radiation. The basis for calculations included in NUKE is generally derived from Effects Manual 1 (DNA93, DNA72) and Glasstone (G177).

BLAST: predicts ranges associated with injuries and lethal ties associated with direct blast effects from conventional explosives.

SHARC: The SHARC code is a JAVA-based graphical user interface (GUI) providing user dialogues to operate the foregoing codes in a flexible and reliable manner. The codes may be operated as individual models or in scenario modes where one or all of the codes may be used to predict plausible outcomes. SHARC also provides a graphical viewer capability common to all the models. Contours are displayed on GIS (graphical information system) maps. SHARC includes the post-processing required to estimate casualties and fatalities due to the effects predicted. Persons exposed, injured, and killed are estimated for various effects by use of U.S. Census data and the Landscan worldwide population database.

Incidence of injury and fatality are characterized by PROBIT (PROBability unIT) expressions. This approach allows continuous adjustment of incidence level to values appropriate for each site at which population estimates are available. Moreover, reasonable estimates of injury and morbidity in response to multiple effects can be developed in consideration of the relative incidence of effects that normally varies appreciably over the calculational domain.

RASCAL

Developed for the U.S. Nuclear Regulatory Commission (NRC), the Radiological Assessment System for Consequence AnaLysis (RASCAL) is designed to assess dose projections for radiological emergencies at NRC licensed facilities. Assessments are based on plant conditions or hand calculational methods.

RASCAL 3.0.3 (May 2002) on CD-ROM and a description, NUREG-1741 (NRC01), are distributed by the Incident Response Operations office of the NRC, sam2@nrc.gov, 301-415-6204. Support is provided by Athey Consulting, gfathey@intrepid.net, 304-725-8834. The software is available on the FRMAC Assessment computers.

The tools are designed to provide a comparison to EPA Protective Action Guidance and thresholds for acute health effects. NRC personnel will use RASCAL to conduct an independent evaluation of dose and consequence projections, and for training and drills. The software consists of four tools accessed from a main menu (or shell).

First, the Decay Calculator (DecayCalc) computes radiological decay and daughter ingrowth. It computes the activity remaining after the decay time selected. It does not compute integrated activity over the decay period. It accesses the RASCAL radionuclide database and displays decay chains as tables or graphs.

Second, the Field Measurement to Dose model (FMDose) uses field measurements to compute emergency worker limits, early-phase and intermediate-phase doses, and derived intervention levels (DILs). Field measurement data must be entered directly in FMDose. FMDose includes access to the RASCAL radionuclide database and has the ability to display decay chains as a table or as a graphic.

Third, the Meteorological data Processor program (MetProc) is used for manually entering meteorological data for use by the atmospheric transport and diffusion model. Meteorological data for the site (release point) and 35 additional meteorological observation points may be entered and processed for use by the STDose model. If data for more than one station is entered, a two-dimensional surface wind field is generated by simple inverse-distance squared weighting of station data. If the location is one of the listed regulated NRC facilities, this surface field is adjusted for mass consistency using local topographic data around that site.

Fourth, the Source Term to Dose model (STDose) uses a Gaussian plume-puff transport and diffusion model to provide doses from radionuclide releases. Near the release, a steady-state Gaussian plume code is used. At later travel distances a time-varying Gaussian puff code computes dispersion. Plume rise, wet and dry deposition, and decay are treated. STDose includes time-dependent source rates for several specific scenarios. Nuclear power reactor releases are determined from plant type and conditions or from monitored release data. Mitigation for various pathways is taken into account. Spent fuel sources may be either in water or dry storage cask. Fuel cycle releases include UF₆ cylinders, fires and explosions involving uranium oxide, criticality accidents, and general direct releases where the user specifies nuclides and amounts. A special steady-state code treats the UF₆ dense gas releases and plume chemistry and thermodynamic products. Products include tables of dose along the centerline as a function of downwind distance. Optionally the user may display a radial plot of sector-average dose ranges.

Hotspot

LLNL developed the Hotspot Health Physics Codes to provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling nuclear material.

Current Hotspot versions run on PCs under Windows 95/98/2000/NT operating systems and are available to download from <http://www.llnl.gov/nai/technologies/hotspot/>. The software is available on the FRMAC Assessment computers.

Four general programs, Plume, Explosion, Fire, and Resuspension, estimate the downwind radiological impact following the release of radioactive material resulting from a continuous or puff release, explosive release, fuel fire, or an area contamination event. Additional programs

deal specifically with the release of plutonium, uranium, and tritium to expedite an initial assessment of accidents involving nuclear weapons. Hotspot may also be used to generate a set of field measurement data for exercise planning.

Hotspot codes are a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. Using the simple steady-state Gaussian plume model, Hotspot is designed to determine close-in effects for short-term releases (up to a few hours) during steady wind conditions over flat terrain. The user must input single values of wind speed, wind direction and atmospheric stability. Virtual source terms are used to model the initial atmospheric distribution of source material following an explosion, fire, resuspension, or user-input geometry. The products are only representative to the extent that single set of meteorological conditions exists downwind.

Hotspot incorporates Dose Conversion Factors (DCFs) for inhalation, submersion, and ground shine. In addition to the inhalation CEDE DCFs, acute (24-hour) DCFs are available for estimating non-stochastic effects. This acute mode can be used for estimating the immediate radiological impact associated with high acute radiation doses (applicable target organs are the lung, small intestine wall, and red bone marrow). Users can add radionuclides and custom mixtures (up to 50 radionuclides per mixture). Tabular and graphical output consists of dose and deposition as a function of plume centerline downwind distance, and dose and deposition contours.

Dose and deposition contours can also be saved as mapping files for display on geographical maps. Latitude and Longitude, Universal Transverse Mercator (UTM), and Military Grid Reference System (MGRS) geographical coordinate systems are supported for interfacing Hotspot dispersion contours with commercial mapping systems. Dose and Deposition plume contours can also be overlaid on geographical maps. Any .bmp file can easily be geo-registered and added to a user's map library.

The Nuclear Explosion program estimates the effects of a surface-burst nuclear weapon. These include prompt effects (Neutron and gamma, blast, and thermal), and fallout information. Fallout includes arrival time, dose rate at arrival time, and integrated dose contours for several time periods, e.g., first 6 hours, first day, first week, etc.

The FIDLER program is a tool for calibrating radiation survey instruments for ground-survey measurements and initial screening of personnel for possible plutonium uptake in the lung.

HPAC

HPAC was developed by Defense Threat Reduction Agency (DTRA) as a forward deployable, counterproliferation and counterforce tool to assess the consequences of weapons of mass destruction. The software assists war fighters in weaponizing targets containing hazardous nuclear, biological, and chemical (NBC) materials. HPAC also supports accidents or terrorist events involving NBC materials including FRMAC scenarios.

HPAC runs under Windows 95/98/2000/NT operating systems and is available from: DTRA Collateral Effects Section (TDACC), HPAChelp@dtra.mil, (703) 325-6106, see

http://www.dtra.mil/td/acecenter/td_hpac.html. Users must obtain a license to run HPAC on their PC. The software is available on the FRMAC Assessment computers.

The code has a variety of modules that perform four principal functions – Source term generation, weather data retrieval, transport and dispersion, and effects.

Source term modules applicable to FRMAC include nuclear facilities with defaults for nuclear power plants worldwide, nuclear weapon accidents, and nuclear yield releases. Many of the source term algorithms for destruction of facilities by weapons have been derived from recent field experiments. HPAC can be used for planning with weather data from an online climatology database. For emergency response, the user needs an account to access the HPAC Meteorological Data Servers, which provide both real-time observations as well as several forecast models worldwide.

A limited series of observations or gridded meteorological data are used to initialize an internal three-dimensional time-varying mass consistent wind field. The wind field may be either run with or without terrain. If chosen, a terrain database with about 1 km resolution is available to initialize a terrain-following coordinate system.

The Second-order Closure Integrated PUFF (SCIPUFF) model performs the dispersion calculation. A series of Gaussian puffs are released and tracked in a Lagrangian or moving frame of reference. Dispersion rate is generated locally as a function of velocity fluctuation statistics. Puffs can either split or merge depending on wind shears and the complexity of the flow. Radiological decay, buoyancy and momentum plume rise, dense gas effects, and dry and wet deposition are included.

HPAC can be operated in one of two modes – the Operational mode in which defaults are used for source terms, and the more complex Advanced mode in which the user must specify all aspects of the source terms. Nearly any source can be entered in the Advanced mode; however, this is only recommended for experienced modelers who have completed the HPAC Advanced Training Course.

Products include mapped plots of dose and deposition with emphasis on lethality values. A unique HPAC feature is a “Hazard Area” plot, which includes the uncertainty in the prediction. The Hazard Area is presented as the probability of exceeding a certain dose level. The maps show major political features and city and national boundaries from a 1:1,000,000 database. Products may be exported in several formats such as ARCInfo.

VARSKIN

VARSKIN calculates the radiation dose (gamma and beta) to skin from radioactive contamination of skin or protective clothing. The Assessment Manual does not cover skin contamination, except for Method M.4.7, which addresses only skin contamination due to resuspension. VARSKIN is ideal for assessing the potential for hot particle injury. J.S. Durham at Pacific Northwest National Laboratory developed the program for the NRC. It is distributed by the DOE Radiation Safety Information Computational Center (RSICC) as NUREG/ CR-5873. The program is available on the FRMAC Assessment computers.

VARSKIN models disk, sphere and slab particles, plus a distributed source (plane). A library of parameters for common radionuclides is included. Parameters for other radionuclides can be prepared using its companion program SADDE. Attenuation by air gaps and clothing can be included. Results with a summary of input parameters are displayed on the screen and can be saved to a file.

CALCULATIONAL AIDS

Spreadsheets

FRMAC developed three Microsoft Excel Spreadsheets to automate use of the previous version of the Assessment Manual (“grd_depo,” “forage,” and “food_sam”). Do not use these spreadsheets, because they are not compatible with the new Assessment Manual.

FRMAC developed another spreadsheet (“FDA_tool”) to accompany the Addendum to the previous FRMAC Manual, which adopted the new FDA food PAGs. This spreadsheet may be used and is compatible with the 2002 revision of the Assessment Manual.

FRMAC will develop a new Assessment Manual automation aid to replace the now obsolete Excel spreadsheets in FY03. FRMAC is also planning to implement many of the assessment methods into the DCENT database application.

DEPDOSE

DEPDOSE is a DOS application, developed by Brookhaven National Laboratory, to aid computation of external dose and assess the potential effectiveness of mitigation measures. DEPDOSE has two modes of operation. First, using a user defined radionuclide mix, it calculates the external dose for a user-defined interval after a user specified initial decay period. Alternatively, it can estimate the initial decay period required for the user’s dose to be below the threshold specified by the user. That is, it estimates how long the relocation must continue for a particular area. DEPDOSE can also be used to determine the mix after decay with ingrowth and to estimate the exposure rate at an arbitrary time in the future. DEPDOSE permits a choice of conversion factor references and addition of more references by the user. Finally, DEPDOSE permits explicit application of factors for weathering, ground roughness, occupancy, and shielding.

METHOD M.6.1 DOCUMENTING ASSESSMENT PRODUCTS

Purpose: Provides a QA cover sheet for Assessment products, which documents inputs, methods, assumptions, and exhibits approvals. Also cites authority for release of a product.

Discussion: All FRMAC products to be released from the FRMAC must have a QA Cover Sheet. This is the product's pedigree. It provides traceability of the data, computation details and developer. The cover sheet also demonstrates if authority for release was granted. All releases must be logged.

Use of a QA Cover Sheet for internal FRMAC Assessment products is not required, but may be prudent for continuity over shift changes or to distinguish difference in versions.

Copies of all QA Cover Sheets must be kept on file in Assessment. All releases must be logged in the journal.

If a FRMAC Assessment product is hard copy, simply attach a copy of the QA Cover Sheet and file a copy. If the product is soft copy, prepare the sheet and file it. Offer a copy to the product recipient.

Step 1. Complete "Assessment Product QA Cover Sheet" (Worksheet 6.1)

1. Purpose of analysis and requester
2. Designate distribution (internal use only or for release)
3. If for release, cite authority by name and date
4. Identify data used and analysis applied
5. Cite assumptions, cautions and restrictions on applicability
6. Describe general quality

Step 2. File copy in Assessment files.

1. Create QA Cover Sheet file, if it does not already exist.
2. Place copy in file.
3. Retain until FRMAC Director directs disposal.

Step 3. Log release authorization in Assessment journal.**Step 4. If Assessment Product is hard copy.**

1. Attach copy of Cover sheet to only the master copy of product.
2. Offer copy to all recipients

METHOD M.6.2 POSTING DEPOSITION DERIVED RESPONSE LEVELS

Purpose: This method establishes the means for posting Derived Response Levels (DRLs) used to relate deposition exposure rates and marker-radionuclide levels to PAGs.

Discussion: DRLs are in the same units as the results of field monitoring and assessment. This allows prompt assessment of environmental data. Because the isotopic mixture of a release may vary with location, DRLs may be required for different spatial locations.

Steps: Fill in Worksheet 6.2 as DRLs are calculated. Post the worksheet in a location that will allow prompt assessment of environmental measurements as they are received.

METHOD M.6.3 DISPLAYING ASSESSMENT RESULTS

Purpose: This method outlines the use of GIS for display of Assessment results as graphics.

Discussion: GIS (Geographical Information System) is the means by which data and Assessment results are graphically presented. This method describes the basics of the GIS presentations. There is no pre-defined color palette. Colors must be chosen to provide adequate contrast with the base on which the data or results are presented (map or photograph). However, the palette generally follows a “rainbow” scheme corresponding high to low.

Several GIS products have been pre-planned (possibly scripted). These are described in detail. They have been prepared for both the primary Assessment products, plus certain supporting and internal products. Adaptation to incident specifics is expected. Some figures must be created as required for the problem at hand. However, certain minimum information is required on all GIS products.

The three steps below are not sequential steps, but levels of GIS products. GIS will produce products other than for Assessment at the direction of the FRMAC Director. Those need not conform to this method.

Step 1. Production of the Primary Assessment Products

These maps require display of the minimum information common to all GIS Assessment products as cited in Step 3 “Development of Other Presentations.”

MONITORING & SAMPLING STATUS MAP

The Monitoring/Sampling Status Map summarizes the location and type of all monitoring and sampling data that has been collected up to the current time. It is automatically plotted by a script, which is scheduled to run at regular clock intervals (if possible, near real-time). The maps are for general release. Their purpose is twofold: 1) portray the progress of the monitoring effort and 2) convey some concept of quality and confidence for the PAG Zone Map. The maps continually grow in density and diversity of data collected. They do not reflect the level of radiation, concentration or dose.

- Previous data (“Assessed” flag set) are plotted first in a muted color.
- Current data being reviewed (“Verified” flag set, but Assessment’s flag not yet set) are plotted last in a bold color. Thus, new data overwrites old data.
- Unique colors or symbols must be used for each measurement and sample type.
 - Expected measurement types may include:
 - Exposure rate ($\mu\text{R/h}$ or mR/h)
 - Deposition ($\mu\text{Ci/m}^2$)
 - Field (in situ) gamma spectroscopy ($\mu\text{Ci/m}^2$)

- GM (cps, cpm, or dpm)
- α survey meter (cpm or dpm)
- Expected sample types may include:
 - Soil
 - Air
 - Water
 - Food
 - Feed

Explanation of Monitoring/Sampling Points Displayed

The plotted points represent the cumulative monitoring and/or sampling completed to the time the plot is made. Points are shown that for which there is at least one Monitoring and/or sampling data point. Locations that have been intensively monitored are plotted in muted colors. New monitoring or sampling locations are plotted in bold colors.

PAG ZONE MAP(S)

The PAG Zone Map indicates zones in which particular PAGs are exceeded, e.g., EPA Early Phase PAGs, EPA Intermediate Phase PAGs, FDA Ingestion PAGs. Two versions (Near Field and Far Field) are required, because some PAGs will only be exceeded very near the incident site (<10 mi.), while other may be exceeded to great distances (>50 mi.). The maps may show any combination of these six (6) zones:

1. Evacuation (Early Phase)
2. Sheltering (Early Phase)
3. Relocation (1st yr.)
4. Long-Term Objective (2nd yr.)
5. Long-Term Objective (50 yr.)
6. Ingestion (food embargo)

PAG Zones

The data have been assessed with respect to published Protective Action Guides (PAGs). Those areas that have been determined to exceed a specific PAG are denoted on this map. All data available (including modeling, where necessary) have been used to create this map. Additional monitoring and sampling will reduce uncertainty and improve quality of this map, but will not alter its essential features. This map does NOT represent any Protective Action Recommendations (PARs).

Evacuation

The EPA early phase PAGs are designed to protect people from acute and long-term radiation effects by considering doses accrued over four days from onset of exposure. This may include plume passage. If the plume has passed, then the dose includes only ground-shine and resuspension. If the plume is present, then the dose includes immersion and inhalation. The limit is 1,000 mrem, unless those affected are relatively immobile, then the limit is 5,000 mrem.

Sheltering

Evacuation may not be required, if sufficient protection can be achieved by “sheltering.” The EPA early phase PAGs for evacuation still apply, but the calculated doses are reduced according to the degree of protection that is anticipated for sheltering.

Relocation

The EPA relocation PAG protects from long-term radiation effects. Doses accrued from onset and for one year are considered. The dose includes only ground-shine and resuspension. The limit is 2,000 mrem during the first year.

2nd Year Long-Term Objective

This is the first of two Long-Term Objectives in the EPA intermediate phase PAGs to protect against long-term radiation effects. The dose considered is onset for a one-year period. The dose includes only ground-shine and resuspension. The limit is 500 mrem during the second year.

50-Year Long-Term Objective

This is the second of two Long-Term Objectives in the EPA intermediate phase PAGs to protect against long-term radiation effects. The dose considered is that from onset and for a 50-year period. The dose includes only ground-shine and resuspension. The limit 5,000 mrem over the next 50 years.

Ingestion

The FDA has established guidelines to protect the food supply. These guidelines apply to the concentration actually found in food. The zone described is an area in which contamination is such that the PAG may be exceeded or samples indicate that a PAG is likely to be exceeded. The PAG establishes the limit of dose at 500 mrem CEDE for the most sensitive population or 5,000 mrem CDE for a specific organ, whichever is most restrictive.

Step 2. Production of Supporting and Internal Products

These maps are those used routinely by Assessment. Usually they will not be distributed, but some may, if necessary.

- Because they are for internal use they can be “Draft” quality and omit many features required for distribution.

- If a map is to be for internal use, then it must be labeled with a banner “Internal Use Only.”
- If the figure is to be released, then it must display the minimum information common to all GIS Assessment products as cited in Step 3 “Development of Other Presentations.”

POSTING PLOTS

A posting plot displays the numeric value of a single measurement or analysis result. It is used to compare results of a single type of measurement with its cohorts for interpolation and QA purposes. Posting Plots will be run separately for each type of measurement or sample. Thus, there can be many individual Posting Plots, which differ only in title, (e.g., POSTING PLOT – Gamma Survey Measurements) and the data query.

Previous data (already reviewed by Assessment) are plotted first in a muted color. Current data (being reviewed) are plotted last in a bold color. Thus, new data overwrites old data.

LOCATION IDENTIFIER MAP

The Location Identifier Map is a visual index, which reports the name assigned to each sample or measurement location. Like the Posting Plot, it reports the alphanumeric value of the name for each location, which may be either pre-designated or assigned as visited.

MEASUREMENT ASSESSMENT MAP

This map portrays the results of the assessment of measurements. The intent is to show which, if any, PAGs are exceeded for each location monitored.

The DRL comparison is automatic. Follow the process below.

- a) Select the PAG and measurement type to assess.
- b) Define DRLs corresponding to the PAG for that measurement type.
- c) Have the Data Center prepare a file of just that data type.
- d) Have GIS set legend break points for the DRL.
- e) Plot that comparison as a single coverage.
- f) More than one measurement type or PAG can be assessed and plotted on the same figure. Three options are available for display: 1) simple icon, 2) semicircle icon, and 3) quadrant icon.
 - If a simple icon is used, care must be taken to observe plotting precedence. That is, the last item plotted overwrites any that preceded it. Therefore, the coverage with the lowest level DRL must plot first, then higher and higher

until the coverage with the highest DRL is plotted last. This is the simplest procedure but requires caution.

- If the semicircle icon is used, then two quantities can be simultaneously displayed without potential of overwriting (Two data sets will be required from the Data Center). The left and right semicircles are plotted independently, but form a circle. If the values plotted are being compared with a DRL, then color the semicircle as transparent (background), green (below DRL), and red (above DRL).
- If the quadrant icon is used, then four quantities can be simultaneously displayed without potential of overwriting (four data sets will be required from the Data Center). A square with four quadrants is used as the icon, where each quadrant represents a different quantity. If the quantities are compared with DRLs, then color each quadrant as follows: transparent (background), green (below DRL), and red (above DRL).

g) The following PAGs may be considered:

- Turn-back (Worker protection)
- Evacuation (Early Phase)
- Sheltering (Early Phase)
- Relocation (1st yr.)
- Long-Term Objective (2nd yr.)
- Long-Term Objective (50 yr.)
- Ingestion (food embargo)

SAMPLE ASSESSMENT MAP

The Sample Assessment Map is analogous to the Measurement Assessment Map. It reports the assessment of sample analyses using a “marker” radionuclide. The intent is to show which, if any, PAGs are exceeded for each location sampled. The process is the same as with measurements. The difference is the source of the data, samples of various types instead of measurements.

The DRL comparison is automatic. Follow the process below.

- a) Select the PAG and sample type to assess.
- b) Define DRLs corresponding to the PAG for that sample type.
- c) Have the Data Center prepare a file of just that data type.
- d) Have GIS set legend break points for the DRL.
- e) Plot that comparison as a single coverage.

-
- f) More than one measurement type or PAG can be assessed and plotted on the same figure. Two options are available for display: 1) a simple icon and 2) a quadrant icon, which displays four comparisons.
 - g) If a simple icon is used, care must be taken to observe plotting precedence. That is, the last item plotted overwrites any that preceded it. Therefore, the coverage with the lowest level DRL must plot first, then higher and higher until the coverage with the highest DRL is plotted last. This is the simplest procedure but requires caution.
 - h) If the quadrant icon is used, then four comparisons can be simultaneously displayed without potential of overwriting (four data sets will be required from the Data Center). A square with four quadrants is used as the icon, where each quadrant represents a different PAG assessment (DRL). Color the icon as follows: transparent (background), green (below DRL), and red (above DRL).
 - g) The following PAGs may be used for comparison of these sample types:

Soil & in situ (DRLs based on EPA PAGs)

- Evacuation (Early Phase)
- Relocation (1st yr.)
- Long-Term Objective (2nd yr.)
- Long-Term Objective (50 yr.)

Food & water (DILs and DRLs based on FDA ingestion PAG)

- Crop
- Milk
- Water
- Feed

QUICK-LOOK AERIAL SURVEY MAP

The aerial measurements performed with the AMS fixed-wing aircraft are presented on this map. The estimated exposure rate or a DRL comparison may be plotted along the flight path as color-coded icons (one for each measurement). More than one flight can be plotted, but separate icons must be used. *(Contours can be used only if the data are adequately sampled to generate contours. Generally, fixed-wing data are under-sampled.)*

Follow the process below.

- a) Select exposure rate or PAG comparison plot.
- b) Import data from AMS to GIS (data are not available from the Data Center).

-
- c) If exposure rate is plotted, have GIS set legend break points for the desired values. Use different colors for each with the highest as red, low as blue. The defaults are: 100 mR/h, 10 mR/h, 1 mR/h, and 0.05 mR/h.
 - d) If plotting a PAG comparison, then several PAGs (DRLs) may be used as different break points. Color the icon with the highest DRL as red and the lowest DRL as blue with other colors in between. Precedence must be understood, but it will not hide data.
 - e) Plot that comparison as a single coverage.
 - f) Additional flights can be added as separate coverages, but different icons must be employed to distinguish between flights.
 - g) The following PAGs and action levels may be considered:
 - Turn-back (Worker protection)
 - Evacuation (Early Phase)
 - Sheltering (Early Phase)
 - Relocation (1st yr.)
 - Long-Term Objective (2nd yr.)
 - Long-Term Objective (50 yr.)
 - Ingestion (food embargo)

DETAILED AERIAL SURVEY MAP

The aerial measurements performed with the AMS helicopters are presented on this map. Survey provides estimated exposure rate, man-made contribution to exposure rate or concentration of a specific nuclide. The map can then report the values of a comparison to DRLs. The map begins with the results from a single flight. Later maps show the results of all flights as a single contoured data set.

Follow the process below.

- a) Select type of plot: exposure rate, man-made, or nuclide concentration.
- b) Obtain that data set from AMS and import into GIS (data are not available from the Data Center).
- c) Have GIS set legend break points for the desired values. Use different colors for each with the highest as red, low as blue. The defaults only for exposure rate: 100 mR/h, 10 mR/h, 1 mR/h, and 0.05 mR/h.
- d) If plotting a PAG comparison, then several PAGs (DRLs) may be used as different break points. Color the contour with the highest DRL as red and the lowest DRL as

blue with other colors in between. Precedence must be understood, but it will not hide data.

- e) Plot that comparison as a single coverage.
- f) The following PAGs and action levels may be considered:
 - Turn-back (Worker protection)
 - Evacuation (Early Phase)
 - Sheltering (Early Phase)
 - Relocation (1st yr.)
 - Long-Term Objective (2nd yr.)
 - Long-Term Objective (50 yr.)
 - Ingestion (food embargo)

CURRENT RADIOLOGICAL CONDITIONS MAP

The Current Radiological Conditions Map is a best estimate of the present dose rate. It is used primarily as a Health and Safety aid to guide/plan field operations. This map is NOT used to convey PAG comparison. If the resuspension dose is negligible, then this is just external exposure rate. However, if resuspension dominates the external dose, then this map is the deposition multiplied by the appropriate dose conversion factor.

Follow the process below.

- a) Determine if dose is external or inhalation.
- b) If external exposure dominates, obtain all exposure rate data available including AMS. Import into GIS as separate coverages.
- c) If inhalation dose dominates, obtain all marker nuclide data available including AMS. Import into GIS as separate coverages.

NOTE: The assessor should work carefully when both internal and external exposures exist in a given situation.

- d) Have GIS set legend break points at the desired values. Use different colors for each with the highest as red, low as blue. The defaults are: 10 mrem/h, 2.5 mrem/h, mrem/h, 0.5 mrem/h and 0.05mrem/h.
- e) Plot that comparison as a single coverage.
- f) Inspect the plot and draw on it the best estimate for the selected contour levels.

- g) Have GIS digitize the hand drawn map as the current condition coverage. Present this coverage as the Current Radiological Conditions Map.

Development of the Current Radiological Conditions Map

This map is the synthesis of all data and predictions available to best portray the current radiological conditions. Highest confidence is in the area, which has been monitored thoroughly and surveyed by air. This area lies inside the dotted border. The least confidence is in the area, where little data is available and the assessment must depend upon modeling. This area is that outside of the dashed border.

PLUME MAP

This map portrays the assessment of measurements with a GM to determine the location of a plume. Exposure rate is not sufficient, because one cannot discriminate between deposition and contaminated air. However, because beta radiation is very short ranged, measurements of beta near the ground will be dominated by surface contamination and elevated measurements will be dominated by plume immersion. Measurement of the beta component of a GM measurement requires comparison of measurements made with the beta shield open and closed. Therefore, a set of four measurements will be acquired at each location i :

$WOup_i$ – window open, elevated measurement

$WCup_i$ – window closed, elevated measurement

$WOdn_i$ – window open, near surface measurement

$WCdn_i$ – window closed, near surface measurement

In addition, an open window background (WO_{bkgd}) must be established that is characteristic of the entire area.

Follow the process below.

1. Request the Data Center to create a new data set from the set of four measurements. Each element of the new data set is the result of logical comparison of the four measurements made each location. The new variable (P_i) can have only four logical values:

P_i = Plume overhead (or no plume)

P_i = Plume immersion

P_i = Deposition only (no plume)

P_i = Indeterminate (due to uncertainty)

Assign the logical values as follows:

Plume overhead if both: $|WOup_i - WCup_i| \leq k \cdot \sqrt{(WOup_i + WCup_i)}$

$$|WOdn_i - WCdn_i| \leq k \cdot \sqrt{(WOdn_i + WCdn_i)}$$

$$WOup_i \geq 3 \cdot WO_{bkgd}$$

And

Plume immersion if both:

$$|WOup_i - WCup_i| \geq k \cdot \sqrt{(WOup_i + WCup_i)}$$

$$|Wodwn_i - WCdwn_i| \geq k \cdot \sqrt{(Wodwn_i + WCdwn_i)}$$

Deposition only if both:

$$|WOup_i - WCup_i| \leq k \cdot \sqrt{(WOup_i + WCup_i)}$$

$$|Wodwn_i - WCdwn_i| \geq k \cdot \sqrt{(Wodwn_i + WCdwn_i)}$$

Indeterminate if no test is passed.

The confidence level of the test is determined by k , where $k=1.285$ at 90%CL, $k=1.645$ at 95% CL and $k=2.5$ at 99% CL.

2. Import P_i data set into GIS.
3. Plot P_i as:

Open Circle	Indeterminate
Yellow Circle	Plume overhead
Red Circle	Plume immersion
Black Circle	Deposition only

Step 3. Development of Other Assessment Maps

Productions of graphic presentations, which are tailored to the incident, are inevitable. The following describes the general production process and provides guidelines for the minimum information required on all maps. This process is to be used for ALL products developed.

1. Determine attributes:
 - Data to be presented and any data manipulations required
 - Area and content of base map
 - Number of icons to be displayed and criteria
 - Legend break points and captions
 - Title and text for text box explanations (if any)
 - Purpose: 1) For Release or 2) Internal Use Only
2. Consult with the Data Center to create the needed data sets and transfer to GIS.

3. Consult with GIS to clearly describe product attributes. Be sure to establish priority, schedule and product purpose.
4. Use colors that provide good contrast with the background. However, high values are to be most red and low values most blue.
5. Be sure the following information is included on the figure.
 - Event Name (main title)
 - Product Name (sub-title)
 - Series or Revision (if not unique product)
 - Scale and north symbol
 - Legend for color code
 - Key for icons
 - Map projection, datum and accuracy
 - Creation date & time
 - Unique file name
6. If product is for internal use, add bold banner “Internal Use Only”
7. If product is for release, then add release text box and log release in journal. Suggested text box content is:

Released: date / time
Approved by: name
8. Review rough draft of product before completion; adjust if needed.
9. Complete a QA Cover Sheet and keep in Assessment files. Offer copy to users.

METHOD M.6.4 SETTING THE “ASSESSMENT” FLAG

Purpose: Assign the final quality measure to data in the database of all measurements (DCENT). Do this often.

Discussion: All monitoring and sampling data is warehoused in the DCENT database. The first quality assessment is performed by the Monitoring & Sampling division, which sets the “Verified” flag. That flag indicates that units and value ranges are proper, required information is present and that the data entry has been double-checked for accuracy. The second quality check is by the Assessment division. The data are plotted/graphed and compared with cohorts to detect outliers, bias or other inconsistencies. Each measurement is assessed separately. If the data seems reliable, the Assessment flag is set to “Assessed.” If there is any question regarding validity, the Assessment flag is set to “Questionable.” Only assessed data are used for assessments and products. Therefore, it is critical that this operation be performed frequently. Questionable data can be investigated and fixed, and then the flag can be set to “Assessed.”

The flag setting is physically performed by the Data Center per Assessment direction.

Step 1. Assess the “new” data

1. Do this about every two hours.
2. Plot or graph the new data. GIS can plot the data type(s) of interest showing a distinction between new and previously assessed data. The “Posting Plot” was defined for this purpose, but any analog will suffice. Note the creation date/time for the data set(s) plotted.
3. Compare the new data with its cohorts. Flag the outliers. If no cohorts are available, compare members of the new data set.
 - Watch for values that are inconsistent with nearby cohorts.
 - Watch for points plotted at an unexpected location.
 - Watch for biases between data types.
4. Flag the questionable data points.

Step 2. Identify the questionable data points

1. Have GIS display the data at a workstation.
2. Find each outlier on the display and query its record.
3. Determine and record its “Key Number.”
4. Repeat until Key Numbers have been determined for all outliers.

Step 3. Set the Assessment flag

1. Have the Data Center set the Assessment flag to “Assessed” for all new data entered prior to the time the data set used for the plot was generated. *Data entered after this time was not plotted.*
2. Have the Data Center set Assessment flag to “Questionable,” for all points recorded as outliers.

Special Case: Bad field or lab instrument

If an instrument goes bad, all the data from it is compromised. In this case assess the data from that instrument against its cohorts. The process is the same as steps 1-3, except instead of “new” data it is the suspect data set.

1. If it is determined that the data is to be set aside, have the Data Center set all the Assessment flags to “Questionable” for data from that instrument and period.
2. If the data is to be salvaged, then have the Data Center create two data sets: 1) data set for the suspect instrument and 2) a data set excluding the suspect instrument. Then follow steps 1,2 and 3 above.

METHOD M.6.5 IMPLEMENTATION OF DATA QUALITY OBJECTIVES (DQOS)

Purpose: This method provides detailed instructions for the implementation of the Data Quality Objective (DQO) process. The DQO process will start becoming formal during the middle of the intermediate phase.

Discussion: The Data Quality Objectives (DQO) Process was developed by EPA (EPA94b) and has become the Federal consensus standard for remediation, MARSSIM-Multi-Agency Radiation Survey and Site Investigation Manual (EPA97b).

The DQO process is comprised of seven steps. Explanation of each of the six steps will be divided into four sections as follows:

- Purpose: This section explains the objective of the step.
- Expected Outputs: This section identifies the products expected upon completion of the DQO Process step.
- Discussion: This section provides background information on the DQO Process step, including the rationale for the activities in the step.
- Activities: This section describes the activities recommended for completing the DQO Process step, including how inputs to the step are used.

Step 1: State the Problem

Purpose: The purpose of this step is to define the problem so that the focus of the FRMAC data collection will be unambiguous.

Expected Outputs:

- A list of the FRMAC/Planning Team members.
- A concise description of the problem.
- A summary of available resources and relevant deadlines.

Discussion: Since most environmental problems present a complex interaction of technical, economic, social, and political factors, it is critical to the success of the process to define the problem COMPLETELY and in AN UNCOMPLICATED FORMAT.

This step in the DQO Process addresses the development of a FRMAC/Planning Team that will define the problem and implement subsequent steps of the Process. The goal is to create a well-structured team that will work effectively and efficiently to develop a concise and complete description of the problem, which will provide the basis for the rest of the DQO development.

Activities:**Step 1.A. Identify members of the planning team.**

The planning team is the group that will develop the DQOs. The number of planning team members will be directly related to the size and complexity of the monitoring and assessment requirements. The team should include representatives from all groups who are stakeholders, including, but not limited to, samplers, chemists and other scientists and engineers, modelers, technical managers, community representatives, administrative and executive managers, QA/QC experts, data users, and assessment group. A reasonable effort should be made to include any Planning team members who may use or have to defend the data findings later. A statistician (or someone knowledgeable and experienced with statistical design of environmental sampling and analysis) should also be included on this team.

Step 1.B. Identify the primary decision-maker of the planning team and define each member's role and responsibility during the DQO process.

The planning team generally has a leader, referred to as the “decision-maker.” The decision-maker has the ultimate authority for making final decisions based on the recommendations of FRMAC Assessment. In cases where the decision-maker cannot attend DQO planning meetings, a senior staff member should keep the decision-maker informed of important planning issues.

Step 1.C. Develop a concise description of the problem.

The problem description provides background information on the fundamental issue to be addressed. Below is a list of steps that may be helpful during this phase of the DQO development.

- Describe the conditions or circumstances that are causing the problem. Typical examples for environmental problems include conditions that may pose a threat to human health or the environment, and circumstances of potential non-compliance with regulations.
- Organize and review relevant information, including preliminary information, and indicate the source and reliability of the information.
- If the problem is highly complex, consider breaking it into more manageable pieces. Identify those pieces that could be address separately. Assign priorities to and logical relationships among the pieces of the problem.

Describe the problem, as it is currently understood, by briefly summarizing existing information. The following elements may be appropriate to include in the problem description. Note this list only provides the basic elements of the problem description. Your elements may be slightly different.

- Data Use/regulatory context
- Persons or organizations involved
- Persons or organizations that have an interest

-
- Political issues surrounding the monitoring and assessment activities.
 - Sources and amount of funding
 - Historical site information
 - Existing sampling design constraints (some aspects of sampling design may be specified in regulations or established through past planning efforts - e.g., stationary environmental air samplers)

Step 1.D. Specify the available resources and relevant deadlines for the study.

Stipulate the anticipated budget, available personnel, and contractual vehicles (if applicable). Also, enumerate any deadlines for completion of the data collection and any intermediate deadlines that may need to be met.

Step 2: Identify the Decision

Purpose: The purpose of this step is to define the decision statement that the data will attempt to resolve.

Expected Outputs:

Develop a decision statement that links the principal data collection question to possible actions that may solve the problem.

Discussion: The goal of this step is to define the question that the monitoring and assessment effort will attempt to resolve and identify the alternative actions that may be taken based on the outcome of the study. In the DQO Process, the combination of these two elements is called the decision statement or decision. The decision statement is critical for defining decision performance criteria later in the Process.

In some cases, especially in the case of emergency response, several decision statements are appropriate to address the problem. In these instances, the planning team should organize the decision statements in order of priority and identify the most logical and efficient sequence for analyzing and resolving them. NOTE: If the principal monitoring and analysis question is not obvious and specific alternative actions cannot be identified, then the study may fall in the category of exploratory research. In this case this step of the DQO Process may not be applicable.

Activities:

Step 2.A. Identify the principal monitoring and analysis data collection question.

Based on a review of the problem stated in STEP 1, identify the principal monitoring and analysis question and state it as specifically as possible. A specific statement of the principal monitoring and analysis question narrows the search for information needed to address the problem. The principal monitoring and analysis question identifies key unknown conditions or unresolved issues. For example:

-
- “Is the release out of compliance with discharge limits?”
 - “Does the offsite radioactive material concentration exceed any applicable health/risk standard(s)?”
 - “Is the contaminant concentration significantly above background levels (confirming that a release has occurred)?”

Note that, in each case, the answer to the principal question will provide the basis for determining what course of action should be taken to solve the problem.

Step 2.B. Define the alternative actions that could result from resolution of the principal monitoring and assessment question.

Identify the possible actions that may be taken to solve the problem, including the alternative that does not require action.

The following is an example of how alternative actions are defined: “Is the radioactive contamination from the accident source above certain X activity per unit area within a particular county/city/street Y?” Possible resolutions of the principal monitoring and assessment question are 1) The radioactivity per unit area is above X, or 2) the radioactivity per unit area is not above X. If the radioactivity per unit area is above X, the action may be to evacuate, shelter in place, remediate. (NOTE: The action to take will depend on the phase of the emergency for which FRMAC is collecting data.) If the radioactivity per unit area is found not be above X then no action will be taken.

Step 2.C. Combine the principal monitoring and assessment question and the alternate actions into a decision statement.

The following standard form may be helpful in drafting decision statements: “Determine whether or not [unknown environmental conditions/issues/criteria from the principal monitoring and assessment question] require (or support) [taking alternative actions].”

To illustrate the decision statement framing activity, consider the previous example. The principal monitoring and assessment question is, “Is the radioactive contamination from the accident source above a certain X activity per unit area within a particular county/city/street Y?” Alternative actions are to “evacuate, shelter in place, remediate” or “take no action.” Therefore, an example of the decision statement is, “Determine whether or not the radioactivity per unit area is above the EPA PAG level and recommend/require evacuation if it is above the limit.”

Step 2.D. Organize multiple decisions.

If several separate decision statements must be defined to address the problem (the most probable case for FRMAC, especially during the emergency phase), list them and identify the sequence in which they should be resolved. It may be useful to document the decision resolution sequence and relationships in a diagram or flowchart.

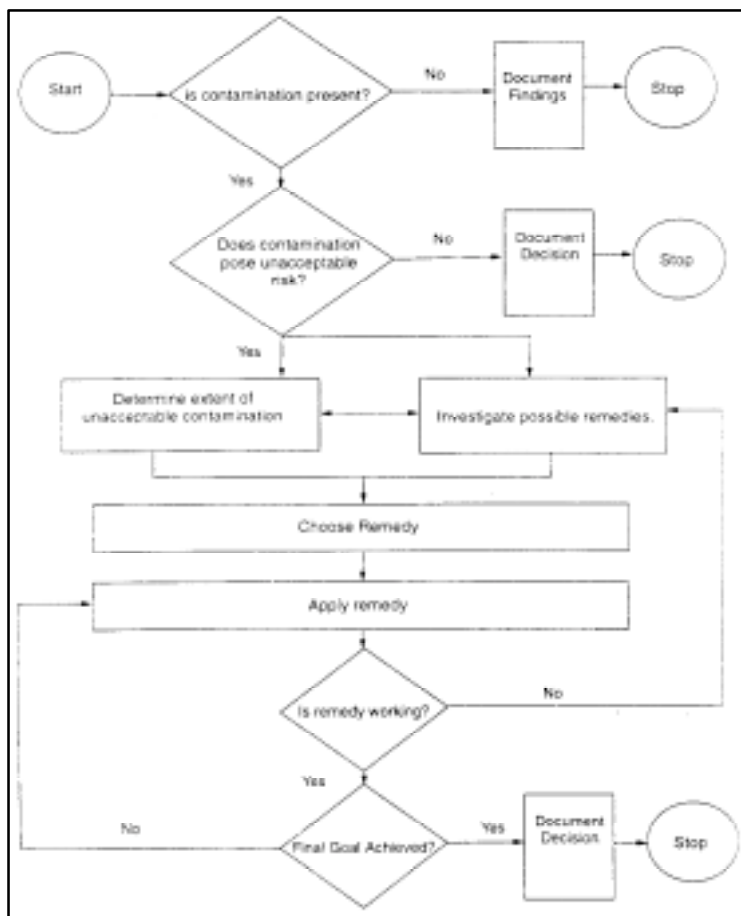


Figure 6.3. Example of Multiple Decisions Organized into a Flowchart

Step 3: Identify the Inputs to the Decision

Purpose: The purpose of this step is to identify the informational inputs that will be required to resolve the decision statement and determine which inputs require environmental measurements.

Expected Outputs:

- A list of informational inputs needed to resolve the decision statement
- A list of environmental variables or characteristics that will be measured

Discussion: To resolve most decision statements, it is necessary to collect data or information. In this step, the planning team identifies the different types of information that will be needed to resolve the decision statement. The key information requirements include the measurements that may be required, the source of data or information (e.g., historic or new data), and the basis for setting the action level. The planning team will determine what needs to be measured. These measurements will be used to refine the specifications and criteria later steps of the DQO Process.

Activities:**Step 3.A. Identify the information that will be required to resolve the decision statement.**

Determine which environmental variables or other information are needed to resolve the decision statement. Consider whether monitoring or modeling approaches, or a combination of both, will be used to acquire the information. Based on the selected data acquisition approach, identify the types of information needed to support the decision statement. Ask general questions such as “Is the information on the physical properties of the media required?” or “Is the information on the chemical characteristics of the matrix needed?” These types of questions and their answers help identify the information needs. In monitoring for contaminants discharged into surface water, examples of environmental variables of interest may include in addition to radioactivity levels, total suspended solids, or temperature measurements.

Step 3.B. Determine the sources for each item of information identified above.

Identify and list the sources for the information needed to resolve the decision statement. These sources may include results of previous data collections, historical records, regulatory guidance, professional judgment, scientific literature, or new data collections. Next qualitatively evaluate whether any existing data are appropriate. Existing data will be evaluated quantitatively in Step 7: Optimize the Design for Obtaining Data.

Step 3.C. Identify the information that is needed to establish the action level.

Define the basis for setting the action level. The action level is the threshold value that provides the criterion for choosing between alternative actions. Action levels may be based on regulatory thresholds or standards, or they may be derived from problem-specific considerations such as risk analysis. In this step, simply determine the criteria that will be used to set the numerical value. The actual numerical action level will be set in Step 5: Develop a Decision Rule.

Step 3.D. Confirm that appropriate measurement methods exist to provide the necessary data.

Use the list of environmental measurements identified earlier in this step to develop a list of potentially appropriate measurement methods. Note the method detection limit and limit of quantization for each potential method. This performance information will be used in steps 5 and 7 of the DQO Process.

Step 4: Identify the Boundaries of the Study

Purpose: The purpose of this step is to define the spatial and temporal boundaries that are covered by the decision statement.

Expected Outputs:

- A detailed description of the spatial boundaries.
- A detailed description of the temporal boundaries.

- A list of any practical constraints that may interfere with the study.

Discussion: It is difficult to interpret data that have not been drawn from a well-defined population. The term “population” refers to the total collection or universe of objects or people to be studied, from which samples will be drawn. The purpose of this step is to define spatial and temporal components of the population that will be covered by the decision statement so that the data can be easily interpreted. These components include:

- Spatial boundaries that define the physical area to be monitored and assessed and from where the samples should be taken, and
- Temporal boundaries that describe the timeframe the monitoring and assessment data will represent and when the samples should be taken.

The boundaries will be used to ensure that the data-collection design incorporates the time periods for implementing the monitoring and assessment, areas that should be sampled, and the time period in which the monitoring and assessment results should apply. This will help ensure that the monitoring and assessment data are representative of the population being studied. Defining boundaries before the data are collected can also prevent inappropriate pooling of data that may mask useful information.

Practical constraints that could interfere with sampling should be identified in this step. A practical constraint is any hindrance or obstacle that potentially may interfere with the full implementation of the data-collection design.

Activities:

Step 4.A. Specify the characteristics that define the population of interest.

Specify the characteristics that define the population. For example, the population may be plutonium concentration in soil, uranium concentration in kidney tissue, or radon concentration in water. There may be several ways to define a population. Always choose the one that is MOST specific. For example, “Uranium 238” is more specific than “depleted uranium” just like “hexavalent chromium” is more specific than “chromium”.

Step 4.B. Define the geographic area to which the decision statement applies.

The geographic area is a region distinctively marked by some physical features (i.e., volume, length, width, and boundary). Some examples of geographic areas are the metropolitan city limits, the soil within the property boundaries down to a depth of 1 inch, or the natural habitat of a particular animal species.

Step 4.C. Divide the population into strata that have relatively homogeneous characteristics, if appropriate.

Using existing information, stratify or segregate the elements of the population into subsets or categories that exhibit relatively homogeneous properties or characteristics that may have an influence on the outcome, such as radioactive contaminant concentrations. Dividing the

population into strata is desirable for studying sub-populations, reducing variability within subsets of data or reducing the complexity of the problem by breaking it into more manageable pieces.

Step 4.D. Define the temporal boundary of the problem.

The temporal boundaries that describe the timeframe the monitoring and assessment data will represent and when the samples should be taken must be defined here. A zero time appropriate to the event should be established and subsequent times should be references to that zero time.

Step 4.E. Determine the time frame to which the decision applies.

It may not be possible to collect data over the full time period to which the decision will apply. Therefore, the planning team should determine the timeframe that the data should reflect. For example, “The data will reflect the condition of contaminant migration over a period of 24 hours.” or “The data will be used to reflect the risk conditions of an average resident over their average length of residence which is estimated to be 2 years.” Timeframes should be defined for the overall population and any sub-populations of interest.

Step 4.F. Determine when to collect data.

Conditions may vary over the course of a monitoring and assessment operation, which may affect the success of data collection and the interpretation of data results. These factors may include weather, temperature, humidity, or amount of sunlight and wind. Determine when conditions are most favorable for collecting data and select the most appropriate time period to collect data that reflect those conditions. For example, a monitoring and assessment plan to measure ambient airborne particulate matter may give misleading information if the sampling is conducted when rain is occurring rather than during dry conditions.

Step 4.G. Define the scale of decision-making.

Define the smallest, most appropriate subsets of the population (sub-populations) for which decisions will be made based on the spatial or temporal boundaries. For example, consider a study in which the decision statement is “Determine whether or not the concentration of plutonium 239/240 in a particular neighborhood’s soil poses an unacceptable health risk to neighborhood children and requires remediation.” In this case, the geographic area is defined as the top few centimeters of soil within the neighborhood boundaries. The scale of decision making could be set to an area that has a size corresponding to the area in which the children are likely to receive the majority of their dose (such as a play area). Studying the site at this scale will be protective of children, a sensitive population in risk assessment.

Step 4.H. Identify any practical constraints on data collection.

Identify any constraints or obstacles that potentially could interfere with the full implementation of the data-collection design, such as seasonal or meteorological conditions when sampling is not possible; inability to gain access to the site or obtain informed consent; or unavailability of personnel, time, or equipment. For example, it may not be possible to take surface soil samples

beyond the east boundaries of an area under investigation the owner(s) of the adjacent properties did not grant permission.

Step 5: Develop a Decision Rule

Purpose: The purposes of this step are to define the parameter of interest, specify the action level, and integrate previous DQO outputs into a single statement that describes a logical basis for choosing among alternative actions.

Expected Outputs:

- The statistical parameter (the parameter of interest) that characterizes the population.
- The action level.
- An “if...then” statement that defines the conditions that would cause the Planning team to choose among alternative actions.

Discussion: The decision rule summarizes what attributes the Planning team wants to know about the population and how that knowledge would guide the selection of a course of action to solve the problem. The Decision Rule step combines criteria from past steps with the parameter of interest (statistical characteristic of the population) and the action level to provide a concise description of what action will be taken based on the results of the data collection.

There are four main elements to a decision rule:

1. The parameter of interest, a descriptive measure (such as a mean, median, or proportion) that specifies the characteristic or attribute that the Planning team would like to know about the statistical population. The purpose of the data-collection design is to produce environmental data that can be used to develop a reasonable estimate of the population parameter.
2. The scale of decision making, the smallest, most appropriate subset (sub-population) for which separate decisions will be made. (The scale of decision-making was defined in Step 4: Define the Boundaries of the Study.)
3. The action level, a measurement threshold value of the parameter of interest that provides the criterion for choosing among alternative actions. The action level can be based on regulatory standards, an exposure assessment, technology based limits, or reference-based standards.
4. The alternative actions, the actions that the Planning team would take, depending on the true value of the parameter of interest. (The alternative actions were identified in Step 2: Identify the Decision.)

Activities:**Step 5.A. Specify the statistical parameter that characterizes the population (the parameter of interest).**

The planning team should specify the parameter of interest (such as the mean, median, or percentile) whose true value the Planning team would like to know and that the data will estimate. For example, to determine if the contamination level at a given site exceeds an action level, the planning team must specify the parameter that will be evaluated with respect to the action level (e.g., the mean concentration). Some regulations specify the parameter, but if this is not the case, it may be necessary to consult with a statistician to help select a parameter that is consistent with the intended application. Recognize that the parameter that is chosen in this step may be changed to an equivalent descriptive measure as more information becomes available based on statistical considerations in Step 7 of the DQO Process and in the Data Quality Assessment Process. Information about positive and negative attributes of commonly used parameters is provided in Chapter 5 of EPA94b.

Step 5.B. Specify the action level for the study.

The Planning team should specify the numerical value that would cause them to choose between alternative actions. For example, the Planning team would choose one action if the true value of the parameter of interest is above the EPA PAG, and different action otherwise. Confirm that the action level is greater than the detection and quantization limits for the potential measurement methods identified in Step 3: Identify the Inputs to the Decision.

Step 5.C. Develop a decision rule.

Develop a decision rule as an “if...then” statement that incorporates the parameter of interest, the scale of decision making, the action level, and the action(s) that would result from resolution of the decision. These four elements are combined in the following way: If the parameter of interest (e.g., true mean concentration of cesium 137) within the scale of decision making (e.g., 1-acre plots) is greater than the action level (e.g., 150 pCi/gm), then take alternative action A (e.g., evacuate people from the site); otherwise take alternative action B (e.g., leave the people on the site).

Step 6: Specify Limits on Decision Errors

Purpose: The purpose of this step is to specify the planning team’s limits on decision errors, which are used to establish performance goals for the data-collection design.

Expected Outputs: The planning team’s decision error rates for Type I (false positive) and Type II (false negative) errors are based upon consideration of the consequences of making an incorrect decision. Also factored into this decision is uncertainty in the derived action or response level, which forms the basis of the decision rule, as specified in Step 5. In addition, the sources of uncertainty, which will be introduced into the study through the sampling and analysis procedures as outlined in Step 7, must also be considered.

Discussion: The planning team specifically wishes to know whether the measured value of the parameter of interest, specified in Step 5.A, exceeds the action level (usually a derived response level) specified in Step 5.B. In their assessments, the planning team needs to include whether protective actions guides or other accepted health-based criteria are likely be exceeded. Uncertainty near the limit is not as tolerable as uncertainty well below the limit.

It is important when specifying limits regarding decision errors to consider the amount of uncertainty introduced by the derivation of the action level for the environmental parameter of interest; how that uncertainty has been addressed must also be determined. This involves consideration of the following sources of uncertainty and their potential impacts:

Model or formula uncertainty - uncertainty introduced through the use of simplifying assumptions to mathematically model the actual environmental problem. (e.g., assuming uniformity of deposition in a certain locale, placement of receptors in the center of contamination, etc.)

Scenario uncertainty - the introduction of assumptions about how people will behave in the future, leading to exposure to contamination (e.g., indoor and outdoor residence time fractions in a contaminated location).

Parameter uncertainty - uncertainty in estimates of the various parameter inputs used in the models/formulae due to limited available data (e.g., daily child or adult ingestion rates for meat, vegetables, drinking water, soil, etc., and radionuclide resuspension rates).

Uncertainty inherent in factors used to convert radioactivity intake (inhalation, ingestion, etc.) to dose. Adequate analysis is not available to quantify uncertainty introduced into these quantities using biokinetic and dosimetric models, estimates of human variability, and the like. As such, it is important to be aware that uncertainty does exist in these conversion factors and that this uncertainty is significant.

In the early stages of a radiological emergency, for which this manual is intended, the standard assessment practice to deal with many sources of uncertainty listed is to apply conservatism in the selection of models, scenario assumptions, parameters, etc. (As the emergency moves into its later phases — recovery, reentry, relocation — it becomes more important to control uncertainty through formal probabilistic assessment and other methods to avoid excessive conservatism, which leads to overly stringent application of high impact measures.) At this stage, however, it is important for the planning team to be aware, at least qualitatively, of the degree of uncertainty and the degree of conservatism inherent in the derived action/response level specified in Step 5.A. If the degree of conservatism in the DRL is already high, that fact should influence the planning team to select higher values for acceptable error rates for Type I (false positive) errors. This is discussed more fully in MARSSIM, Appendix D page D-21.

In addition to uncertainty introduced by derivation of the action level, the planning team must consider uncertainty introduced into the measurement process through the application of sampling and analysis methods selected in Step 7 of the DQO process. The sources of such uncertainty include sampling error, sample collection error, field measurement error, lab analytical error (which is probably the smallest and most controllable source of uncertainty), and

the like. The MARSSIM formalism has been developed to address some of these sources of uncertainty in certain situations (relatively uniform radioactive contamination of surface areas), and should be applied whenever appropriate. However, MARSSIM is not applicable to a number of problems likely to be encountered during a radiological emergency. These include hot particle contamination of surfaces, contamination of bodies of water, contamination of populations of animals, subsurface contamination, contamination of indoor and/or outdoor air, etc. Because of this, an experienced statistician, who is familiar with sampling design in a variety of situations, should be included in the planning team. Based on Steps 1-5 taken thus far, it is appropriate to sketch out a preliminary design for environmental measurements to ascertain what is feasible in terms of control of sampling/measurement uncertainty, and to determine to what degree decision errors may be limited without significantly impacting the feasibility or cost of such a study. For guidance on this aspect of the DQO process, see the *Decision Error Feasibility Trials (DEFT), Software and User's Guide G-4D*, (EPA/240/B-01/007, September 2001).

With these considerations in mind, the planning team should control decision errors using a scientific approach (the example that follows uses the MARSSIM formalism). In this approach, measured values of the parameter of interest (Step 5.A), are compared to the action level (Step 5.B) to decide whether the decision rule (Step 5.C) should be implemented (alternative hypothesis) or not (null hypothesis). The null hypothesis is treated like a baseline condition that is presumed to be true in the absence of strong evidence to the contrary. This feature provides a way to guard against making the decision error that the planning team considers the more undesirable consequence. Consequences include health, ecological, political, social, and resource risks associated with the implementation of protective measures and risks related to not implementing protective measures. For example, in the case of evacuation as a protective measure, one must weigh the possibility of injury and death from relocating a frightened population against the possibility of long-term health effects from continued exposure to radioactivity and radiation.

A Type I error (false positive) occurs when the planning team rejects the null hypothesis when it is true. A Type II error (false negative) occurs when the team fails to reject the null hypothesis when it is false. The probability of making a Type I decision error is denoted by alpha (α), which reflects the amount of evidence that the decision-maker would like to see before abandoning the null hypothesis. The probability of making a Type II decision error is denoted by beta (β). The term $(1-\beta)$ is the probability of rejecting the null hypothesis when it is false. Specifying limits on decision errors involves specifying acceptable values to decision-makers for α and β (consequence analysis) that result in a feasible study possibility. For example, selecting values that are too small can lead to a study that requires excessive numbers of samples or results in prohibitively low laboratory sensitivity resulting in a study that is too expensive or time consuming to be practical.

Five activities are associated with specifying limits on decision errors:

- Determine the possible range of the parameter of interest. Establish an acceptable range of error by estimating the likely upper and lower bounds.
- Identify the decision errors and choose the null hypothesis.

1. Define both types of decision errors (Type I and Type II) and establish the true condition of the area or population to be studied for each decision error. Note that the “true” condition in this case generally represents radioactivity in appropriate units above or below a derived and uncertain action level — see above.
 2. Specify and evaluate the potential consequences of each decision error.
 3. Specify which decision error has more severe consequences near the action level. Use professional judgement in considering all types of consequences.
 4. Define the null hypothesis (the decision associated with the least severe consequences, which is presumed to be true unless there is compelling evidence to the contrary). Define an alternative hypothesis (the opposite of the null hypothesis, scenario with the most severe consequences), and assign the terms Type I (false positive) and Type II (false negative) to the appropriate decision error. As an example, consider a DRL for surface radioactivity, for evacuation. The null hypothesis might be “the area is clean” (unless highly influenced by political considerations). Later in the emergency a DRL for reentry might give rise to a null hypothesis “the area is dirty” (unless highly influenced by economic considerations).
- Specify a range of possible values for the parameter of interest, “a gray area,” in which the consequences of decision errors are relatively minor. It is necessary to specify a gray area because of variability in the parameter of interest. In addition, a gray area is needed because imprecision is unavoidable in the measurement system. These two effects combine to produce variability in the data such that a decision may be “too close to call” when the true, but unknown, value of the parameter is very near the action level.

Additional guidance on specifying a gray area is available in *Guidance for the Data Quality Objectives Process* (EPA G/5), (EPA/600/R-96/055, August 2000). This document and the DEFT Software and User’s Guide cited above are available from the EPA Quality website (http://www.epa.gov/quality/qa_docs.html#EPARqts).

- Assign probability limits to points above and below the gray area that reflect the probability for the occurrence of decision errors. In general, the wider the gray area, the larger the probability of a Type II error that can be tolerated. (This can be significantly restricted by cost and feasibility considerations, for which the DEFT software can be useful.)
- Graphically represent the decision rule.

Guidance for implementing the above steps to a MARSSIM applicable problem is presented in Appendix D of MARSSIM. It is again imperative that an experienced statistician be part of the planning team when other types of problems, as cited above, are to be addressed.

Step 7: Optimize the Design for Obtaining Data

Purpose: The purpose of this step is to identify a resource-effective, data-collection design for generating data that are expected to satisfy the DQOs.

Expected Outputs:

- The most resource-effective design for the study that is expected to achieve the DQOs.

Discussion: In this step, statistical techniques are used to develop alternative data-collection designs and evaluate their efficiency in meeting the DQOs. To develop the optimal design for this study, it may be necessary to work through this step more than once after revisiting previous steps of the DQO Process.

The objectives of this step is to identify the most resource-effective data-collection design expected to generate data that satisfy the DQOs specified in the preceding steps.

Activities:**Step 7.A. Review the DQO outputs and existing environmental data.**

Review the DQO outputs in the preceding six steps to ensure that they are internally consistent. The DQOs should provide a succinct collection of information on the context of, requirements for, and constraints on the data-collection design. Review existing data in more detail if it appears that they can be used to support the data-collection design (e.g., analyze the variability in existing data if they appear to provide good information about the variance for the new data). If existing data are to be combined with new data to support the decision, then determine if there are any gaps that can be filled or deficiencies that might be mitigated by including appropriate features in the new data-collection design.

Step 7.B. Develop general data-collection design alternatives.

Develop alternative data-collection and analysis designs based on the DQO outputs and other relevant information, such as historical patterns of contaminant deposition, estimates of variance, and technical characteristics of the contaminants and media. Generally, the goal is to find cost-effective alternatives that balance sample size and measurement performance, given the feasible choices for sample collection techniques and analytical methods. In some cases in which there is a relatively high spatial or temporal variability, it may be more cost-effective to use less expensive and less precise analytical methods so that a relatively large number of samples can be taken, thereby controlling the sampling design error component. In cases in which the contaminant distribution is relatively homogeneous, or the action level is very near the method detection limit, it may be more cost-effective to use more expensive and more precise and/or more sensitive analytical methods and collect fewer samples, thereby controlling the analytical measurement error component.

Step 7.C. Formulate the mathematical expressions needed to solve the design problem for each data-collection design alternative.

Develop the following three mathematical expressions:

- Define a suggested method for testing the statistical hypothesis and define a sample size formula that corresponds to the method, if one exists.

- Develop a statistical model that describes the relationship of the measured value to the “true” value.
- Develop a cost function that relates the number of samples to the total cost of sampling and analysis.

Step 7.D Select the optimal sample size that satisfies the DQOs for each data-collection design alternative.

Use the mathematical expression above to solve for the optimal sample size that satisfies the DQOs and meets the decision-makers’ limits on decision errors. If no solutions exist, then the planners must relax one or more requirements.

Step 7.E Select the most resource effective data-collection design that satisfies all of the DQOs.

Evaluate the design options based on cost and ability to meet the DQO constraints. Choose the one that provides the best balance between cost and ability to meet the DQOs.

Step 7.F Document the operational details and theoretical assumptions of the selected design in the sampling and analysis plan.

Assure study design features that are vital to the valid interpretation of the data are clearly cited. Enlist a statistician to review the final statistical methodology employed, if not to help develop it.

APPENDIX A. GLOSSARY

The glossary contains definitions for terms and acronyms used in the manual.

Acute Health Effects	See Early Health Effects.
AGL	Above ground level.
ALI	Annual Limit of Intake
AMAD	Activity Median Aerodynamic Diameter
AMS	Aerial Measuring System
ARAC	Atmospheric Release Advisory Capability.
ARF	Airborne release fraction
ARG	Accident Response Group
ASHG	Accident Site Health Group
BN	Bechtel Nevada
BWR	Boiling-Water Reactor
CDC	Centers for Disease Control and Prevention
Child	A 10-year-old person.
Cloud Shine	Gamma radiation from radioactive materials in the air (plume).
CMRT	Consequence Management Response Team
Committed Dose Equivalent (CDE)	The dose equivalent to a specific organ for 50 years following intake (inhalation or ingestion). It does not include contributions from external dose.
Committed Effective Dose Equivalent (CEDE)	The sum of the dose equivalent for 50 years following intake (inhalation or ingestion) of a radionuclide to each organ multiplied by a weighting factor. CEDE is used to estimate the risk from delayed health effects.
Concentration	The amount of activity per unit of measure (volume, mass, area, sample, etc.) considered for a sample.

Critical	Most important source of dose, the most important organ, or the most important group of (potentially) exposed population. That is, effects will be dominated by this source of dose or effects (<i>e.g.</i> , deaths) will occur first as a result of exposure to this organ or population (<i>e.g.</i> , infants) when exposed to radiation through a certain pathway.
DAC	Derived Air Concentration
DCENT	Computer database maintained by the FRMAC Data Center
Delayed Health Effects	A wide range of cancers and hereditary effects that usually occur many years after exposure. In contrast to early health effects, it is assumed there are no dose thresholds below which these effects do not occur.
Deposition	The contamination found on the surface of the ground.
Derived Intervention Level (DIL)	The concentration of a radionuclide in food derived from the protective action guide and at which introduction of protective measures should be considered.
Derived Response Level (DRL)	A calculated value (<i>e.g.</i> , exposure rate or radionuclide concentration) that corresponds to an early health effect threshold, a PAG, or a DIL. DRLs can be used to relate environmental measurements or laboratory analysis to the potential for early health effects or need for protective actions. Used to facilitate prompt assessments.
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy.
Dose Conversion Factor (DCF)	The dose equivalent per unit intake of a radionuclide (mrem/ μ Ci).
DOT	U.S. Department of Transportation
DQO	Data Quality Objective
DRL	Derived Response Level
Early Health Effects	Health effects that are likely to occur shortly after exposure (hours, weeks) resulting from high doses over a short period (acute doses) to specific organs and involve thresholds below which these health effects are not expected to occur.
Early Phase	The period of time that extends from the time the threat of a major release is identified (before the release) until the release or threat of

	major release has ended, and areas of major deposition have been identified.
Effective Dose Equivalent (EDE)	The sum of the dose equivalent from external exposure to each organ multiplied by a weighting factor. EDE is used to estimate the risk from delayed health effects. EDE rate from air submersion and ground shine is assumed to equal the exposure rate.
Emergency Worker Guidance	Guidance on the external dose and CEDE incurred by workers (other than a pregnant woman) while performing emergency services.
EPA	U.S. Environmental Protection Agency.
ESRI	Environmental Systems Research Institute, Inc.
External Dose	The dose of radiation received by an individual from a source of ionizing radiation outside the body.
Facility Operator	The organization that operates the facility.
FDA	U.S. Food and Drug Administration.
FRMAC	Federal Radiological Monitoring and Assessment Center.
GIS	Geographic Information System
GM	Geiger-Mueller
Groundshine	Gamma radiation from radioactive materials deposited on the ground.
H&S	Health and Safety.
HHS	U.S. Department of Health and Human Services.
Immersion	To be surrounded or engulfed by the radioactive cloud.
Infant	A child one year of age or less.
Intermediate Phase	The period beginning after the release and potential for further major release is over and reliable environmental data are available for use as a basis for relocation and ingestion protective actions. Usually one year of deposition and 30 days of ingestion calculation.
IR	Radionuclide Ratio.
LANL	Los Alamos National Laboratory.

LET	Linear Energy Transfer.
LFA	Lead Federal Agency.
Light-Water Reactor (LWR)	A nuclear reactor that uses natural water as a coolant and moderator. All U.S. commercial power reactors in the United States are LWRs, as are the Russian-constructed VVERs.
LLNL	Lawrence Livermore National Laboratory.
Marker Nuclide	A nuclide contained in deposition or samples that is easily identified in the field or laboratory. It is used to determine areas of concern before performing a comprehensive nuclide analysis.
MDA	Minimum Detectable Activity.
Mix	The nuclide ratio (relative abundance) of the radionuclides in a sample or deposition.
NARAC	National Atmospheric Release Advisory Center.
NDA	National Defense Area.
NNSA	National Nuclear Security Administration.
NRC	U.S. Nuclear Regulatory Commission.
NSA	National Security Area.
Pathways	The paths radionuclides follow from the source through the environment, including vegetation and animals, to reach an individual or a population.
Protective Action Guide (PAG)	The projected dose, from an accidental release of radioactive material, where specific actions to reduce or avoid dose are warranted.
PPE	Personal Protective Equipment
PWR	Pressurized-Water Reactor
Quality Factor (QF)	The principal modifying factor that represents the biological effectiveness of different radiation types with respect to induction of stochastic effects. It is used to calculate the dose equivalent from the absorbed dose. The absorbed dose, expressed in rad or Gy, is multiplied by the appropriate quality factor to obtain the dose equivalent

RAP	Radiological Assistance Program
Relative Biological Effectiveness (RBE)	The RBE of a given type of ionizing radiation is a factor used to compare the biological effectiveness of absorbed radiation doses (i.e., rads) due to one type of ionizing radiation with that of other types of ionizing radiation; more specifically, it is the experimentally determined ratio of an absorbed dose of a radiation in question to the absorbed dose of a reference radiation required to produce an identical biological effect in a particular experimental organism or tissue.
Resuspension	Reintroduction to the atmosphere of material originally deposited onto surfaces.
RF	Respirable Fraction or Resuspension Factor (depending on context)
RHU	Radioisotope Heater Unit
RTG	Radioisotope Thermoelectric Generator
RTM	Response Technical Manual.
SCA	Single Channel Analyzer
SCBA	Self-Contained Breathing Apparatus
SI	International System of Units
SNL	Sandia National Laboratories
SNM	Special Nuclear Material
Stability Class	A class that describes conditions of atmospheric turbulence. Classes are generally grouped into six classes ranging from class A, very unstable, through class F, very stable.
TNT	Trinitrotoluene
Total Early Organ Dose (TEOD_{Organ})	Dose estimates used to determine if early health effects are possible from dose to the indicated organ. The organs considered in this manual are the small intestine, red bone marrow, thyroid, and lung. Bone marrow is a critical organ when considering deaths from LWR accidents. TEOD projections in the manual include (1) EDE from air submersion, (2) four days of EDE from ground deposition, (3) early inhalation dose from the plume (dose to the organ for 30 days after inhalation of the radioactive material), and (4) early inhalation from four days of resuspension.

Total Effective Dose Equivalent (TEDE) The sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). Dose projections used for comparison with the EPA Early Phase PAG (EPA92), which is expressed in terms of TEDE, include: (1) the EDE from air submersion, (2) four days of EDE from ground deposition, (3) the inhalation CEDE dose from the plume, and (4) CEDE from inhalation of four days of resuspension.

Total Effective Exposure Period The time span, considering decay, that will approximate the integrated dose over a period of time when multiplied by the dose rate at the beginning.

Turn-Back Guidance Guidance given to emergency workers indicating when they should seek areas of lower exposure rate or potential. This guidance is usually implemented via a DRL expressed as an integrated dose reading on a self-reading dosimeter, an exposure rate, or a deposition concentration indicating that the emergency worker should leave the area where further exposure is possible.

USDA U.S. Department of Agriculture.

Weathering Reduction of dose from deposited radionuclides (external and resuspension) over time due to movement of contamination below the surface or binding on surface materials.

Weighting Factors An estimate of the mortality risk from delayed health effects arising from irradiation of a particular organ and used to calculate CEDE and EDE.

Organ	Weighting Factor^a
Gonads	0.25
Breasts	0.15
Red Bone Marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone Surface	0.03
Remainder	0.30

^aSource: EPA88 (page 6)

WGPu **Weapons-Grade Plutonium**