UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 10, 1997

ALL AGREEMENT AND NON-AGREEMENT STATES
LOW-LEVEL RADIOACTIVE WASTE COMPACT DISTRIBUTION

TRANSMITTAL OF STATE PROGRAM INFORMATION (SP-97-041)

Your attention is invited to the enclosed correspondence which contains:

INCIDENT AND EVENT INFORMATION..........

PROGRAM MANAGEMENT INFORMATION....

TRAINING COURSE INFORMATION.............

TECHNICAL INFORMATION...................... XX Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste (LLW) Disposal Facilities, NUREG-1573

OTHER INFORMATION.............................

Supplementary information: Enclosed for your information and comment is the draft "Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities," NUREG-1573, May 1997. Also enclosed is the Federal Register notice on the availability of NUREG-1573 for public comment (62 FR 29164, May 29, 1997).

A low-level radioactive waste (LLW) performance assessment is a technical analysis that can be used to demonstrate compliance with NRC's performance objective for radiological protection of the general public — 10 CFR 61.41. NRC's Performance Assessment Working Group has prepared a draft Branch Technical Proposal (BTP), designated NUREG-1573, as a step toward providing detailed LLW performance assessment guidance to potential applicants for an NRC license. The BTP may contain information that may be useful to Agreement States and disposal site developers on LLW performance assessment. In this regard, the draft BTP includes the staff's technical positions on: (a) an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (b) five principal regulatory issues regarding interpreting and implementing Part 61 performance objectives and technical requirements governing LLW site post-closure performance; and (c) implementation of NRC's LLW performance assessment methodology.

The staff is interested in your views on both the suitability of approaches presented in the draft BTP for measuring the performance of LLW disposal facilities, as well as the staff's proposed positions on certain LLW regulatory issues: (a) consideration of future site conditions, processes, and events; (b) performance of engineered barriers; (c) time frame for a LLW performance assessment; (d) treatment of sensitivity and uncertainty; and (e) the role of performance assessment during the operational and closure periods.

Also, the staff is interested in your views concerning whether it would be appropriate to discount potential doses, from a hypothetical LLW disposal site, to future generations. In the context of LLW disposal, application of discounting, either qualitative or quantitative, might more appropriately weigh present-day economic cost of design and performance features associated with LLW disposal against expectations about future health risks. This approach would not allow the standard to be exceeded, but would address the level of assurance necessary to demonstrate that the LLW performance objectives will be met. Although the draft BTP does not address this issue, the staff has been asked by the Commission to request comment on this concept as part of the public comment process.

Send comments within 90 days of May 29, 1997, to Chief, Rules Review and Directives Branch, Division of Freedom of Information and Publications Services, U.S. Nuclear Regulatory Commission, 11545 Rockville Pike, Mail Stop T-6-D59, Rockville, Maryland 20852-2738. For further technical information, contact Anne E. Garcia, Division of Waste Management, Office of Nuclear Material Safety and Safeguards. Her telephone is (301) 415-6631 and INTERNET: AEG@NRC.GOV.

If you have any questions or comments regarding this letter, please contact me or the individual named below.

POINT OF CONTACT: Stephen N. Salomon
TELEPHONE: (301) 415-2368
FAX: (301) 415-3502
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Original Signed By:
PAUL H. LOHAUS

Paul H. Lohaus, Deputy Director
Office of State Programs

Enclosures:
As stated

Distribution:
DIR R/F(7S-135)
SDroggitis
JKennedy, LLDP
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DCD (SP03)
PDR (YES ✓)

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OSP FILE CODE: SP-A-4, SP-L-5

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6/5/97

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Paul H. Lohaus

Paul H. Lohaus, Deputy Director
Office of State Programs

Enclosures:
As stated

NUCLEAR REGULATORY COMMISSION

Availability of Draft Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities

AGENCY: Nuclear Regulatory Commission.

ACTION: Availability of Draft Branch Technical Position.

SUMMARY: The U.S. Nuclear Regulatory Commission is announcing the availability of the "Draft Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities."

DATES: The comment period expires August 27, 1997.

ADDRESSES: Send comments to Chief, Rules Review and Directives Branch, Division of Freedom of Information and Publications Services, U.S. Nuclear Regulatory Commission, 11545 Rockville Pike, Mail Stop T–6–D59, Rockville, Maryland 20852–2738. Comments may be delivered to the same address between 7:45 a.m. and 4:15 p.m., on Federal workdays.

A copy of the draft Branch Technical Position (BTP) is available for public inspection and/or copying at the NRC Public Document Room, 2120 L Street (Lower Level), NW, Washington, DC 20555–0001. Copies of the draft BTP may also be obtained by contacting Karen S. Vandervort, Division of Waste Management, Office of Nuclear Material Safety and Safeguards. Telephone: (301) 415–7252.

FOR FURTHER INFORMATION CONTACT: Anne E. Garcia, Division of Waste Management, Office of Nuclear Material Safety and Safeguards. Telephone: (301) 415–6631.

SUPPLEMENTARY INFORMATION: The U.S. Nuclear Regulatory Commission's (NRC's) regulation regarding the licensing requirements for the land disposal of low-level radioactive waste (LLW) can be found at 10 CFR part 61. Part 61 requires that technical analyses be performed to demonstrate protection of the general population from releases of radioactivity to the general environment in certain environmental pathways such as ground water, surface water, air, soil, and biota (plants). A LLW performance assessment is a technical analysis that can be used to demonstrate compliance with NRC's performance objective for radiological protection of the general public—10 CFR 61.41. NRC's Performance Assessment Working Group has prepared a draft BTP, designated NUREG–1573, as a step toward providing detailed LLW performance assessment guidance to potential applicants for a NRC license. When finalized, the BTP may contain information that may be useful to Agreement States and disposal site developers on LLW performance assessment. In this regard, the draft BTP includes the staff's technical positions on: (a) An acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (b) five principal regulatory issues regarding interpreting and implementing Part 61 performance objectives and technical requirements governing LLW site post-closure performance; and (c) implementation of NRC's LLW performance assessment methodology. In arriving at the proposed positions taken on these issues in the draft BTP, the staff has considered a number of alternatives. Nevertheless, the staff is interested in the public's views on both the suitability of approaches presented in the draft BTP for measuring the performance of LLW disposal facilities, as well as the staff's proposed positions on certain LLW regulatory issues: (a) Consideration of future site conditions, processes, and events; (b) performance of engineered barriers; (c) timeframe for an LLW performance assessment; (d) treatment of sensitivity and uncertainty; and (e) the role of performance assessment during the operational and closure periods.

To obtain early feedback on the guidance for LLW performance assessment under development by the staff, a preliminary draft of the BTP was distributed for comment to LLW-sited and host Agreement State regulatory entities; the Advisory Committee on Nuclear Waste (ACNW); the U.S. Department of Energy (DOE); the U.S. Environmental Protection Agency; and the U.S. Geological Survey in January 1994. The staff briefed the ACNW and the Commission on the scope and content of the BTP in March and April 1994, respectively. The staff subsequently held two workshops on the BTP and LLW performance assessment. The first was a 2-day workshop held at NRC Headquarters on November 16–17, 1994. The second was a half-day workshop, limited to certain technical issues in LLW performance assessment, held at the 16th Annual DOE/LLW Management Conference on December 13–15, 1994. Finally, the staff briefed the ACNW on key regulatory issues and its evaluation of the workshop comments on March 16, 1995. This draft BTP reflects the staff's consideration of feedback received during those interactions. However, the staff did not formally respond to these comments in preparing this version.

In a related matter, the staff would be interested in the views of the public concerning whether it would be appropriate to discount potential doses, from a hypothetical LLW disposal site, to future generations. In the context of LLW disposal, it does not appear that the use of the "time-value of money" approach to discounting is implementable considering the long time frames of performance considered. In the context of LLW disposal, application of discounting, either qualitative or quantitative, might more appropriately weigh present-day economic cost of design and performance features associated with LLW disposal against expectations about future health risks. This approach would not allow the standard to be exceeded, but would address the level of assurance necessary to demonstrate that the LLW performance objectives will be met. Although the draft BTP does not address this issue, the staff has been asked by the Commission to request comment on this concept as part of the public comment process.

Finally, the staff is aware that several entities have commented on aspects of the BTP, as presented in the January 1994, preliminary draft, through the Commission's November 1995 Strategic Assessment and Rebaselining Initiative. The staff was directed by the Commission to inform it on how it plans to resolve those comments prior to a decision to finalize the BTP. As part of the public comment process, the staff will provide the Commission with a summary of all public comments, including those made during the Strategic Assessment and Rebaselining Initiative, and proposed resolutions to those comments prior to finalizing the BTP.

Dated at Rockville, Maryland, this 22nd day of May 1997.

For the U.S. Nuclear Regulatory Commission.

Michael J. Bell,

Acting Chief, Performance Assessment and High-Level Waste Integration Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards.

[FR Doc. 97–14010 Filed 5–28–97; 8:45 am]

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NUREG-1573

BRANCH TECHNICAL POSITION ON A PERFORMANCE ASSESSMENT METHODOLOGY FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES

Draft for Public Comment

Draft Manuscript Completed: May 1997

Performance Assessment Working Group

Division of Waste Management
Office of Nuclear Material Safety and Safeguards

Waste Management Branch
Office of Nuclear Regulatory Research

U.S. Nuclear Regulatory Commission
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ABSTRACT

The relationship between the overall 10 CFR Part 61 data and design requirements, and detailed low-level radioactive waste (LLW) performance assessment needs are not directly apparent from the existing U.S. Nuclear Regulatory Commission guidance documents. To address this concern, NRC's Performance Assessment Working Group has prepared this draft Branch Technical Position as a means of providing more detailed guidance on performance assessment as it relates to the objective concerned with the radiological protection of the general public — 10 CFR 61.41. Specifically, this guidance includes the staff's technical positions on: (a) an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (b) 5 principal regulatory issues regarding interpreting and implementing Part 61 performance objectives and technical requirements integral to an LLW performance assessment; and (c) implementation of NRC's performance assessment methodology. Moreover, the staff does not expect separate intruder scenario dose analyses would be included in an LLW performance assessment because 10 CFR 61.13(b) requires that analyses of the protection of individuals from inadvertent intrusion must include a demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.

Finally, this guidance attempts to share with the Agreement States and LLW disposal facility developers some of the staff's collective experience, and insights as they relate to the use of LLW performance assessments. In this regard, these groups may also find this NUREG useful as they proceed with the implementation of their respective programs.

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EXECUTIVE SUMMARY

1. INTRODUCTION

Performance assessment for low-level waste (LLW) disposal facilities is a type of technical analysis used in connection with demonstrating compliance with the 10 CFR Part 61 post-closure performance objective governing radiological protection of the general public (10 CFR 61.41). This Branch Technical Position (BTP) provides extensive guidance, to potential Part 61 applicants, on conducting performance assessments for LLW disposal facilities. It describes a comprehensive process within which site characterization, facility design, and performance assessment are conducted concurrently so that assessment results can be used to identify additional information needs and direct the course of subsequent information-gathering activities. The BTP also addresses certain LLW regulatory issues concerning how to interpret and implement the Part 61 technical requirements pertaining to performance assessment. These regulatory issues are: (a) treatment of future site conditions, processes, and events; (b) performance of engineered barriers; (c) timeframe for an LLW performance assessment; (d) treatment of sensitivity and uncertainty; and (e) the role of a performance assessment during operational and post-closure periods. Finally, this BTP describes acceptable modeling approaches for implementing the U.S. Nuclear Regulatory Commission performance assessment methodology (PAM).

This guidance also attempts to share with the Agreement States and LLW disposal facility developers some of the staff's collective experience, and insights as they relate to the use of LLW performance assessments. In this regard, these groups may also find this NUREG useful as they proceed with the implementation of their respective programs.

2. LLW PERFORMANCE ASSESSMENT PROCESS

The goal of the performance assessment process is to defensibly and transparently address uncertainty when analyzing future LLW disposal site performance. In developing an effective performance assessment process, several attributes and objectives are considered essential. *The central attribute of the process is that it is to be conducted **iteratively** — starting with a combination of generic and limited site-specific information in support of relatively simple conservative models and analyses, and progressing to more site-specific and detailed analyses, **as necessary**, to reduce uncertainty in assessing performance of a LLW disposal facility.* Initial screening analyses identify the most important issues and data needs, and as more site and design information is collected, modeling assumptions, conceptual models, and data needs are reevaluated. Site characterization and design bases are then revised to obtain data or modify the design as needed to reduce uncertainty and defend assessment results. The process is intended to be open and transparent in that all data, assumptions, and models should be well-documented and explained. Moreover, the reasons for any subsequent modification of assumptions and models should also be documented and supported by an appropriate combination of site investigation and assessment data, valid technical reasoning, and professional judgment. The process incorporates a formal treatment

of uncertainty to provide a basis for performance assessment decision-making, provides a technical basis for identifying the completion of site characterization, and helps build confidence that the disposal site meets the performance objective.

3. STAFF APPROACHES TO REGULATORY ISSUES

The staff has identified five Part 61 performance assessment issues that need to be addressed in the BTP. These regulatory issues are: (a) consideration of future site conditions, processes, and events; (b) performance of engineered barriers; (c) timeframe for an LLW performance assessment; (d) treatment of sensitivity and uncertainty in LLW performance assessments; and (e) role of performance assessment during operational and closure periods. The staff's technical positions on these five issues recommend general approaches to addressing them in the context of an LLW performance assessment.

3.1 Consideration of Future Site Conditions, Processes, and Events

The Part 61 siting requirements emphasize site stability, waste isolation, long-term performance, and defensible modeling of future site behavior. To help achieve these goals, the requirements stipulate avoiding sites where the frequency and extent of geologic processes and events will adversely affect performance of an LLW disposal facility or preclude defensible modeling of long-term performance. Therefore, it should be possible to define a set of natural conditions, processes, and events that comprise the "reference geologic setting" to be used in an LLW performance assessment. It is important to emphasize that the goal of the analysis is not to accurately predict the future but to test the robustness of the facility against a reasonable range of possibilities. The staff recommends the use of conservative assumptions and ranges of parameters that could effectively bound the reference geologic setting for the site. To capture the variability in natural processes and events and bound dynamic site behavior, the range of siting assumptions and data should be sufficient to understand the long-term trends in natural phenomena acting on the site. The staff emphasizes that there should be a limit on the range of possible site conditions, processes, and events to be considered in a LLW performance assessment and that unnecessary speculation in the assessment should be eliminated.

Additionally, consideration of societal changes would result in unnecessary speculation and therefore should not be included in a performance assessment.

3.2 Performance of Engineered Barriers

Engineered barriers are typically used to enhance overall facility performance by limiting the flux of water that comes into contact with the waste and the subsequent release of radionuclides from disposal units. However, significant uncertainty exists concerning predicting the service (i.e., design) life and long-term degradation rates of most engineered barriers, and concerning demonstration of their long-term performance. To limit unnecessary speculation as to their performance, the staff believes that materials typically used in engineered barriers should be assumed to have physically degraded after 500 years

following site closure.[1] Thus, at 500 years and beyond, the engineered barriers should be assumed to function at levels of performance that are considerably less than their optimum level, but credit for structural stability and chemical buffering effects may be taken for longer periods of time.[2] For time-frames longer than 500 years, it is unreasonable to assume that any engineered barrier can be designed to function long enough to influence the eventual release of long-lived radionuclides such as carbon-14 (half-life: 5700 years), technetium-99 (half-life: 214,000 years) and iodine-129 (half-life: 15,800,000 years), if they are present.

3.3 Timeframe for an LLW Performance Assessment

Part 61 does not specify a time of compliance for meeting the post-closure performance objective of 10 CFR 61.41. Specification of a period for analysis needs to consider a timeframe appropriate for evaluating the performance of both the engineered barriers and geologic barriers with consideration given to the types (i.e., activity, half-life, and mobility) of radionuclides being disposed of as LLW. The key concern is that release and transport are sensitive to a number of uncertain site-specific parameters such as the degradation rates of engineered barriers, and estimates for geochemical retardation in soils. This sensitivity can result in order-of-magnitude uncertainties in the predicted time of peak dose at an off-site receptor point. To reduce unnecessary speculation regarding the performance assessment, a period of 10,000 years (i.e., the period of regulatory concern) is sufficiently long to capture the peak dose from the more mobile long-lived radionuclides and to demonstrate the relationship of site suitability to the performance objective. Shorter periods, such as the 1000 years being used in dose assessments for site decommissioning, are considered generally inappropriate for assessments of LLW facilities. The staff is concerned that reliance on shorter compliance periods may result in an over-reliance on engineered barriers, to an extent that the performance of the natural setting would not be sufficiently evaluated, and would not consider peak dose, should it occur beyond the 1000-year period. Assessments beyond 10,000 years can be carried out, to ensure that the disposal of certain types of waste does not result in markedly high doses to future generations, or to evaluate waste disposal at arid sites with extremely long ground-water travel times. However, assessments of doses occurring after 10,000 years are not recommended for use as a basis for compliance with the performance objective.

3.4 Treatment of Sensitivity and Uncertainty in an LLW Performance Assessment

Uncertainty is inherent in all performance assessment calculations, whether they are deterministic or probabilistic, and regulatory decision-makers need to consider how the uncertainty associated with the models and parameters translates into uncertainty in performance measures. The staff recommends that formal sensitivity and uncertainty

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1 Any period of time claimed for performance of engineered barriers, including periods exceeding 500 years, should be supported by suitable information and justification evaluated on a case-by-case basis.

2 For "typical" commercial LLW, the inventory of short-lived radionuclides decays to insignificant quantities at about 500 years.

analyses be conducted in support of performance assessment calculations. The staff considered two different approaches for representing system performance in the context of the post-closure performance objective. One approach provides a single bounding estimate of system performance supported by data and assumptions that clearly demonstrate the conservative nature of the analysis. The other approach provides a quantitative evaluation of uncertainty with regard to system performance represented by a distribution of potential outcomes.[3]

When compliance, as measured against the 10 CFR 61.41 performance objective, is based on a single (deterministic) estimate of performance, the applicant is relying on the demonstration of the conservative nature of the analysis, rather than a quantitative analysis of uncertainty. Therefore, if it is to be used as a performance measure, a single estimate of performance should be at or below the 10 CFR 61.41 performance objective. In cases where a formal uncertainty analysis is performed and a distribution of potential outcomes for system performance is provided, the staff recommends that the mean of the distribution be less than the performance objective and the 95th percentile of the distribution be less than 1 mSv (100 mrem), to consider a facility in compliance.

3.5 Role of Performance Assessment during the Operational and Closure Periods

Part 61 requires that final LLW site closure plans demonstrate the long-term safety of the facility, and include any additional geologic, hydrologic, or other disposal site data obtained during the operational period pertinent to the long-term containment of waste, and the results of tests, experiments, or analyses pertaining to long-term containment of waste. This could include testing of assumptions about the performance of engineered aspects of the facility that are amenable to confirmation during operations. The site closure requirements suggest a need to keep performance assessments up to date as new information brings into question the bases of earlier assessments of LLW site safety.

4 RECOMMENDED ANALYTICAL APPROACHES TO MODELING ISSUES

NRC formulated a performance assessment strategy in 1987 that promotes a modular approach to modeling LLW disposal facility systems. The PAM, which was subsequently developed around this strategy, embodies a generalized conceptual model of an LLW disposal site, necessary for undertaking performance assessment analyses. The purpose of the PAM is to provide a basic set of system component models for conducting LLW performance assessments. The PAM considers disposal system component models for: (a) infiltration; (b) source term; (c) engineered barriers; (d) transport via (i) ground water, (ii) surface water, and (iii) air; and (e) dose. The PAM's modular structure allows a mix of

[3] Probabilistic approaches encompass a wide range of analysis techniques and methods. For the purposes of this BTP, probabilistic approach refers to the use of a formal, systematic uncertainty analysis to quantify the uncertainty in performance estimates caused by uncertainty in models and parameters. Assigning probabilities to scenarios, which is characteristic of some probabilistic approaches, is **not** recommended by the staff for LLW performance assessments.

both complex and simple models to be used in the overall LLW performance assessment. Given the technical uncertainty of modeling LLW site performance and the diversity of sites and facility designs being considered by various States and compacts, flexibility to select appropriate subsystem models and codes is an important PAM attribute.

This BTP identifies technical issues and describes analytical approaches for modeling disposal system components set out in the PAM. Although it is possible to implement the PAM manually, creating input to one subsystem model based on the results of another, this guidance discusses the potential benefits of automating subsystem model or code inputs and outputs with an overall "system" code. The benefits of an automated system code over manually linked subsystem models may include: (a) increased ability to step through successive iterations of the performance-assessment process and perform uncertainty and sensitivity analyses; (b) a higher degree of quality assurance; (c) explicit recognition of assumptions that might be vague or addressed inconsistently; and (d) use of consistent parameters and values among subsystem models. However, no matter how model integration is performed, it is important that analysts scrutinize and understand the intermediate model results. Although specific models and codes may be discussed or referenced in the guidance, NRC does not endorse the use of any particular models or codes for an LLW performance assessment.

TABLE SHOWING ENGLISH/METRIC SYSTEM CONVERSION FACTORS

The preferred system of measurement today is the "Systèm Internationale" or the metric system. However, for some physical quantities, many scientists and engineers prefer the familiar and continue to use the English system (foot-pound units). With few exceptions, all units of measure cited in this report are usually in the metric system.

The following table provides the appropriate conversion factors to allow the user to switch between these two systems of measure. Not all units nor methods of conversion are shown. Unit abbreviations are shown in parentheses. All conversion factors are approximate.

QUANTITY	*TO INCH-POUND UNITS*	*FROM METRIC UNITS* [1]	*CONVERSION FACTOR* [2]
SPACE AND TIME			
length	mile (mi) [statute] foot (ft) inch (in)	kilometer (km) meter (m) centimeter (cm)	0.6214 km 3.2808 m 0.3937 cm
area	square mile (mi^2) acre square foot (ft^2) square inch (in^2)	square kilometer (km^2) square kilometer square meter (m^2) square centimeter (cm^2)	0.3861 km^2 0.2471 km^2 10.7639 m^2 0.1550 cm^2
volume	cubic yard (yd^3) cubic foot (ft^3) cubic inch (in^3)	cubic meter (m^3) cubic meter liter (L) centimeter (cm^3)	1.3080 m^3 35.3147 m^3 0.0353 L 0.0610 cm^3
HEAT			
temperature	degrees Fahrenheit (°F)	degrees Celsius (°C) degrees Kelvin (°K)	°F = 1.8°C + 32 °F = 1.8°K - 459.67
IONIZING RADIATION			
activity (of a radionuclide)	curie (Ci)	megabecquerel (MBq)	2.7027×10^{-5} MBq
absorbed dose	rad	gray (Gy)	100 Gy
dose equivalent	rem	sievert (Sv)	100 Sv

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1 Not all metric units are shown. Most metric units can be arrived at by multiplying the value by 10^n.

2 For additional unit conversions, refer to C.J. Pennycuick. *Conversion Factors: SI Units and Many Others*, Chicago, The University of Chicago Press, 1988.

ACKNOWLEDGMENTS

The Performance Assessment Working Group (PAWG) is comprised of past and present staff of the U.S. Nuclear Regulatory Commission's Office of Nuclear Material Safety and Safeguards (NMSS) and the Office of Nuclear Regulatory Research (RES). The authors, contributors, and editors responsible for compiling this Branch Technical Position (BTP) are cited below:

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Engineering	**R. Shewmaker/NMSS** E. O'Donnell/RES J. Kane/NMSS J. Philip/RES
Ground Water	**R. Cady/RES** T. Nicholson/RES F. Ross/NMSS M. Thaggard/NMSS
Infiltration	**M. Thaggard/NMSS** R. Cady/RES T. Nicholson/RES P. Ross/NMSS
Source Term	**T. McCartin/NMSS** J. Bradbury/NMSS A. Campbell/NMSS[5] R. Lewis/NMSS[6] C. McKenney/NMSS P. Reed/RES

[4] Bold type designates lead.

[5] PAWG Project Manager until 1995. Now with NRC's Advisory Committee on Nuclear Waste.

[6] Now with NRC's Spent Fuel Project Office.

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Brookhaven National Laboratory
California State University
Idaho National Engineering and Environmental Laboratory (INEL)
National Institute of Standards and Technology
Oak Ridge National Laboratory
Pacific Northwest Laboratory
Princeton University
Massachusetts Institute of Technology
Sandia National Laboratories
University of California

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FOREWORD

This Branch Technical Position (BTP) has been developed by the Performance Assessment Working Group, which is composed of U.S. Nuclear Regulatory Commission staff from the Division of Waste Management, Office of Nuclear Material Safety and Safeguards, and the Waste Management Branch, Office of Nuclear Regulatory Research.

In January 1994, a preliminary draft of the BTP was first prepared and distributed for comment to all low-level radioactive waste (LLW)-sited and host Agreement States; the Advisory Committee on Nuclear Waste (ACNW); the U.S. Department of Energy (DOE); the U.S. Environmental Protection Agency; and the U.S. Geological Survey. The staff briefed the ACNW and the Commission, respectively, in March and April 1994. It also evaluated State and Federal agency comments on the preliminary draft of the BTP, revised certain sections of the BTP, and organized two workshops on the BTP and LLW performance assessment. The first was a 2-day workshop on the BTP and test case held at NRC Headquarters on November 16-17, 1994. The second was a half-day workshop that focused on certain technical issues in LLW performance assessment and was held at the 16th Annual DOE/LLW Management Conference on December 13-15, 1994. The staff also briefed the ACNW on key regulatory issues and its evaluation of the workshop comments on March 16, 1995. This BTP reflects the staff's consideration of comments received during those interactions.

1 INTRODUCTION

The U.S. Nuclear Regulatory Commission's licensing and related regulatory authority are provided by the Atomic Energy Act of 1954 (Public Law 83-703), as amended, and the Energy Reorganization Act of 1974 (Public Law 93-438). Before 1983, NRC regulated the disposal of low-level radioactive waste (LLW) using a collection of generic regulations specified in 10 CFR Parts 30, 40, and 70. In response to the needs and requests of the public, the States, industry and others, the Commission promulgated specific requirements for licensing the near-surface land disposal of LLW. NRC's requirements are in the form of 10 CFR Part 61 (NRC, 1982; 47 *FR* 57446).[1] Part 61 establishes licensing procedures, performance objectives, and technical criteria for licensing facilities for the land disposal of LLW.

Since 1983, the staff has developed several documents intended to aid in the implementation of Part 61. Foremost among these are: the "Environmental Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility" -- NUREG-1300 (NRC, 1987); the "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility" — NUREG-1199 (NRC, 1991a); and the "Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility" — NUREG-1200 (NRC, 1991b). However, in terms of measuring performance against the Part 61 performance objectives, the guidance provided by these documents is general and many specific implementation issues and acceptable approaches for resolving them are not addressed. Moreover, the relationship between the overall Part 61 data and design requirements, and specific LLW performance assessment needs are not explicitly addressed by the existing guidance documents. Previously, site characterization, facility design, and performance modeling were activities that heretofore were considered separate. To clarify these issues, the staff has prepared this Branch Technical Position (BTP) as a means of providing detailed guidance, to potential applicants,[2] in this area, as it relates to the performance objective concerned with the radiological protection of the general public — 10 CFR 61.41.

1.1 Background

A primary consideration of a decision to authorize a license to operate an LLW disposal facility will be whether the site and design meet the performance objectives and technical

[1] Under Section 274 of the Atomic Energy Act, NRC can relinquish portions of its LLW regulatory authority to the States. "Agreement States" are those States whose Governors have entered into limited agreements with the Commission to assume this authority and are permitted to license new disposal facilities under comparable regulations.

[2] In addition to potential Part 61 applicants, existing LLW licensees, operating under comparable Agreement State regulations, may also find the guidance in this NUREG useful as they proceed with the implementation of their respective programs. (See Section 1.8.)

requirements contained in Subparts C and D, respectively, of Part 61. A potential licensee must characterize the site and provide a demonstration that the disposal site and design will comply with explicit standards. There will be unavoidable uncertainties in predicting the long-term performance of an LLW disposal facility. Conclusions as to the performance of the disposal facility and of particular barriers over long periods of time, by necessity, will be based largely on inference, as it will not be possible to carry out test programs of sufficient duration or that simulate the full range of potential conditions expected over the period of regulatory concern. Given these uncertainties, it will be necessary for a potential licensee to adopt a variety of design features, develop models, perform tests, acquire data, and undertake other measures to be able to demonstrate, with reasonable assurance, that the performance objectives will be met.

For its part, in reaching a potential LLW licensing decision, the Commission can be expected to apply the standard of "reasonable assurance," based on the record before it, that the Part 61 performance objectives and technical criteria will be met. Performance assessments are one mechanism for providing reasonable assurance, and, therefore, are expected to play an important role in any potential LLW licensing proceeding.

1.2 Overview of LLW Disposal Concepts, Performance, and Technical Issues

A *land disposal facility* is the land, buildings, and equipment necessary to carry out the disposal of LLW. A *disposal site* is that portion of a land disposal facility that is used for the disposal of waste. It consists of a number of covered disposal units surrounded by a buffer zone. A *disposal unit* is a discrete portion of the disposal site into which waste is placed for disposal. Near-surface disposal units may range from earthen trenches to concrete vaults. They may be covered with simple earthen caps or complex multi-layer systems of drainage layers, capillary breaks, and moisture wicks (see Cartwright *et al.*, 1987; Schulz *et al.*, 1988 and 1992; Smyth *et al.*, 1990; Bennett, 1991; Bennett and Horz, 1991; and Bennett and Kimbrell, 1991). The *buffer zone* is that portion of the disposal site that is controlled by the licensee and which lies under and between the disposal units and any disposal site boundary. The buffer zone provides controlled space to establish monitoring locations that are intended to provide an early warning of radionuclide movement.

The *natural site* in which an LLW disposal facility is located consists of: (i) the geosphere and hydrosphere (i.e., geologic and hydrogeologic systems, including surface water); (ii) the surrounding atmosphere; and (iii) the biosphere. The natural characteristics of an LLW disposal site should promote disposal site stability and attenuate the transport of radionuclides away from the disposal site into the general environment. Although engineered barriers can be used to improve or enhance disposal site performance, the natural (geologic) setting must be relied on, in the long term, for safety. Minimum characteristics that a disposal site must have to be acceptable for near-surface disposal of LLW are specified in the technical requirements of 10 CFR 61.50. Sites generally must possess the following characteristics: (i) relatively simple geology; (ii) well-drained soils free from frequent ponding or flooding; (iii) lack of susceptibility to surface geological processes such as mass wasting, erosion,

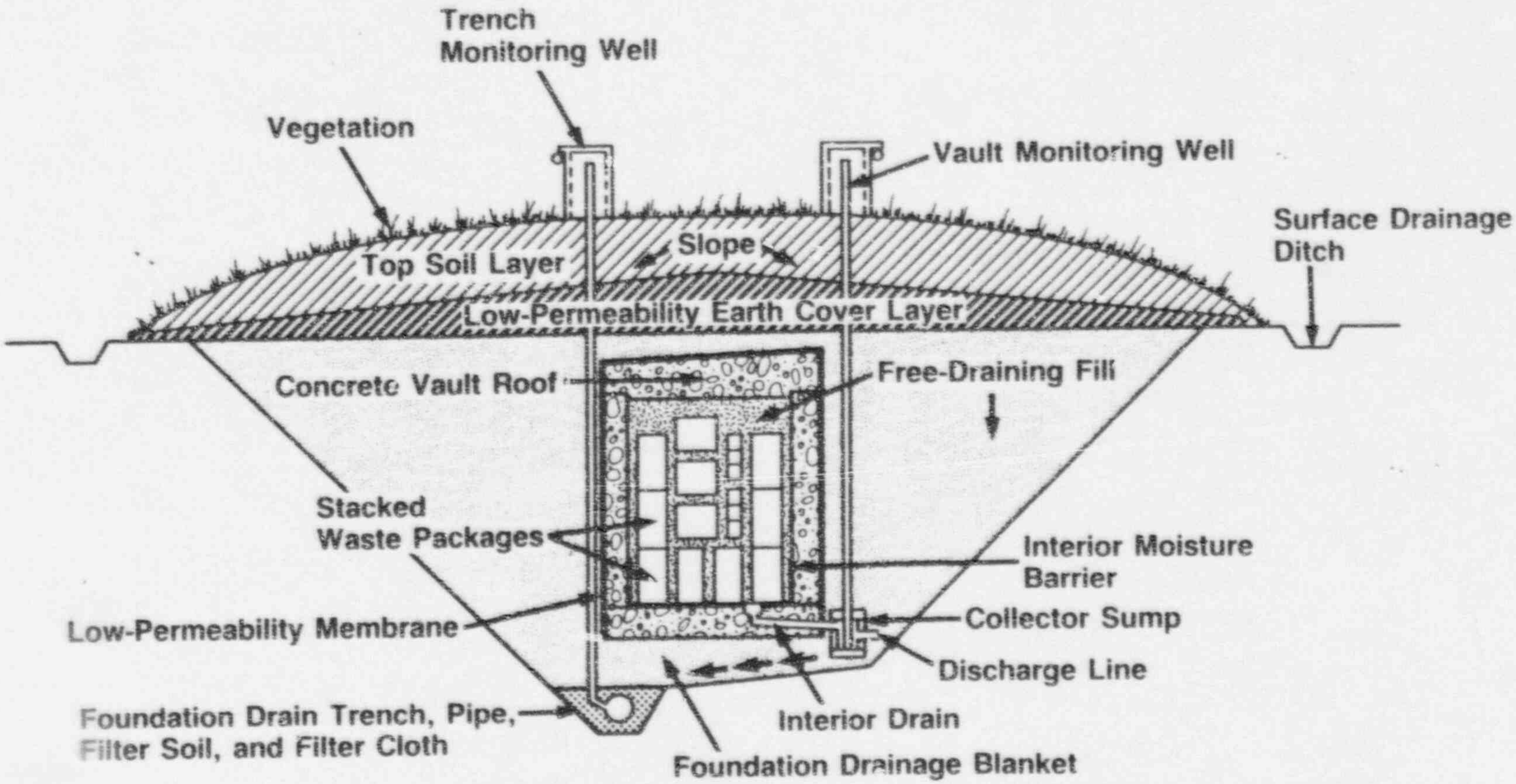
slumping, landslides, and weathering occurring with such frequency or to such an extent as to significantly affect disposal site performance; (iv) a water table of sufficient depth so that ground water will not periodically intrude into the waste or discharge on site; (v) lack of susceptibility to tectonic processes such as folding, seismic activity, and volcanism with such frequency or to such an extent as to significantly affect disposal site performance; (vi) no known potentially exploitable natural resources; (vii) limited future population growth or development; and (viii) capability of not being adversely impacted by nearby facilities or activities.

Engineered barriers are man-made structures or devices designed to improve or enhance the site's natural ability to isolate and contain waste, and to minimize releases of radionuclides to the environment. An engineered barrier system operates in conjunction with the characteristics of the natural site to form an integrated waste disposal system. Figure 1 depicts an example of an engineered barrier system consisting of various engineered system components, including: (i) a layered earthen cover; (ii) a disposal vault; (iii) a drainage system; (iv) waste forms and containers; (v) back-fill material; and (vi) an interior moisture barrier and low-permeability membrane. Covers are required to be designed to prevent significant quantities of water from contacting the waste (10 CFR 61.51(a)(4)) and they also must provide shielding from direct gamma exposure (10 CFR 61.52(a)(6)). Cover performance depends on site stability and many of the technical requirements governing facility design, operation, and siting are directed at promoting waste package and cover stability. Most of the disposal facilities proposed by States and compacts will use concrete vault systems to help isolate waste from the accessible environment. Concrete vault systems include below-ground vaults (BGVs), earth-mounded concrete bunkers ((EMCBs) — i.e., above-grade, but covered with earthen material) and above-ground vaults (AGVs) with no earthen covers (see Bennett *et al.*, 1984; Warriner and Bennett, 1985; Bennett and Warriner, 1985; Miller and Bennett, 1985; Bennett, 1985; and Denson *et al.*, 1987 and 1988).

The transient nature of surficial (i.e., geomorphic) processes, which are influenced by patterns of weather and long-term climatic variability, and soil heterogeneity, contribute to uncertainty in modeling the movement of water into and through disposal unit covers. Furthermore, given the sparsity of data on the long-term durability of engineered materials — how effectively engineered barriers perform over time, to limit the flux of water into the disposal units — is a major uncertainty that must be addressed by relying primarily on engineering judgment.

Source term refers to the radionuclide flux leaving the disposal units. Releases of radionuclides from an LLW disposal unit are caused by a number of physical and chemical processes that occur primarily in the presence of water. Water enters the disposal unit covers because a portion of the precipitation that impinges on disposal unit covers passes through them. Water is the primary medium for mobilizing radionuclides from disposed LLW. Therefore, container degradation and waste-form leaching, by infiltrating water, must occur before significant releases of radionuclides from the facility develop. (Note that small amounts of gas may exist in the waste (e.g., krypton-85 (^{85}Kr)), or be generated in the

Figure 1. Example of engineered barrier system for an LLW disposal facility.


Trench
Monitoring Well
Vegetation
Vault Monitoring Well
Surface Drainage
Ditch
Slope
Top Soil Layer
Low-Permeability Earth Cover Layer
Concrete Vault Roof
Free-Draining Fill
Stacked
Waste Packages
Interior Moisture
Barrier
Collector Sump
Low-Permeability Membrane
Discharge Line
Foundation Drain Trench, Pipe,
Filter Soil, and Filter Cloth
Interior Drain
Foundation Drainage Blanket

absence of water (e.g., radon-222 (^{222}Rn)), but generation of large amounts of carbon-14 (^{14}C) and tritium (^{3}H) containing gaseous species (e.g., $^{14}CO_2$, $^{14}CH_4$, etc.) generally occurs in the presence of infiltrating water.) Backfill material placed around waste containers for structural stability may also be engineered to have chemical and physical properties that enhance radionuclide retention.

Significant uncertainty in modeling the source term arises from variations within waste types, waste forms, waste containers, and the many complex physical and chemical interactions occurring among them and with the backfill material. These uncertainties are encountered when: (i) characterizing a site-specific waste inventory by waste class (A, B, and C), waste stream, and waste form; (ii) determining credible container lifetimes (especially for high-integrity containers for B/C Classes of waste); (iii) identifying waste-form-specific release mechanisms; and (iv) ascertaining chemical considerations, such as solubility limits, that may be included in source term modeling.

Site-specific environmental transport media should be characterized and appropriate exposure pathways, scenarios, and receptor locations identified. Principal transport media at LLW disposal sites include ground water, surface water, and air. Ground water is typically the most important transport medium from a subsurface disposal facility because radionuclides are mobilized by infiltrating water and convected and dispersed in ground water moving beneath the site. The most important ground-water exposure pathways are linked to well water used for drinking and crop irrigation. Transport of contaminants to surface water via seepage and springs, and subsequent exposure through other pathways are considered of secondary importance because of the extent of dilution that generally occurs in surface-water systems. However, for an AGV facility subject to degradation by surficial processes, direct transport in surface runoff can be significant, particularly in humid regions. Air exposure pathways are typically of secondary importance relative to exposure from ground- and surface-water-related pathways. However, air exposure pathways may be significant for particular designs, such as AGVs with no earthen cover (Kozak *et al.*, 1993), or if specific chemical and physical conditions at the facility (e.g., at arid sites) promote generation of gases containing ^{14}C and ^{3}H that are released to the atmosphere. Significant uncertainty is inherent in collecting and interpreting data on site conditions, and in setting initial model boundary conditions and selecting model input parameters for analyzing radionuclide transport. Uncertainty also exists in selecting appropriate site-specific exposure scenarios and pathways, and human receptor locations.

Radiation doses to humans from radionuclides transported through environmental media are typically calculated using a linear relationship between the dose and the time-dependent concentration of radionuclides at human access locations. Human exposure to radiation occurs through internal and external dose pathways. Internal doses result from radionuclides being incorporated into the body primarily through inhalation of contaminated air, and by ingesting contaminated food and water. External doses occur from direct radiation sources outside the body, such as contaminated surfaces and air. The sum of the doses from all the radionuclides in all significant exposure pathways is the total dose to individual members of

the general population. Calculations of radiological exposures to any member of the general population should be made in terms of the average member of the critical group. For the purposes of this guidance, the *critical group* is defined as the group of individuals reasonably expected to receive the greatest exposure to radiological releases from the disposal facility over time based on conservative but reasonable exposure assumptions and model parameter values.

1.3 What is LLW Performance Assessment ?

Low-level waste performance assessment is a type of systematic (risk) analysis that addresses what can happen, how likely is it to happen, and what are the resulting impacts. The essential elements of a performance assessment for a LLW disposal site are: (i) a description of the site and engineered system; (ii) an understanding of events likely to effect long-term facility performance; (iii) a description of processes controlling the movement of radionuclides from LLW disposal units to the general environment; (iv) a computation of doses to members of the general population; and (v) an evaluation of uncertainties in the computational results. (Also see DOE *et al.* (1992).) Quantitative estimates of LLW site performance are matched to need: deterministic, bounding analyses for simple problems; and probabilistic analyses for more complex problems, with large uncertainties. Performance assessment ties disposal site performance to site characterization and facility design alternatives so that disposal system knowledge is obtained and integrated in a systematic and efficient way. Performance assessment establishes a record to support the technical basis and written documentation of model assumptions and data needed for a successful compliance demonstration.

To integrate site characterization and facility design activities, LLW performance assessment can be performed iteratively. For example, simple screening calculations can provide insights on the performance of proposed sites and conceptual designs to enhance the prospects of selecting a suitable site. Moreover, in designing an LLW facility, performance assessment can be used to optimize disposal facility design to achieve potentially higher levels of performance for the overall system. In characterizing a site, initial screening analyses should help the performance assessment analyst to identify important issues and data needs that must be factored into any program to investigate and evaluate a candidate site. As more site information is collected, the analyst should reevaluate modeling assumptions, conceptual models, and data needs, and revise the site characterization program accordingly, to obtain data identified as most needed to reduce uncertainty and defend assessment results. The site-specific nature of performance assessment will dictate the type and amount of feedback between performance assessment and site characterization. The process intrinsically builds confidence in performance assessment results because the reasons for modifying assumptions, models, and conditions are well-documented and supported by data amassed from preceding site investigations and assessments. If at some point it appears likely that very extensive and/or expensive site characterization will be needed to continue the process, the developer may decide to consider evaluation of another site. Such a decision would reflect practical implementation of the 10 CFR 61.50(a)(2) requirement that "The disposal

site be capable of being characterized, modeled, analyzed and monitored."

To provide a defensible result, uncertainty analysis needs to be part of the LLW performance assessment. Analyses of uncertainty and sensitivity drive the performance assessment process toward a defensible final decision on site compliance. The most commonly cited sources of uncertainty in performance assessment are uncertainty about conceptual models (model uncertainty), which may include doubts about future site conditions, processes and events, and uncertainty regarding data, parameters, and coefficients used in models (parameter uncertainty). The objective of uncertainty analysis is to assess the degree of variability in calculated results as a function of the variability in model and input parameters. The treatment of model uncertainty necessitates analyzing those conceptual model alternatives not refuted by site data. Methods for treating parameter uncertainty are usually based on establishing the degree of belief in a value or range of values for each parameter selected for model input. The objective of sensitivity analyses is to focus attention on important parameters by determining the relative contributions of input variables to the resulting dose. Sensitivity studies on the intermediate results from sub-system models (infiltration, source term, transport media, etc.) also may provide valuable insight on those factors that most influence the performance of the overall system. Before a compliance demonstration can be made, a number of data collection and assessment iterations may need to be undertaken to refute some of the alternative conceptual models and to narrow parameter ranges. Gauging uncertainty through formal validation exercises, such as model calibration, history matching, and prediction, is not possible because of the inherent nature of uncertainty in performance assessment modeling. What is important, however, is being able to build confidence that the models perform as they are designed, capture relevant features and processes of the disposal system being modeled, and reflect the uncertainty in system knowledge.

Finally, LLW performance assessments can be used to provide site-specific inventory limits for certain long-lived radionuclides in those cases where the performance assessment results do not meet the performance objective. Radionuclides of concern include such long-lived radionuclides as iodine-129 (^{129}I), technetium-99 (^{99}Tc), ^{14}C, chlorine-36 (^{36}Cl), and thorium (Th), uranium (U), and their daughter products. The concept of site-specific inventory limits for controlling radionuclide releases through the ground-water pathway is part of the supporting analyses for Part 61 presented in the *Draft* and *Final Environmental Impact Statements* (DEIS and FEIS, respectively -- see NRC, 1981 and 1982) and the Commission is authorized under 10 CFR 61.7(b)(2) to establish maximum radionuclide inventories. Because of the site-specific nature of potential impacts of radionuclide migration in ground water, which are a function of the total inventory of particular radionuclides disposed of at the facility, NRC did not establish generic inventory or concentration limits for the protection of individuals off-site. Rather, each disposal facility must be analyzed on a case-by-case basis and, depending on site environmental conditions and the design of the disposal facility, maximum site inventories may be imposed by license condition for certain radionuclides. Even if initial inventories of long-lived radionuclides are projected to be low, knowing the potential site-specific disposal limits for these radionuclides, through some type of LLW performance assessment, would ensure site safety should unforeseen disposal needs arise.

1.4 Previous Staff Activities in the Area of LLW Performance Assessment

Traditionally, all commercially generated LLW in the United States has been disposed of at the near-surface, using shallow land burial (SLB) methods. This disposal method relies on relatively simple engineering designs to isolate wastes from infiltrating water — the natural (geologic) characteristics of the site are the principal attenuators of any radioactivity that might be released to the accessible environment. SLB facilities for LLW at Barnwell, South Carolina, and Richland, Washington, are currently operational and are based on these somewhat simple designs. In conjunction with the development of Part 61 and after its publication in 1982 (NRC, 1982; 47 *FR* 57446), the staff began to undertake a variety of performance assessment-related projects that primarily addressed SLB facilities. These projects were initiated in such areas as waste package performance and leaching, hydrogeological and hydrogeochemical characterization and modeling, and cover performance. The staff also began to investigate alternatives to SLB and developed guidance for the licensing of new disposal facilities (see NRC, 1991a,b).

To address the need for a more integrated approach to LLW performance assessment, the staff formulated an overall LLW performance assessment strategy in 1987 (Starmer *et al.*, 1988). This strategy recommended a modular approach for modeling LLW disposal facility system performance by quantifying potential release and transport of radionuclides through significant environmental pathways. An LLW performance assessment methodology (PAM) based on this strategy was subsequently developed by the Sandia National Laboratories (SNL), at the request of the staff, and published in a five-volume series as NUREG/CR-5453.[3]

Concurrently, the staff published its LLW Research Program Plan (O'Donnell and Lambert, 1989), which presents the staff's strategy for LLW research. The development of the research program plan reflected the staff's interactions at the time with the Agreement States, regional compacts, the U.S. Department of Energy (DOE), and its technical assistance contractors.

In the early 1990s, the staff began developing an LLW performance assessment program plan (see NRC, 1992). This program had two primary goals: (i) to enhance the staff's capability to review and evaluate new LLW license applications; and (ii) to develop the in-house capability needed to prepare the necessary guidance. This plan was begun in response to needs identified by Agreement States and the staff through interactions with prospective applicants, the review of DOE prototype license applications, and in response to specific performance assessment issues raised by the States. It was also during this time that the staff formed the Performance Assessment Working Group (PAWG) to ensure the inter-office coordination of the respective LLW performance assessment efforts within the Agency.

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[3] See Shipers (1989); Shipers and Harlan (1989); Kozak *et al.* (1989a,b); and Kozak *et al.* (1990a,b).

Since the early 1990s, the staff has continued to enhance its LLW performance assessment expertise and capability, consistent with its 1992 program plan, through a variety of measures. For example, the staff and its technical assistance contractors have been involved with a number of LLW performance assessment modeling exercises and analyses. (Many of these efforts are cited in "References," Section 4).[4] As part of this work, in 1992, PAWG began to develop this BTP and also initiated computer simulations of a test case problem of a hypothetical LLW disposal system. Using actual site data representative of a humid environment and a staff-generated facility design and source term inventory, the staff hopes to: (i) test models selected for use in conducting a performance assessment; and (ii) gain experience with the use and limitations of performance assessment modeling. The staff's efforts to enhance its performance assessment expertise and capability have also benefited from related work in the area of high-level radioactive waste (see Codell *et al.* (1992) and Wescott *et al.* (1995)). Finally, it should be noted that the staff has gained additional performance assessment experience and insight through workshops and meetings with interested States; other Federal agencies (DOE; the U.S. Environmental Protection Agency (EPA); and the U.S. Geological Survey (USGS)); comparable regulatory entities in foreign countries (France, Spain, and Germany); and international organizations, such as the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA).

1.5 NRC's LLW PAM

As noted earlier, the staff first formulated a general performance assessment strategy in 1987. This strategy recommended a modular approach to the modeling of LLW disposal facility system performance (Starmer *et al.*, 1988). This approach, represented graphically in Figure 2, logically divides the disposal system into separate modeling areas:

- Infiltration and unsaturated (vadose) zone flow;
- Engineered barrier performance (coupled with infiltration analysis to calculate the water flux into disposal units);
- Radionuclide releases from waste forms and the bottoms of disposal units (container failure, leaching, and near-field transport);
- Transport media — ground water, surface water, and air;
- Plant and animal uptake (food chain); and
- Dose to humans.

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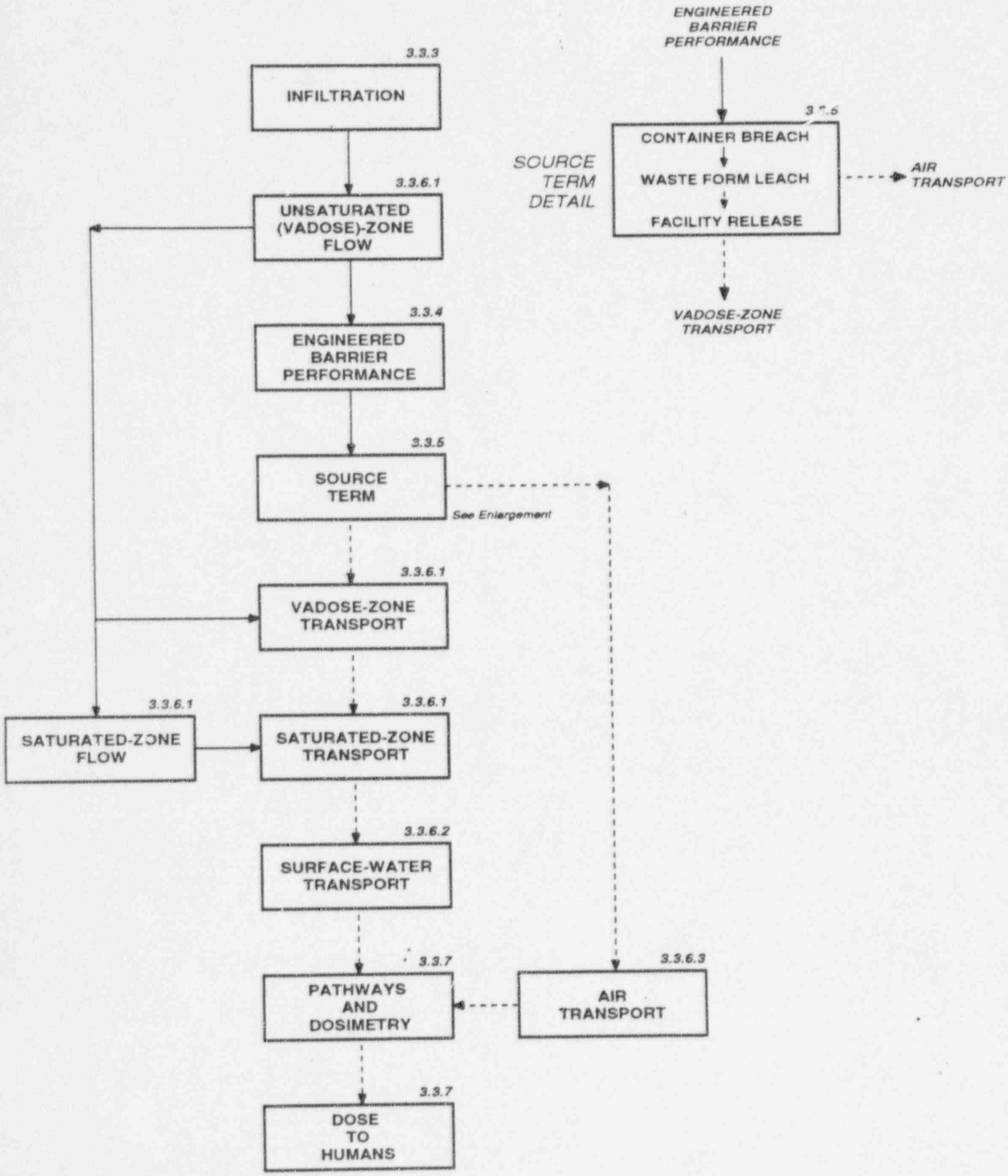
[4] For an extensive summary of NRC-sponsored technical assistance work performed before 1990, see Dunkelman (1987).

Figure 2. **Conceptual model showing processes to be considered in an LLW performance assessment (modified from Kozak *et al.*, 1990b).** (Numbers next to the process blocks correspond to the technical position statements described in Section 3.3 of the text. Solid lines correspond to water flow pathways, and the dashed lines correspond to radionuclide transport pathways. The "source term" process block, "Technical Position 3.3.5," corresponds to the LLW disposal cell(s).)



ENGINEERED BARRIER PERFORMANCE
3.3.3
INFILTRATION
SOURCE TERM DETAIL
CONTAINER BREACH
WASTE FORM LEACH
FACILITY RELEASE
AIR TRANSPORT
VADOSE-ZONE TRANSPORT
3.3.6.1
UNSATURATED (VADOSE)-ZONE FLOW
3.3.4
ENGINEERED BARRIER PERFORMANCE
3.3.5
SOURCE TERM
See Enlargement
3.3.6.1
VADOSE-ZONE TRANSPORT
3.3.6.1
SATURATED-ZONE FLOW
3.3.6.1
SATURATED-ZONE TRANSPORT
3.3.6.2
SURFACE-WATER TRANSPORT
3.3.7
PATHWAYS AND DOSIMETRY
3.3.6.3
AIR TRANSPORT
3.3.7
DOSE TO HUMANS

Given the constraints imposed by site-specific conditions, the modular approach allows a mix of both complex and simple models to be used to capture the critical interactions among important processes affecting disposal site performance. Generally, complex models require more abundant and detailed input data than less sophisticated models, which rely more on simplifying assumptions and generalized information. The appropriate degree of modeling complexity within a module is determined by the purpose of the modeling, and the availability of suitable data and associated data uncertainty.

Over a 3-year period from 1988 through 1990, NRC, through its technical assistance contractor, SNL, developed the PAM. The PAM is a suite of models and codes suitable for analyzing the various disposal system modules set out in the staff's performance assessment strategy and was produced in five steps:

Step 1 — Identifying potential human exposure pathways.

Step 2 — Assessing the relative significance of exposure pathways.

Step 3 — Selecting and integrating system component models.

Step 4 — Identifying and recommending computer codes for solving the models.

Step 5 — Implementing and assessing the performance of recommended codes.

In the course of developing the PAM, a number of significant policy and technical issues were identified and described but not addressed (Kozak *et al.*, 1993), and although the PAM addresses the mechanics of analyzing and modeling LLW disposal system performance, it does not constitute a way of systematically conducting, documenting, and preparing performance assessments acceptable for licensing.

Since 1990, the staff made considerable efforts regarding gaining insights into resolving these LLW performance assessment issues. Most recent staff efforts include conducting a realistic test case performance assessment modeling study for a hypothetical site, interacting with Agreement States on site-specific performance assessment issues, conducting a performance assessment workshop for Agreement States, conducting NRC research and technical assistance contractor studies, and participating in international programs. These include: (i) an IAEA project on LLW site performance assessment (IAEA, 1996); (ii) various international symposiums on the verification and validation of geosphere performance assessment models (Statens Kärnkraftinspektion (SKI), 1988; SKI/Organisation for Economic Co-operation and Development (OECD) NEA, 1991; and OECD NEA, 1995); and (iii) the International Cooperative Project on Geosphere Model Validation (INTRAVAL) Project (SKI, 1993). The technical position statements contained in this document reflect consideration of these other efforts.

1.6 Purpose of the BTP

As noted in Section 1.2, a range of land disposal technologies has been developed, in addition to SLB, that could be applied toward the disposal of LLW. They include BGVs, EMCBs, AGVs, mined cavities, and augured holes. Most of the designs being considered for future LLW facilities center on improved engineering enhancements, such as concrete vaults and multi-layered covers, to help isolate waste from the accessible environment. Based on the collective State and staff experience, it is believed that guidance is needed on not only on how to analyze and model natural systems, but also on analyzing the performance and reliability of more complex engineered barriers over the long term. Several areas have thus been identified where guidance on how to conduct an LLW performance assessment may be needed. These areas include:

- An overall understanding of the performance assessment process;
- The relationship between site characterization and performance assessment data collection;
- Modeling of infiltration rates, source term releases, and concrete and engineered barrier degradation;
- Transport of radionuclides in the environment;
- Verification and validation of computer models;
- The use of generic data in performance assessment; and
- Uncertainty and sensitivity analyses.

The guidance presented in this BTP is intended to be generally applicable to any method of land disposal; however, only technical issues that specifically are attributable to the performance of near-surface disposal technologies are addressed. Technical issues related to land disposal in AGVs or disposal deeper than 30 meters (mined cavities and augured holes) will need to be evaluated and addressed separately.

As noted earlier, performance assessments are expected to play an important role in any potential LLW licensing proceeding under Part 61. The purpose of this BTP, therefore, is to provide guidance on an acceptable overall approach for conducting an LLW performance assessment. Specifically, this guidance includes the staff's technical positions on:

(a) An example of an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process;

(b) Policy issues with respect to interpreting and implementing Part 61 performance objectives and technical requirements as they may pertain to LLW performance assessment; and

(c) Ways to implement NRC's PAM.

Moreover, this BTP augments existing LLW performance assessment guidance currently contained in NUREG-1199 (NRC, 1991a) and in NUREG-1200 (NRC, 1991b).

However, the technical positions in this BTP are not intended to address safety issues that are recommended to be addressed in any *Safety Analysis Report*[5] submitted as part of a potential Part 61 license application. For example, operational performance issues (Subpart C), and the necessary technical analyses to address them (10 CFR 61.13), are not considered, within the context of this guidance, unless particular aspects of disposal facility operations might have an impact on the long-term performance of the disposal site. In addition, issues relating to site characterization (10 CFR 61.12(a)), including the design and construction of a disposal facility (10 CFR 61.12(b)-(i)), are not discussed except as they relate to assessing the post-closure performance of the disposal site (Subpart C). Moreover, the performance assessment approach described in this BTP is not intended to address radiation safety. For example, issues related to demonstrating compliance with the Part 61 performance objectives governing protection of inadvertent intruders (10 CFR 61.42)[6]; protection of individuals during operations (10 CFR 61.43); and stability of the disposal site after closure (10 CFR 61.44) are beyond the scope of this guidance. Operational practices, emergency responses to accidents, and monitoring programs, as described in the radiation safety program for control and monitoring of potential operational releases (10 CFR 61.12(k)), should provide assurance that individuals on and off-site are protected from routine operations and from accidents that may occur when waste handling, storage, and disposal activities would occur. Environmental monitoring programs (10 CFR 61.53(c)), including proposed plans for corrective measures (61.12(l)), will provide early warning of radionuclide releases from the disposal facility, before they leave the site boundary. If necessary,

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[5] As suggested in NUREG-1199 (NRC, 1991a; pp. xi).

[6] Separate intruder scenario dose analyses are not envisioned to be included in an LLW performance assessment. Rather, 10 CFR 61.13(b) requires that "...analyses of the protection of individuals from inadvertent intrusion must include demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided...."

That being said, separate intruder scenario analyses may be necessary in cases where the projected waste spectra are fundamentally different from those considered in the technical analyses supporting any Part 61 DEIS (see NRC, 1981). For example, an intruder analysis might be necessary if the waste form(s) proposed for disposal contain anomalous quantities and concentrations of certain long-lived radionuclides (e.g., uranium or thorium) such that the intruder cannot reasonably be protected by the waste classification and intruder barrier requirements of Part 61.

operational procedures may be modified or other mitigating actions taken to ensure that operational releases of radioactivity are maintained within the individual dose requirements of 10 CFR 61.41 (which are incorporated by reference in 10 CFR 61.43).

Section 2 of this BTP summarizes the principal regulatory requirements and policy considerations that relate to this topic. The staff's technical position statements are listed in Section 3. Section 3 also includes a discussion of the supporting rationale behind each statement of position. Definitions of key terms used in the BTP are provided as Appendix A.

1.7 BTPs as Technical Guidance

BTPs are issued to describe, and make available to the public and Agreement States, methods acceptable to the staff, for implementing specific parts of the Commission's regulations, and to provide regulatory guidance to regulated entities. BTPs are not substitutes for regulations, and compliance with them is not required. Methods and solutions differing from those set out in the BTP will be acceptable if they provide a sufficient basis for the findings requisite to the issuance of a permit or license by the Commission.

This BTP constitutes informal pre-licensing activity between the staff and a prospective applicant under 10 CFR 2.101(a)(1) and is not part of a proceeding under the Atomic Energy Act (Public Law 83-703), as amended. Nothing in this BTP constitutes a commitment to issue any authorization or license, or in any way affects the authority of the Commission, the Atomic Safety and Licensing Boards, other presiding officers, or the Director, in any such proceeding.

Published BTPs will be revised, as appropriate, to accommodate comments and to reflect new information and experience.

1.8 Use of this BTP by Other Regulatory Entities

A motivating factor influencing the development of this BTP was the desire to share with the Agreement States and LLW disposal facility developers (as potential applicants) some of the staff's collective experience and insights, as they relate to the use of LLW performance assessments in a regulatory context. The extent to which the Agreement States or other regulatory entities implement the recommended technical position statements found in this NUREG is, of course, a matter for their consideration and decision. However, as other regulatory entities consider the application of this guidance to their respective programs, the staff also thought it useful to discuss how performance assessment contributes to regulatory decision-making.

The burden of demonstrating compliance with the applicable disposal regulations resides with the potential license applicant. Thus, once a potential applicant decides that adequate analyses have been conducted, it is anticipated that it would be documented and submitted as

part of an overall license application. For their part, it will be the job of the regulatory body to independently evaluate the license application to ensure that it provides the technical data and analyses necessary to support a regulatory conclusion that the proposed LLW disposal facility can operate safely.

In this regard, the recommended process described in Technical Position 3.1 provides a useful guide. This recommended process emphasizes the selection of important items of information that are useful in defending why a particular LLW performance assessment is sufficient and is likely to be an acceptable indicator of disposal site performance. The process focuses attention on: (i) selection of assumptions and conceptual models; (ii) basis for model input data selection; (iii) appropriateness of computer model application; (iv) integration of subsystem models; and (v) analysis of uncertainties and sensitivities of data and assumptions. Questions raised about any aspect of the performance assessment would constitute feedback to the developer. Based on this feedback, it is intended that the developer re-evaluate the data and assumptions, and perform further iterations, through the performance assessment process, as necessary, to answer the questions. As suggested above, it is important to the regulatory staff that the license application provide comprehensive documentation of the performance assessment. Once the review process is completed and the application found to be technically acceptable, the regulator's findings and supporting independent assessments are documented. It is through this documentation that the regulator's conclusions and findings are communicated to the public.

Thus, it may be desirable to make the site characterization-performance assessment process participatory, where interested parties would be encouraged to participate in developing and refuting conceptual models as the disposal site is being characterized and evaluated. An open process can be expected to improve the technical breadth and defensibility of performance assessments, and eliminate the perception of applicant bias toward more optimistic results. The performance assessment process should readily accommodate a wide variety of alternative approaches for public participation and openness. A final consideration also related to the defensibility of performance assessment analyses is that the entire performance assessment process, including all iterations, should be thoroughly documented to enable independent auditors to trace the modeling results, thereby demonstrating that they can be reproduced.

Finally, in preparing the guidance proposed in this NUREG, it was not the staff's intent to imply that other regulatory entities need to independently undertake comprehensive, corroborating LLW performance assessments of their own or precisely repeat every part of the recommended overall process. Other regulatory entities may, however, decide to conduct independent performance assessment modeling for the entire system or for selected subsystem areas, to corroborate certain aspects of the reported results. The amount of modeling should be based on technical judgment; the level of confidence the respective regulatory staff has in the data, assumptions, models, and codes used by the developer; and the relative significance of subsystem modeling results to the overall compliance demonstration.

2 REGULATORY FRAMEWORK

As noted earlier, the Commission's regulations found in Part 61 address the licensing of near-surface land disposal of LLW. There are several requirements in Part 61 that provide a basis for the conduct of an LLW performance assessment. These requirements can be found in Subparts C, B, D, and G. In Subpart C, for example, one of the major performance objectives is described in 10 CFR 61.41 ("Protection of the General Population from Releases of Radioactivity"). During and following facility operations, 10 CFR 61.41 requires that:

> Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants or animals must not result in an annual dose exceeding an equivalent of 25 millirems [0.25mSv] to the whole body, 75 millirems [0.75 mSv] to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

The specific technical information needed to demonstrate compliance with 10 CFR 61.41 is described in Subpart B (content of license application). Section 61.13(a) requires that the following three information needs must be met:

- That the "Pathways analyzed in demonstrating protection of the general population from releases of radioactivity must include air, soil, ground water, surface water, plant uptake and exhumation by burrowing animals";

- That "The analyses must clearly identify and differentiate between the roles performed by the natural disposal site characteristics and design features in isolating and segregating the wastes"; and

- That "The analysis must clearly demonstrate that there is reasonable assurance that the exposure to humans from the release of radioactivity will not exceed the limits set forth in 10 CFR 61.41."

Additional requirements are set forth in Subpart D. Section 61.50(a)(2) requires that "The disposal site shall be capable of being characterized, modeled, analyzed, and monitored." The intent of this requirement is to provide a criterion for site suitability that is aimed at minimizing the complexity of the site and the associated uncertainty in the technical analyses of site safety, including an assessment of the site's performance. Section 61.53 requires that during the operational and post-operational periods, a licensee is responsible for conducting an environmental monitoring program. Measurements and observations must be made and recorded to provide data to evaluate potential health and environmental impacts and long-term effects of the facility.

In Subpart G, 10 CFR 61.80 requires licensees to maintain records, by waste class, of activities and quantities of radionuclides disposed of, and report to the Commission the results of environmental monitoring and any instances in which observed site characteristics were significantly different than those described in the license application.

Finally, in a license application amendment to close an LLW disposal facility, 10 CFR 61.28(a) of Subpart B requires that the final site closure plans should include any additional hydrologic or other site data obtained during the operational period of the site, and the results of tests, experiments, or analyses pertinent to the long-term containment of emplaced radioactive wastes.

NUREGs-1199, 1200, and 1300 provide some guidance on performance assessment-related issues. NUREG-1200 provides guidance applicable to evaluating a performance assessment and presents the process that would be used by staff in reviewing a license application. NUREG-1199 details the necessary components and information needed in a license application for an LLW disposal facility required under Part 61. In both documents, Chapter 6, "Safety Assessment," deals with the technical analyses required to demonstrate compliance with Part 61 performance objectives. Section 6.1, "Release of Radioactivity" (Subsections 6.1.1 - 6.1.5.4) specifically deals with meeting 10 CFR 61.41 requirements and is primarily concerned with performance assessment. However, the performance assessment guidance provided refers to only general issues, and many specific issues or recommended means for resolving them are not addressed.

Chapters 2 ("Site Characteristics") and 3 ("Design and Construction") of NUREGs-1199 and 1200 describe information related to meeting the Part 61 siting and facility design requirements. However, some of the site and design data identified would be used for purposes other than performance assessment, such as for establishing site monitoring networks, or demonstrating operational safety and stability in design. One of the goals of this technical position is to provide a linkage between overall data and design requirements, and specific performance assessment needs, which may not be directly obvious from NUREGs 1199 and 1200.

With respect to quality assurance (QA), 10 CFR 61.12(j) describes the requirements for a QA program, to be included in any potential license application, that are necessary to meet the performance objectives and technical criteria set forth in Part 61. NUREG-0856 (Pittiglio, 1989) provides specific guidance on how to meet the Part 61 requirements.[7] Additional QA guidance for potential applicants is provided in Chapter 9 of NUREGs-1199 and 1200.

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[7] The criteria describe in NUREG-1293 are similar to the criteria contained in Appendix B of 10 CFR Part 50. Although Appendix B to Part 50 is not applicable to NRC's LLW disposal regulation, the criteria it contains are basic to any nuclear regulatory QA program.

3 BRANCH TECHNICAL POSITIONS (WITH DISCUSSION)

It is the staff's position that a potential license applicant should develop and use a defensible methodology to demonstrate LLW disposal facility design compliance with the performance objective set forth in 10 CFR 61.41. In that regard, an example of an acceptable approach is described in Technical Position 3.1. Technical Position 3.2 provides guidance on assessing site conditions, processes and events, and the long-term performance of engineered barriers that need to be considered when demonstrating compliance with 10 CFR 61.41. Technical Position 3.3 describes the staff's views on some general technical issues related to the conduct of a performance assessment that should be considered when analyzing disposal site subsystem components.

3.1 Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41

The activities recommended for an integrated LLW performance assessment are depicted in Figure 3. The process is designed to build confidence in model estimates of LLW disposal site performance by providing a useful decision-making framework for evaluating and defending the appropriateness of data, assumptions, models, and codes used in a performance assessment to demonstrate compliance with the post-closure performance objective of 10 CFR 61.41. Moreover, the staff believes that this process systematically brings together, as a single endeavor, all aspects of site data, facility design, and waste characterization information needed for assessing disposal site performance. If properly implemented, it will direct the applicant, through uncertainty and sensitivity studies, to identify data and assumptions that contribute most to disposal site performance. In successive iterations of this process, additional site data are collected, auxiliary analyses[8] or laboratory modeling are performed, alternative conceptual models are evaluated, and/or modifications to the facility design are made as needed to reduce parameter and model uncertainty. By building confidence in performance assessment results in this fashion, issues concerning model validation are addressed to a reasonable degree. However, because the goal of the LLW performance assessment analysis is intended to develop a supportable demonstration of compliance, *the applicant need only to undertake a depth of analysis and conduct as many iterations as necessary to show that the performance objective has been met*. Thus, the staff expects that the extent to which the recommended process depicted in Figure 3 is followed will be tempered according to the complexities of the LLW disposal system being modeled, uncertainties surrounding system performance, and the estimated risk.

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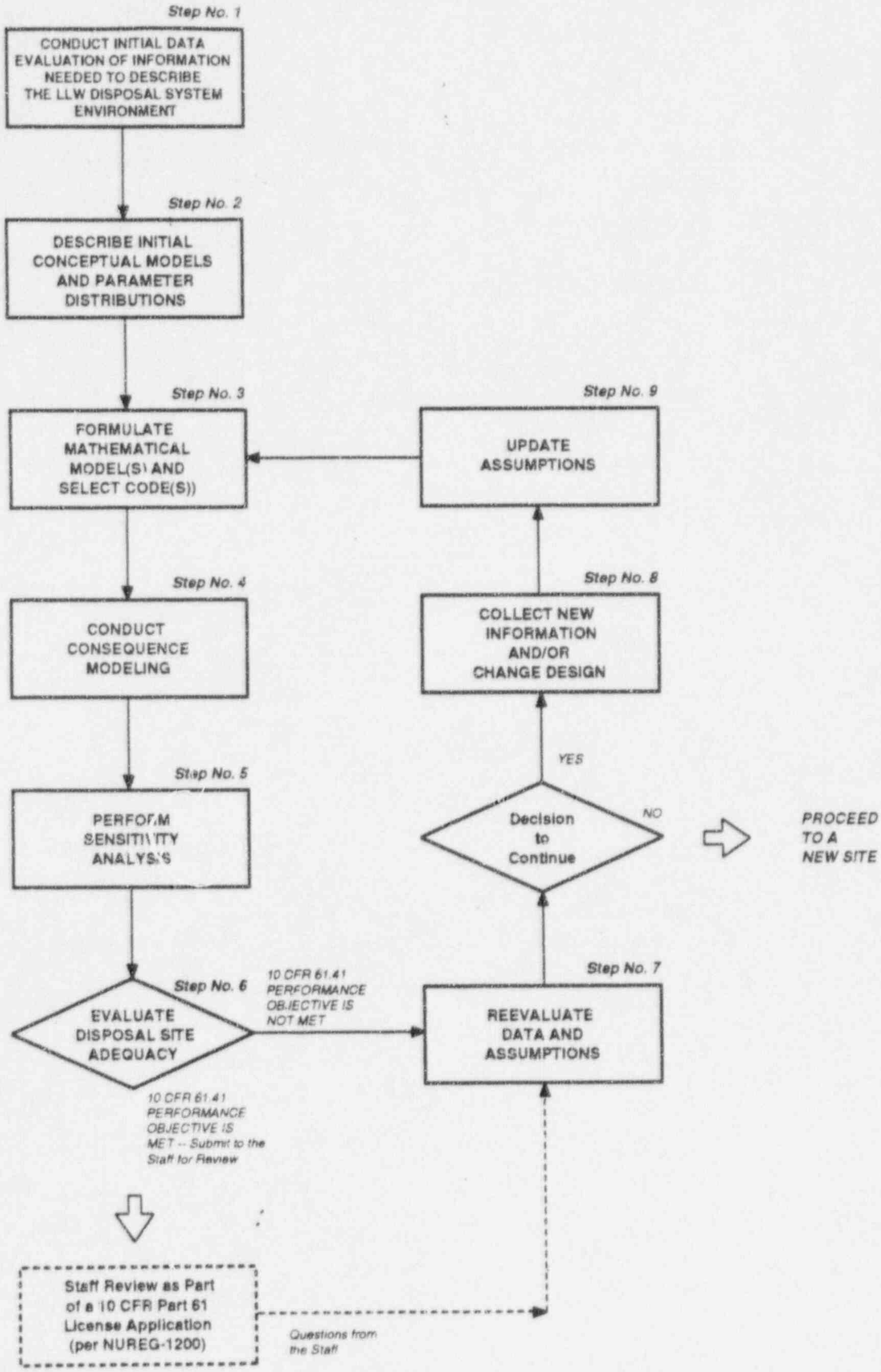
[8] In a number of places in this NUREG, the staff is recommending that auxiliary analyses be conducted as part of the investigations described to examine specific processes and factors that may be important to system performance. Auxiliary analyses support the LLW performance assessment by using more detailed models to: (i) provide greater insight into cause-and-effect relationships; (ii) evaluate conservatism of model assumptions; (iii) evaluate alternate modeling approaches; and/or (iv) interpret field and laboratory data.

Figure 3. **Technical Position 3.1: Detail to the "Example of an Acceptable Process for Demonstrating Compliance with 10 CFR 61.41."** The activities shown by the dotted lines depict the compliance review to be performed by the NRC staff.


Step No. 1
CONDUCT INITIAL DATA EVALUATION OF INFORMATION NEEDED TO DESCRIBE THE LLW DISPOSAL SYSTEM ENVIRONMENT
Step No. 2
DESCRIBE INITIAL CONCEPTUAL MODELS AND PARAMETER DISTRIBUTIONS
Step No. 3
FORMULATE MATHEMATICAL MODEL(S) AND SELECT CODE(S))
Step No. 4
CONDUCT CONSEQUENCE MODELING
Step No. 5
PERFORM SENSITIVITY ANALYSIS
Step No. 6
EVALUATE DISPOSAL SITE ADEQUACY
10 CFR 61.41 PERFORMANCE OBJECTIVE IS NOT MET
10 CFR 61.41 PERFORMANCE OBJECTIVE IS MET -- Submit to the Staff for Review
Staff Review as Part of a 10 CFR Part 61 License Application (per NUREG-1200)
Questions from the Staff
Step No. 7
REEVALUATE DATA AND ASSUMPTIONS
Decision to Continue
YES
NO
PROCEED TO A NEW SITE
Step No. 8
COLLECT NEW INFORMATION AND/OR CHANGE DESIGN
Step No. 9
UPDATE ASSUMPTIONS

The integrated performance assessment process depicted in Figure 3 consists of nine process steps. Certain steps in the process may be performed concurrently, particularly in the initial assessment stages. Steps 1 through 9 are carried out by the applicant, in meeting its responsibility to demonstrate that the LLW disposal facility will comply with the post-closure performance objective in 10 CFR 61.41. These nine steps are discussed below. As noted above, the process is intended to be iterative inasmuch as the applicant should go through this process as many times as necessary to demonstrate compliance. The activities also loop back to the applicant through questions posed by the staff about the performance assessment or disposal site adequacy. Because an overall LLW disposal system performance assessment is composed of subsystem models (i.e., infiltration, source term, transport media, and dose), the following discussions apply, as appropriate, to subsystems' models as well. As noted in Section 2, it should be understood that approaches to site characterization undertaken for meeting non-performance assessment-related regulatory requirements, such as for establishing monitoring networks, are outside the scope of the LLW performance assessment process.

Step No. 1 — Conduct Initial Data Evaluation of Information Needed to Describe the LLW Disposal System Environment

An LLW disposal facility is a complex system comprised of numerous natural and engineered features. The complexity of the system can be further complicated by many different waste species, containers, and forms that may be disposed of in it. Therefore, the first step should be to identify and consider every credible factor or key process that could contribute to effecting a radionuclide release, including changes to the disposal site over time from natural processes and events. In other words, the notion behind this first process step is to develop a complete view of how the disposal system might actually perform, including consideration of possible alternative hypotheses. To be as complete as possible, a multidisciplinary physical/engineering science team approach is recommended. Although this description is primarily qualitative in nature, it should highlight deficiencies in the overall level of knowledge about the disposal site from which to begin the process of evaluating site-specific technical issues and data needs. The disposal site description (and accompanying database) provide the basis for the initial set of site-specific conceptual models appropriate for the mathematical analyses performed later.

At this stage of the process, much of the information used to describe the disposal system will need to be generic. Subjective judgments about the performance of the disposal system — based on information drawn from the fundamental principles of chemistry, physics, geology, and the engineering sciences, and past experience or data from similar sites, precedent, and professional judgment[9] — are also appropriate.

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[9] Professional judgment would be, for example, the technical experts' evaluations and interpretations of some scientific knowledge base, to the extent that the knowledge base exists. Also referred to as *engineering judgment* for the purposes of this NUREG — see Technical Position 3.3.4.6. Also refer to Meyer and Booker (1990, p. 3).

However, reliable information on waste characteristics and amounts, as well as a detailed facility conceptual design, should be available. There should be sufficient site and regional data available to at least describe the general nature of the facility's natural setting. It is important to note that there is always some performance-assessment-relevant information available about all parts of the United States. For instance, geologic maps, regional hydrologic data, and meteorologic statistics are generally available and, in many cases, more detailed information may also be available from other engineering projects. NUREG-1199 (NRC, 1991a) contains detailed guidance on basic data needs, suggested sources for published and unpublished reports, and records of specific information on natural site characteristics.

Step No. 2 — Describe Initial Conceptual Models and Parameter Distributions
The detailed disposal system description, including all initially available data and information (Step No. 1), should next be used to develop site-specific conceptual models. Conceptual model development involves abstracting the system description into a form that can be mathematically modeled. This generally means imposing a number of simplifying assumptions to approximate the behavior of the disposal site while accounting for all of the processes and features judged to be important to site safety. Although clearly not a trivial task, deciding on the necessary level of complexity should be dependent on the purpose of the analysis. For example, initial "screening" assessments may be very simple; however, more realism and complexity will likely be needed as the performance assessment process progresses. The analyst should be able to describe, in words, conceptual model assumptions and their technical bases, including how the models incorporate or account for important disposal site features and processes.

At this initial stage, conceptual models and parameter distributions should be as broad as necessary to reflect the level of uncertainty in the behavior of the system. This does not mean that knowledge about the system is ignored. Conceptual models should include only those assumptions or conditions that cannot be refuted by site information or data, and parameter distributions should assume the broadest ranges possible within the limits of available information. The result is that at this stage of the process, when only sparse or generic data are prevalent for many parts of the analysis, conceptual models and parameters would bound a greater range of possible conditions than would likely be the case when more site-specific information is made available.

Step No. 3 — Formulate Mathematical Model(s) and Select Code(s)
At this stage in the performance assessment process, the analyst formulates mathematical representations of the conceptual models based on site-specific physical and chemical process considerations. The mathematical models may be solved numerically or in the form of analytical approximations. However, representations of conceptual models should not be constrained by the limitations of a particular computer code simply because a code is available or easy to use. This means that the

analyst may have to develop a computer code for the express purpose of evaluating a particular conceptual model. However, it is not expected that this level of effort usually will be necessary, because a large number of computer codes exist that can be used to represent a broad range of potential conceptual models. As when developing conceptual models, the analyst should identify and describe, in words, all assumptions embedded in mathematical models and codes. As noted in NUREG-0856 (Silling, 1983), it is important that codes and databases used in the analysis be properly verified and documented according to a rigorous QA/quality control (QC) program.

Step No. 4 — Conduct Consequence Modeling
The purpose of consequence modeling is to calculate site performance for credible conceptual models. Because uncertainty is inherent in all performance assessment calculations, analysts need to consider how uncertainty associated with the models and parameters translates into uncertainty in consequence modeling. The amount of information and the level of analysis needed for treating uncertainty will vary from facility to facility because of significant differences among site characteristics, engineering designs, and radionuclide inventories. Technical Position 3.3.2 provides a discussion of approaches for addressing uncertainty in compliance demonstrations.

Step No. 5 — Perform Sensitivity Analysis
Sensitivity analysis is performed on the consequence analysis results (Step No. 4) to evaluate which models, assumptions, and combinations of parameters were most significant in producing the resulting doses. Sensitivity analysis allows the analyst to carefully scrutinize what most affects analysis results to: (a) optimize characterization efforts by specifying information to be collected to most reduce uncertainty; (b) better explain and defend the meaning of the performance assessment results; and (c) provide information that assists in the selection of an appropriate approach for the compliance demonstration. (See Technical Position 3.3.2 for additional information.)

Step No. 6 — Evaluate Disposal Site Adequacy
Step No. 6 is a decision point to determine whether the LLW performance objective has been met. The evaluation to take place here should be a simple comparison between the consequence analyses (Step No. 4) and the 10 CFR 61.41 performance objective. If the comparison shows that the performance objective has been met, it would be documented and submitted for review as part of a Part 61 license application. (An important issue relating to the evaluation of site adequacy is to determine what part of the output distribution of doses should not exceed the 10 CFR 61.41 performance objective. This policy issue is addressed in Technical Position 3.2.4.)

If the comparison indicates that the performance objective has not been met, the applicant should proceed to Step No. 7. However, as noted previously, because the goal of the LLW performance assessment analysis is to develop a supportable demonstration of compliance, the applicant need only to undertake a depth of analysis

and conduct as many additional iterations as necessary (Step Nos. 7 through 9) to show that the performance objective has been met. In this regard, the staff expects that the need for additional iterations in the analysis will be tempered according to the complexities of the LLW disposal system being modeled, uncertainties surrounding system performance, and the estimated risk.

Step No. 7 — Reevaluate Data and Assumptions
From the sensitivity studies conducted in Step No. 5, to identify those data and assumptions having the greatest influence over the calculated results (Step No. 6), the analyst may be faced with a number of choices related to how best to reduce uncertainty further in additional performance assessment iterations. Uncertainty may be reduced in any or a combination of several ways including, obtaining new data from additional site investigations, performing adjunct modeling studies with new or existing data, and/or making changes to facility design. Thus, at this stage of the performance assessment process, the analyst should be concerned with how to optimize the allocation of resources for obtaining the information and data needed to reduce uncertainty and demonstrate compliance. Entering into this evaluation would be the relative uncertainties of assumptions and data, the degree that uncertainty was accounted for in the preceding analysis, and the cost of producing more or better data. This has been called "data worth analysis" in decision-making models (Kozak *et al.*, 1993; Bear *et al.*, 1992; and Freeze *et al.*, 1990). If, however, the analyst determines that extensive additional data are needed to continue the process, owing to site complexity or other factors, it may be more cost-effective for the developer to reject the site altogether and proceed to another site.

Step No. 8 — Collect New Information and/or Change Design
Having completed the data worth analysis (in the preceding step), the information identified at this time as being the most beneficial to reducing uncertainty should be gathered. As stated in Step No. 7, above, information developed can be of one type or a combination of several possible types, including site characterization data, changes to facility design, and adjunct modeling studies. Based on the sensitivity studies performed in Step No. 5, any of these sources of new information may significantly affect the subsequent consequence analysis iteration. A developer may, for example: (a) obtain new disposal site data with the goal of eliminating a conceptual model from consideration or narrowing a parameter range; (b) change the facility design to influence how barrier degradation is modeled, or confine problem radionuclides through the addition of special backfills; and/or (c) perform sophisticated modeling of geochemical conditions inside of disposal units, including cement buffering, to lower the source term release.

Step No. 9 — Update Assumptions
Assumptions and conceptual models are modified in this step, based on the new information and/or design changes obtained from performing Step No. 8, above. The principles to be applied in this step are the same as those for the initial data evaluation

and conceptual model development (Steps 1 and 2, above). Subsequent model formulation may involve elimination of a conceptual model, modification of a conceptual model, or introduction of new models, as suggested by additional information. A smaller range of potential outcomes will result when models are updated to reduce uncertainty. As shown by the process flow chart (Figure 3), mathematical representations of the updated models are formulated (Step No. 3) for the next performance assessment iteration. Every successive iteration of the performance assessment should provide a rationale for the goals of the next iteration, such as the evaluation of new information (data) or improved conceptual models. Models, assumptions, and data may not be rejected simply because the analyst does not like the results of the current iteration or believes for insupportable reasons that it is too conservative.

3.2 Staff Views on Policy Issues Regarding 10 CFR Part 61 Performance Objectives and Technical Requirements

Technical policy issues represent fundamental questions pertaining to the interpretation and implementation of specific Part 61 performance objectives and technical requirements. The staff identified five areas in the regulation that pertain to LLW performance assessment and that this supplemental guidance should, therefore, address. These areas are:

- Consideration of future site conditions, processes, and events;
- Performance of engineered barriers;
- Timeframe for LLW performance assessment;
- Treatment of sensitivity and uncertainty in LLW performance assessment; and
- Role of performance assessment during the operational and closure periods.

This guidance is intended to be general and related technical issues will need to be addressed by applicants on a site-specific basis. Guidance on addressing some technical issues as well as on conducting site-specific analyses is set out in Technical Position 3.3.

3.2.1 Role of the Site and Consideration of Site Conditions, Processes, and Events

3.2.1.1 Site Selection

The natural site contributes to overall disposal system performance by providing a stable environment for waste disposal, and by attenuating the movement of radionuclides off-site through environmental transport media (ground water, surface water, and air). The minimum characteristics of an acceptable near-surface LLW disposal site are specified by the site suitability requirements of 10 CFR 61.50. The requirements emphasize site stability, in connection with the longevity engineered barriers; waste isolation, in terms of rates of radionuclide mobilization and transport; and long-term performance, with respect to defensible modeling of future site behavior. The siting requirements in 10 CFR 61.50(a)(9)

and 60.51(a)(10) stipulate the need to avoid sites where the frequency, rate, and extent of geologic processes and events will adversely affect performance of an LLW disposal facility or preclude defensible modeling of long-term performance. The requirements are intended to eliminate, to the extent practicable, areas having characteristics that are known to, or highly likely to, produce problems over the long term (NRC, 1981). This means that sites should be selected where natural processes are occurring at consistent and definable rates, such that performance assessment models will represent both present and anticipated site conditions (NRC, 1982). Thus, a site carefully selected, to reduce uncertainty about its characteristics and behavior, adds to the credibility of performance assessment results.

In choosing a disposal site, 10 CFR 61.7(a)(2) requires that site characteristics should be considered in terms of the indefinite future and evaluated for at least a 500-year timeframe. The 500-year timeframe corresponds to the period when the hazard from moderately high-activity, short- and intermediate-lived radionuclides contained in Classes B and C waste is greatest, and when the ensuing need for achieving long-term stability of engineered features, such as multi-layered covers, concrete vaults, high-integrity waste containers (HICs), stabilized waste forms, and intruder barriers to Class C waste is greatest. The main design function of these engineered features is to limit infiltration of water into the waste so as to minimize leaching of radionuclides into the environment, and to provide protection to an inadvertent intruder. Part 61 requires stability lifetimes on the order of 300 to 500 years for B/C Class waste forms, HICs, and intruder barriers. The timeframe recommended for considering design bases, natural events, or phenomena for engineered barriers is 500 years (NRC, 1982). As discussed in Technical Position 3.2.2 ("Role of Engineered Barriers"), service lives for engineered barriers, on the order of a few hundred years, are considered credible.

Beyond 500 years and into "the indefinite future," the focus of performance is on the continued isolation of long-lived radionuclides in the waste. At this time, the performance of engineered systems can no longer be assumed and reliance must be placed primarily on the site's natural characteristics to continue to limit environmental releases of long-lived radionuclides. In evaluating site suitability, the staff suggests refraining from excessive speculation about the extremely distant future, and recommends limiting evaluations of the natural site's geologic evolution to the next 10,000 years. This 10,000-year timeframe is the time period of regulatory concern recommended by the staff (see Technical Position 3.2.3, "Timeframe for LLW Performance Assessment Analyses"). All significant conditions, processes, and events that are of concern to the ability of the engineered disposal system and natural site to meet the performance objectives need to be considered. However, it is not necessary to demonstrate that siting requirements, primarily intended for achieving stability of engineered barriers, will continue to be met beyond 500 years.

3.2.1.2 Site Conditions in Performance Assessment Models

At the time scale appropriate to assessing LLW disposal, natural site conditions may range from being relatively static to highly dynamic, depending on the influence of processes that are driven by the forces of tectonics and climate. Natural events occurring at a site, which at

times may be catastrophic, are tangible manifestations of these active processes. However, as stated above, Part 61 emphasizes selecting sites based on geologic stability, waste isolation, long-term performance, and defensible modeling. Therefore, it should be possible to develop a set of reasonably anticipated natural conditions, processes, and events to be represented in site conceptual models (e.g., distribution of infiltration to account for variation in rainfall, a service life for concrete which bounds the impact of degradation processes). The overall intent is to discourage excessive speculation about future events and the staff does not intend for analysts to model long-term transient or dynamic site conditions, or to assign probabilities to natural occurrences. In developing this "reference natural setting," changes in vegetation, cycles of drought and precipitation, and erosional and depositional processes should be considered; future events should include those that are known to occur periodically at the site (e.g., storms, floods, and earthquakes). It must be emphasized that the goal of the analysis is not to accurately predict the future but to test the robustness of the disposal facility against a reasonable range of potential outcomes. Accordingly, the parameter ranges and model assumptions selected for the LLW performance assessment should be sufficient to capture the variability in natural conditions, processes, and events.

Consistent with the above, consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influences of human behavior should be limited so as to avoid unnecessary speculation. It is possible that, within some disposal site regions, glaciation or an interglacial rise in sea level could occur in response to changes in global climate. These events are envisaged as broadly disrupting the disposal site region to the extent that the human population would leave affected areas as the ice sheet or shoreline advances. Accordingly, an appropriate assumption under these conditions would be that no individual is living close enough to the facility to receive a meaningful dose. In addition, the hazard from the inventory remaining in typical LLW after about 500 years is expected to be relatively low. The staff believes that an applicant could use similar reasoning to explain how potential effects of glaciation will not render a disposal site unacceptable. Therefore, the staff recommends that new site conditions that may arise directly from significant changes to existing natural conditions, processes, and events do not need to be quantified in LLW performance assessment modeling.

For disposal sites where the impacts of global climate change consist primarily of changes from present-day meteorologic patterns, ascertaining the nature, timing, and magnitude of related meteorological processes and events (i.e., regional consequences) and their effects on disposal site performance is highly uncertain. However, a key aspect of an LLW performance assessment is determining how variations in precipitation result in varying rates of percolation into disposal units and of recharge to the water table. The staff recommends using historical and current weather data, and other site information (e.g., field tests) to establish a broad range of infiltration rates that may be used to simulate both wetter and drier conditions than the current average. Sensitivity analyses performed as part of the LLW performance assessment will provide some insight into the effects that such variations could have on the dose calculations. The staff believes that the treatment of infiltration in this manner will allow an analyst to consider the effects of broad variations in weather, without

the need for speculating on how climate might change.

Given the uncertainty in projecting the site's biological environment beyond relatively short periods of a few hundred years, it is sufficient to assume that current biological trends remain unchanged throughout the period of analyzed performance. Similarly, consideration of societal changes would result in unnecessary speculation and should not be included in performance assessments. With respect to human behavior, it may be assumed that current local land-use practices and other human behaviors continue unchanged throughout the duration of the analysis. For instance, it is reasonable to assume that current local well-drilling techniques and/or water use practices will be followed at all times in the future. Finally, the disruptive actions of an inadvertent intruder do **not** need to be considered when assessing releases of radioactivity off-site.

Assurance about site performance into the far future is also provided by limiting the amounts of long-lived radionuclides that may be disposed of at an LLW disposal facility, including those shown by analysis to be significant only after tens of thousands of years have passed. The effect of placing inventory limits on long-lived radionuclides is to mitigate, given what is foreseeable today, the potential consequences of waste disposal to generations in the distant future. See Technical Position 3.2.3 for a discussion of timeframes for dose calculations in LLW performance assessments and inventory limits on long-lived radionuclides.

3.2.2 Role of Engineered Barriers

The term engineered barrier as defined in Section 61.2 means "... a man-made structure or device that is intended to improve the land disposal facility's ability to meet the performance objectives in Subpart C...." As such, engineered barriers are usually designed to inhibit water from contacting waste, limit release of radionuclides from disposal units, or mitigate doses to potential human intruders. Materials composing engineered barriers may range from purely synthetic membranes to natural soils that are reconfigured to impart some characteristic or property enabling it to perform as an engineered barrier. Examples of engineered barriers are surface drainage systems and cover systems. Both types of barriers improve performance by limiting the amount of water that can contact disposed of waste. Features to include as engineered barriers, and how they should be designed are site-specific decisions left to the discretion of the disposal facility developer. Although engineered barriers may be used to improve facility performance, it is nonetheless expected that the disposal characteristics of the site itself will meet the suitability requirements of 10 CFR 61.50.

The FEIS for Part 61 (NRC, 1982) clearly recognized that in time a disposal site's natural characteristics must be relied on to isolate waste. A later study of LLW disposed of in the United States from 1987 through 1989 (Roles, 1990) shows that although most of the activity in initial waste inventories resides in Class C waste, Class A waste contains the largest quantity of long-lived radionuclides (radionuclides with half-lives greater than 100 years). This means that within about 1000 years after disposal, the higher-activity short- and intermediate-lived radionuclides of B/C Class waste will have decayed to the point where

most of the remaining activity will be from Class A waste. The remaining radionuclides in Class A waste will have such long half lives that it is unreasonable to assume that any physical barrier can be designed to function long enough to influence, through radioactive decay, the amount of long-lived radionuclides eventually available for release.

The staff studied the longevity of natural and man-made constituents (concrete, plastics, soils, etc.) of engineered barrier types currently being proposed for near-surface LLW disposal facilities. Available information and performance records on some of these materials are limited and there are large uncertainties about how natural processes and events may affect engineered barrier performance. The staff concluded that some constituent materials of engineered barriers are likely to remain physically distinct and structurally stable long after 500 years. However, given natural forces likely to cause unavoidable and unpredictable deterioration of engineered barriers, no compelling evidence was found to suggest that engineered barriers will perform at design levels past 500 years. For example, the integrity of soil covers will ultimately be compromised by penetrating tree roots and burrowing animals, and reinforced concrete structures are subject to localized cracking or opening along joints followed by partial disintegration of concrete sections.

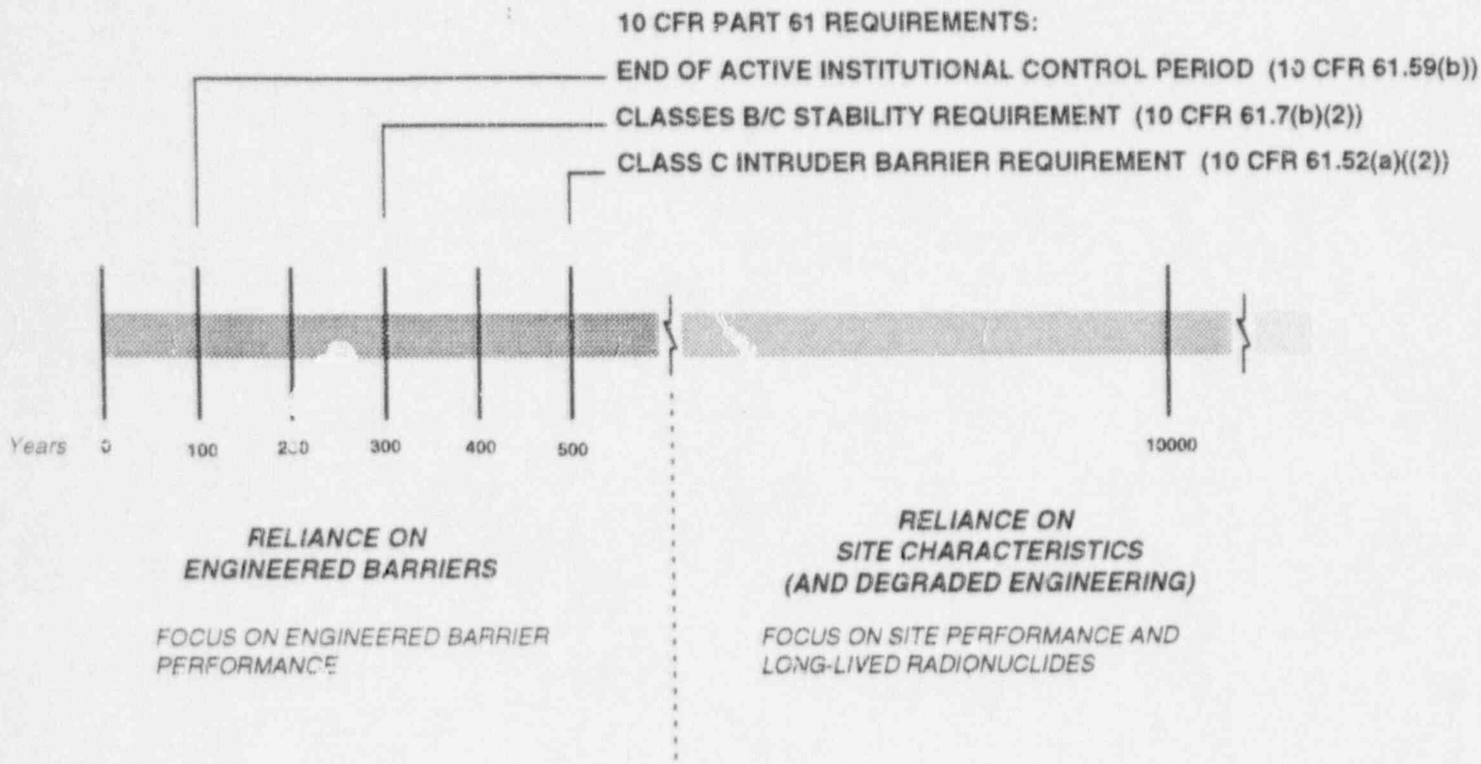
The staff recommends that an applicant should assume that engineered barriers have physically degraded after 500 years following site closure. In the degraded condition, an engineered barrier (e.g., concrete vault, engineered subsurface drainage system, etc.) can still perform a function, but the function would be established based on the assumed properties of its constituent materials. Any period of time claimed for performance of engineered barriers, including periods exceeding 500 years, should be supported by suitable information and justification evaluated on a case-by-case basis. For example, considering site conditions, it may be assumed that the barriers will maintain their structural stability and chemical buffering capacity periods considerably longer than 500 years. Credit may be taken for redundant engineered systems if it can be demonstrated that they perform sequentially. Otherwise, individual barrier performance should be assumed as being concurrent with the performance of other barriers. Technical Position 3.3.4 ("Engineered Barriers") provides a detailed discussion on modeling physical behavior of engineered barriers from their intended design condition through complete degradation. Analyses of several other site and design engineering issues related to meeting the long-term stability requirements of 10 CFR 61.44 (i.e., surface drainage and erosion protection, stability of cover slopes, and settlement and subsidence) are typically evaluated independently of performance assessment.

3.2.3 Timeframe for LLW Performance Assessment Analyses

The staff recommends a time period of 10,000 years for analyzing performance with respect to 10 CFR 61.41. In specifying the timeframe of regulatory interest, the staff considered several issues related to the nature of LLW and how engineered barriers and the site contribute to isolating radionuclides from the general environment. Figure 4 depicts the timeframes of importance to performance assessment of LLW disposal facilities.

Part 61 specifies compliance times for particular aspects of LLW disposal — B/C Class

Figure 4. Timeframes to be considered in an LLW performance assessment. (Adopted from NRC (1989, p. 2c).)


10 CFR PART 61 REQUIREMENTS:
END OF ACTIVE INSTITUTIONAL CONTROL PERIOD (10 CFR 61.59(b))
CLASSES B/C STABILITY REQUIREMENT (10 CFR 61.7(b)(2))
CLASS C INTRUDER BARRIER REQUIREMENT (10 CFR 61.52(a)((2))
Years
0
100
200
300
400
500
10000
RELIANCE ON ENGINEERED BARRIERS
FOCUS ON ENGINEERED BARRIER PERFORMANCE
RELIANCE ON SITE CHARACTERISTICS (AND DEGRADED ENGINEERING)
FOCUS ON SITE PERFORMANCE AND LONG-LIVED RADIONUCLIDES

waste form stability is required for 300 years; intruder barriers must last 500 years; and site characteristics are to be evaluated for a minimum of 500 years. However, the regulation does not specify a time of compliance for meeting the overall performance objective of 10 CFR 61.41. Disposal site performance is determined by activity, half-life, and mobility of radionuclides in the waste inventory; and processes and conditions that control engineered barrier degradation, water infiltration and leaching of waste, and release and transport of radionuclides to the general environment. The objective of specifying a regulatory timeframe is to ensure that all these determinants are fully evaluated with respect to achieving compliance with the performance objective. If the timeframe is too short, the performance objective could be met primarily through reliance on engineered barriers and site performance would not be adequately evaluated. On the other hand, strict application of the performance objective, for an extremely long compliance period, may not be meaningful given the amount of long-lived radioactivity in typical LLW and the uncertainties inherently associated with the analysis.

Mobile radionuclides in LLW — ^{14}C, ^{36}Cl, ^{99}Tc, and ^{129}I — have half-lives greatly exceeding the time when engineered barriers can reasonably be relied on to isolate waste from the environment. In addition, immobile uranium is being disposed of as LLW in quantities exceeding what was considered in the Part 61 DEIS (NRC, 1981). The dose potential from the progenies of uranium decay is significantly higher than that of uranium, and the concentrations of the progenies increase continuously until equilibrium with the parent uranium is established after 1 to 2 million years. Because analyses of total system performance are sensitive to uncertain site-specific disposal parameters (e.g., degradation rates of engineered barriers and estimates of geochemical retardation in soils), order-of-magnitude uncertainties in the time of peak dose, at off-site receptor points, are possible. Manipulation of these variables within relatively conservative ranges can readily shift the calculated peak dose beyond a specified period of time without having to account for a substantial inventory of long-lived activity.

Through its LLW performance assessment test-case calculations for a humid site,[10] the staff has some useful insights into this issue. Twenty-thousand years constituted a typical calculation time, but some calculations were carried out to 100,000 years, to include the transport of radionuclides with relatively large retardation coefficients and the ingrowth of uranium daughter products, principally radium-226 (^{226}Ra). The test-case simulations show that for most radionuclides, the magnitude of the peak dose decreases with the time at which the peak occurs (i.e., for a particular radionuclide the peak dose will be reduced as the time of the peak is delayed). This is caused by the combined effects of dispersion in the ground-water system, radionuclide decay, and depletion of the inventory. In addition, the test-case simulations confirm that mobile long-lived radionuclides (e.g., ^{14}C, ^{36}Cl, ^{99}Tc, and ^{129}I) tend to bound the peak doses for other radionuclides in LLW. Thus, a time of compliance that is sufficiently long to capture the peaks from the more mobile long-lived radionuclides (i.e.,

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[10] Currently being documented by the staff.

10,000 years) will tend to bound the potential doses at longer timeframes ($>$10,000 years). However, specific exceptions include: (a) ingrowth of daughter products from large inventories of uranium ($> \sim 3.7 \times 10^{13}$Bq [$> \sim 1000$ Ci]); and (b) peak doses at humid sites from large inventories of lonr-lived transuranics.

The staff believes that a period of 10,000 years is sufficiently long to: (a) evaluate performance of both engineered barriers and the site; (b) capture the peak doses from the most mobile long-lived radionuclides; : nd (c) bound the potential peak doses at longer times. In examining shorter periods, such as the 1000 years being used for decommissioning facilities, it should be recognized that at facilities undergoing decommissioning, the number and quantity of long-lived radionuclides of concern are generally limited and the parameters controlling their mobility less uncertain. The release of radionuclides also will not be delayed for hundreds of years by the presence of engineered barriers. Should analyses indicate failure to meet the performance objective is due to a release of a long-lived radionuclide(s), a 10,000-year period is generally sufficient for setting a site-specific inventory limit for that radionuclide, under 10 CFR 61.7(b)(2). Generic inventory limits for protection of individuals off-site, analogous to the waste classification system for intruder protection, are not provided in the rule because of the site-specific nature of radionuclide migration in ground water. The technical analysis done in the Part 61 DEIS (NRC, 1981; p. 5-73) identified ^{3}H and three long-lived radionuclides of particular concern for migration in ground water (^{14}C, ^{99}Tc, and ^{129}I), but others may also be important, depending on the particular radionuclides that are projected to be in the inventory.

However, it should be noted that for performance assessments carried out beyond 10,000 years, it may be necessary to ensure that the disposal of certain types of waste will not result in markedly high doses to individuals living at any time in the future. Potentially high doses relative to the performance objective could occur within a timeframe longer than 10,000 years, from disposing of large quantities of uranium or transuranics, or possibly by mobile long-lived radionuclides at arid sites with long ground-water travel times. If at 10,000 years, a radionuclide shows evidence of breakthrough below a peak, the calculation should be continued, assuming the same set of conditions, processes, and events considered significant over the initial 10,000 years, until the radionuclide's peak dose is reached regardless of when that occurs. For example, an uranium-238 (^{238}U) inventory resulting in a ^{226}Ra dose at 10,000 years may indicate a potential ^{226}Ra dose in excess of the performance objective beyond 10,000 years. The staff recommends that assessments beyond 10,000 years not be used for determining regulatory compliance with the performance objective. However, as a basis for making judgments about the magnitude of the estimated dose relative to the performance objective and its time of occurrence beyond the regulatory compliance period, such assessments may provide an important contribution to the site environmental evaluation. If, after considering the magnitude and time of the dose, and associated uncertainty, the regulatory authority decides that the dose is unacceptably high, either inventory limits would have to be imposed or the problem waste is not suitable for disposal as LLW at the site. However, for typical LLW disposal site inventories, staff does not expect doses from long-

lived radionuclides at any time to exceed 1 mSv *total effective dose equivalent*[11] (TEDE).

3.2.4 Treatment of Sensitivity and Uncertainty in LLW Performance Assessment

The objective of the LLW performance assessment is to quantitatively estimate disposal system performance for comparison with the performance objective in 10 CFR 61.41. Uncertainty is inherent in all LLW performance assessment calculations and regulatory decision-makers need to consider how uncertainties within the analysis translate into uncertainty in estimates of performance. Uncertainties in the assessment may be classified as: (a) *parameter uncertainty*; and/or (b) *model uncertainty*. Although this classification is neither precise nor exhaustive, it facilitates discussion of uncertainties related to estimated performance of an LLW disposal facility over long periods of time. *Parameter uncertainty* describes the variability of physicochemical properties over spatial scales of interest and the incomplete knowledge of the natural system because of necessarily sparse measurement. Parameter uncertainty is expected to be described by distributions of variables, such as hydraulic conductivity, porosity, or the retardation coefficient. *Model uncertainty* describes the limited knowledge inherent in applying predictive models (a) over long periods of time for which direct validation is precluded and (b) to complex systems for which measurement and characterization are limited. These uncertainties are expected to be described: (a) by consideration of reasonable range of fundamental conditions, processes, or events to test the robustness of the facility; and (b) by distributions of parameters describing the manifestations of these conditions, processes, or events. Therefore, analysis of these model uncertainties may involve evaluation of the variation in parameters and/or the use of different conceptual models. For example, variation of the parameter used for estimating the degradation rate of a disposal unit cover could also be used to represent uncertainty in the degradation of the engineered materials of the cover in the environment because of uncertain conditions, processes, and events (e.g., erosion, freeze-thaw action, tree root penetration, etc.). Although some model uncertainty may be parameterized, performance estimates based on a reasonable range of the alternative models considered may be more applicable for particular modeling approaches (e.g., consideration of the uncertainties of chemical buffering of a cementitious waste form on solubility limits may require comparison of analyses which use chemical buffering with analyses which do not use chemical buffering rather than an analysis which varies the solubility limits over a range of values that encompasses chemical buffering to no buffering).

3.2.4.1 Role of Sensitivity and Uncertainty Analyses

Sensitivity and uncertainty analyses, integral parts of the LLW performance assessment

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[11] As per 10 CFR Part 20 (see Appendix B for a discussion of Table 2), non-stochastic organ-specific limits are not necessary when using the Part 20 dose methodology because "...non-stochastic effects are presumed not to occur at the dose levels established for individual members of the public...." (International Commission on Radiation Protection (ICRP), 1979) In addition, in the ICRP 30 dose methodology, human organs have been assigned weighting factors, based on the risks of stochastic effects to the organ, to evaluate the calculated committed dose equivalent to an organ with a value of *committed effective dose equivalent* (CEDE) that represents the same risk of stochastic effects to the whole body.

process, are often used to assist in interpreting results and to optimize strategies for building confidence in compliance demonstrations. Sensitivity analysis is used in identifying parameters and assumptions that have the largest effect on the model result. The insights from this analysis can be used to assist in developing and refining LLW performance assessment models and approaches. Zimmerman (1990) identified that sensitivity analysis results can be used to justify the use of a simple model as a surrogate for a more complex model without loss of important detail, define priorities for data acquisition, and reduce the number of parameters for the uncertainty analysis.

Uncertainty analysis provides a tool for understanding and explaining the influence or impact of the assumptions and parametric values on the variability of the quantitative estimate of performance. An uncertainty analysis propagates the uncertainty in model inputs and assumptions through the analysis to the output. Model output can then be displayed in a variety of ways such as scatter plots, histograms, or cumulative distribution functions, to graphically display the effect of input uncertainty on model output (performance measure). Additionally, statistical attributes of output distributions such as mean, median, and variance can be evaluated to provide the analyst with quantitative measures for the influence of uncertainty on system performance.

Insights gained from sensitivity and uncertainty analysis assist both the staff, as the regulating body, and potential applicants. An applicant can use these insights to optimize resources and focus on supporting approaches/assumptions that are key to the compliance calculation.

3.2.4.2 Recommended Approaches for Sensitivity and Uncertainty Analyses

Because LLW performance assessment analyses for any particular site may involve a spectrum of models of differing complexity, the most appropriate methods for evaluating sensitivity and uncertainty need to be tailored to the complexity of the analysis and the nature of the uncertainties being analyzed. Early in the performance assessment process, sensitivity analysis can provide valuable insights to assist further model development and data collection. The staff recommends that sensitivity analysis be conducted to identify the conceptual models and parametric values that most influence the performance calculation. A variety of approaches can be used to identify key sensitivities in the LLW performance assessment analysis, including: (a) calculations in which one parameter related to a single feature or process (i.e., cover performance, source term, or ground-water flow) is varied over a reasonable range of values while holding all other parameters constant; (b) calculations in which many parameters are varied simultaneously over a reasonable range of values; and (c) calculations considering multiple conceptual models. Sensitivity analysis results should be used to help explain and ensure how conceptual models and parameter values provide a reasonable test of the robustness of the facility, and to help select an appropriate approach for analyzing uncertainty in the context of the compliance demonstration.

The staff has considered a range of different approaches for evaluating uncertainty in LLW performance calculations. On one end of the spectrum is a *deterministic estimate* of system

performance that clearly and demonstrably bounds the potential doses and on the other end is a *probabilistic approach* which quantitatively depicts system performance as a distribution of potential outcomes based on variation in models and parameters. For example, a bounding analysis relies predominantly on very long transport times in the unsaturated zone (typical of some arid environments). It may focus on site characterization and infiltration tests to understand and bound uncertainty associated with infiltration rates and unsaturated zone properties, for use in calculating a single, *deterministic estimate* of performance. In contrast, an analysis that relies on the combined performance of a number of facility attributes such as long-term performance of multi-layer covers and concrete vaults, diffusional release of radionuclides from cement waste forms, and solubility limits and retardation factors (as may be typical in some humid environments), may need to use a *probabilistic approach* to quantify the uncertainty in system performance. In this latter case, the applicant may decide to reduce the uncertainty associated with a conceptual model or parameter range by further site characterization activities, engineering design enhancements, and modeling improvements. (Note: Probabilistic approaches encompass a wide range of analysis techniques and methods. For this technical position, probabilistic approach refers to the use of a formal, systematic uncertainty analysis to quantify the uncertainty in performance estimates because of uncertainty in models and parameters. Assigning probabilities to scenarios, which is characteristic of some probabilistic approaches, is **not** recommended for LLW performance assessments.)

In any approach, it is essential that the applicant present a reasonable, comprehensive, and persuasive understanding of the disposal system performance and provide interpretation of the results consistent with that understanding. The applicant needs to support the rationale for the analysis and the basis supporting the uncertainties considered and not considered in the LLW performance assessment.

3.2.4.3 Compliance Determination

Variations in approaches for demonstrating compliance with the LLW performance objectives require appropriate flexibility in the selected approach for determining compliance. The staff has considered compliance determination approaches appropriate for deterministic (characterized by a single estimate for performance) and probabilistic (characterized by a distribution of potential outcomes of system performance) analyses based on distributions of input.

For a deterministic approach to LLW performance assessment, the applicant should provide a single estimate of performance that is believed to bound performance. Dependability of this type of analysis requires the applicant to demonstrate that the performance assessment models and parameters are bounding, especially with respect to any key uncertainties in the analysis. The applicant is relying on the bounding nature of the analysis, rather than a quantitative analysis of uncertainty. A single estimate of performance does not provide insight into the quantitative margin of safety provided by the bounding analysis. Therefore, a single, deterministic estimate of performance should be at or below the performance objective defined in 10 CFR 61.41.

For a probabilistic approach to LLW performance assessment, the applicant should conduct a formal uncertainty analysis and provide a distribution of potential outcomes for system performance. This type of assessment, which relies on more realistic estimates of performance for multiple system components, should be supported by a demonstration by the applicant that justifies the representation of the uncertainty (defendable parameter ranges, appropriate random selection, and combination of parameters, etc.). The staff considered a number of aspects of the analysis to gain insight into appropriate measures for determining compliance based on a distribution of results. The *mean value* of the distribution, as a representation of the central tendency of system performance or the "best model estimate" of performance, was considered the most reliable statistic of the distribution and therefore a logical choice for the point for compliance determination. The staff also considered a need for more assurance that the performance objective in 10 CFR 61.41 would not be exceeded than is provided by the mean of the distribution. The approach to LLW performance assessment modeling discussed in this guidance is designed to ensure that the model results provide a conservative bias compared with actual disposal system and site performance. Therefore, the staff recommends that the mean of the distribution be less than the performance objective and the 95th percentile of the distribution be less than 1 mSv (100 mrem TEDE) to consider a facility in compliance with the performance objective in 10 CFR 61.41.

3.2.5 Role of LLW Performance Assessment during Operational and Closure Periods

As noted in Section 2, 10 CFR 61.28(a) requires that the final revision to site closure plans should contain any additional geologic, hydrologic, or other disposal site data obtained during the operational period pertinent to the long-term containment of waste, and the results of tests, experiments, or analyses pertaining to long-term containment of waste. Site closure will be authorized if the final site closure plan provides reasonable assurance of the long-term safety of the facility. One way to address the site closure requirements is to update the performance assessment with new information that may bring into question the parameters or model assumptions of earlier assessments. For instance, the as-built permeability of concrete or the performance of the engineered covers may be tested to ensure that the performance assessment assumptions remain conservative relative to an as-built facility.

3.3 RECOMMENDED APPROACHES TO LLW PERFORMANCE ASSESSMENT MODELING ISSUES

3.3.1 Introduction

The NRC PAM, introduced in Section 1.4, provides a basic set of component models and analytical approaches for conducting LLW performance assessments. Although the conceptual models and related uncertainties documented in the PAM have not changed, the analytical approaches recommended (i.e. technical positions) in the following pages have evolved from staff and NRC contractor insights obtained from applying the PAM to a site-specific test case problem. Consistent with the overall structure of the PAM, the technical positions in this section of the guidance includes suggested analytical approaches for each of the recommended system components and/or processes. These modeling areas (and the staff's corresponding technical positions) are as follows:

- Uncertainty and Sensitivity Analysis: *Technical Position 3.3.2*
- Infiltration and unsaturated zone flow: *Technical Position 3.3.3*
- Engineered barrier performance (coupled with infiltration analysis to calculate the water flux into disposal units): *Technical Position 3.3.4*
- Radionuclide releases from waste forms and disposal units: *Technical Position 3.3.5*
- Transport media — ground water, surface water, and air: *Technical Position 3.3.6*
- Plant and animal uptake: *Technical Position 3.3.7*
- Dose to humans: *Technical Position 3.3.7*

Because understanding and addressing uncertainty are vital to the supporting basis of any compliance demonstration, guidance on approaches for treating uncertainty and for performing parametric sensitive analyses is included in Technical Position 3.3.2. This guidance identifies the various sources of uncertainty within LLW performance assessment analyses and discusses how these uncertainties should be addressed and translated by the analyst into uncertainty about decisions on regulatory compliance. Because there is no "best" approach to demonstrating compliance, the recommended guidance is flexible to include a simple, bounding deterministic as well as a more complex, probabilistic approach to uncertainty as warranted by specific disposal site conditions.

To implement the PAM, the staff has found that it is necessary to develop a proper method of integrating the multiple computer codes used to analyze the respective subsystem models. It is possible to step through the PAM manually, where analysts submit input to one subsystem module based on the results (output) of another. This approach enables the output of individual subsystem codes to be critically reviewed before its use as input to subsequent

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subsystem codes. At the other extreme is a purely automated approach in which computer codes (in the form of a "system manager") are used to run (execute) the various subsystem computer codes in the proper sequences and thereby permit the extraction of relevant output automatically as input to succeeding subsystem modules without the benefit of any type of review. Intermediate approaches might automate the process to a lesser degree, for example, by using a program to extract relevant code output and process it as usable input to a specific subsystem code that the analyst then runs manually. However, regardless of the method of model integration used, the staff believes that it is important for analysts to have the ability to scrutinize and thereby understand the intermediate model results during any phase of an LLW performance assessment (i.e., Technical Position 3.1) and to understand the relationship of the results to the overall analysis, and to analyze parameter uncertainty and sensitivities.

For working the performance assessment test case problem, the staff developed an overall "systems" code to automate the execution of the individual subsystem modules (and computer codes) as well as their linkages. Developing the systems code resulted in a considerable amount of problem-dependent computer code that had to be written. However, the code enabled the staff to efficiently run the multiple model realizations needed for analyzing parameter uncertainty probabilistically. Generally, the benefits derived from automating the PAM over linking and running subsystem codes manually appear to be significant and include:

(a) Greatly enhanced ability to step through successive iterations of the performance assessment process described in Technical Position 3.1 (see Figure 3), thereby making uncertainty analyses and assessing sensitivity and robustness of the system much easier;

(b) Most likely, obtainment of a higher degree of QA;

(c) Explicit recognition of assumptions that might be vague or addressed inconsistently; and

(d) Better assurance that parameters and values are consistent among subsystem models.

Although specific models and computer codes may be discussed or referenced in the guidance to follow, NRC does not endorse the use of any particular models and/or codes for an LLW performance assessment. Moreover, as noted in Section 2.1, it is important for potential applicants to have established a rigorous QA program at the beginning of the performance assessment process, and to provide an appropriate technical basis (e.g., justification and documentation) regarding the particular models and/or computer codes used in the analysis.

Finally, to better understand the approaches to the issues described in the following technical positions, the reader should be familiar with the staff's positions on the policy issues described in Technical Position 3.2.

3.3.2 Uncertainty and Sensitivity Analysis

Uncertainty is inherent in all performance assessments and regulatory decision-makers need to consider how uncertainties within the analysis translate into uncertainty in modeling results used to measure performance. The amount of information and level of analysis needed for treating uncertainty will vary from facility to facility because of significant differences among their site characteristics, engineering designs, and radionuclide inventories. To accommodate these differences, flexibility in analyzing uncertainty is necessary. Technical Position 3.2.4 discusses the role of sensitivity and uncertainty analysis in performance assessment and presents two possible approaches for treating uncertainty. One approach provides a single bounding estimate of system performance supported by data and assumptions that clearly demonstrate the conservative nature of the analysis. The other approach provides a quantitative evaluation of uncertainty and its impact on system performance represented by a distribution of potential outcomes. This "probabilistic" approach will likely involve more calculational effort than will the bounding "deterministic" approach, and should be used in complex situations where a single estimate of performance is difficult to defend. Regardless of the particular approach used, the supporting basis for demonstrating compliance should include an uncertainty analysis.

3.3.2.1 Sources of Uncertainty

Distinct sources of uncertainty in performance assessment modeling include: (a) uncertainty regarding abstracting a real system and its evolution into a form that can be mathematically modeled (i.e., model uncertainty); and (b) uncertainty, in the data, parameters, and coefficients used in the models (i.e., parameter uncertainty) (see Kozak *et al.*, 1993; and Davis *et al.*, 1990).

3.3.2.1.1 Model Uncertainty

Model uncertainty results from limitations in models used to represent complex system behavior, including the system's evolution (future site conditions, processes, and events), for a specific site and engineering design. This includes uncertainty about the interpretation and use of data (e.g., parameter variability in space and time), and assumptions about system dimensionality, isotropy, and initial boundary conditions (Kozak *et al.*, 1993). Although model uncertainty may be difficult to quantify in a rigorous numerical fashion, these sources of uncertainty may be significant and should not be neglected in the analysis.

Treating model uncertainty requires making credible assumptions about likely processes and events, and expressing them through selection of appropriate conceptual models and input variables. Although system and subsystem models are designed to be "reasonably conservative" or "conservative, yet realistic," credible alternative models may be possible given: (a) limitations in available site data; (b) ambiguities in interpreting site features; and (c) inadequacies in understanding processes (e.g., physical, chemical, geologic, and meteorologic) relevant to long-term performance of engineered barriers and the site. When evaluating model uncertainty, it may be preferable to quantify performance using multiple alternative models, and choose the most conservative conceptual model for demonstrating compliance. However, the evaluation should be performed in the context of providing a

reasonable range of potential outcomes — incredible events, highly unlikely combinations of parameters, and unreasonable modeling assumptions should not be used. Additionally, it is important to recognize that the assumed future state of the system is not intended to correspond to all possible future site conditions, but is intended to test the robustness of the facility against a reasonable range of potential outcomes.

3.3.2.1.2 Parameter Uncertainty

Parameter uncertainty is connected with the data, parameters, and coefficients used in mathematical models and computer codes. This uncertainty originates from a number of sources, including: uncertainty associated with laboratory and field measurements (e.g., standard error in analytical techniques, sampling bias errors, etc.); uncertainty in determining parameter and coefficient values used in a model (e.g., assumptions used to determine degradation rates of engineered barriers); and uncertainty associated with the intrinsic heterogeneity of natural systems (e.g., spatial variability of measured hydraulic conductivities and distribution coefficients within a geologic unit, variability of source term release rates).

Parameter uncertainty is more readily quantified than model uncertainty. There are numerous approaches for dealing with data, parameter, and coefficient uncertainty (see Maheras and Kotecki, 1990; Zimmerman *et al.*, 1990; and Peck *et al.*, 1988); all involve some degree of quantitative treatment. The main types of approaches for treating parameter uncertainty quantitatively are: (a) analytical methods, including stochastic approaches; and (b) Monte Carlo methods, which include random and Latin Hypercube Sampling (LHS) techniques (Iman and Shortencarier, 1984). For these probabilistic approaches, ranges and/or distribution functions should be specified for the data, parameters, and coefficients.

3.3.2.2 Issues

The sophistication of the compliance calculation depends on facility-specific characteristics such as: inventory and waste form characteristics; infiltration rates; engineered barriers; and hydrogeologic properties of the site. Questions that should be addressed before selecting an approach for demonstrating compliance are:

- What are the key uncertainties?
- What are the key sensitivities?
- Is a simple, deterministic approach justified?
- If needed, what is the most appropriate method for quantitatively evaluating uncertainty?

There are no simple generic answers to these questions. They should be addressed at the initial stages of the LLW performance assessment process by identifying and evaluating the strengths and weaknesses of facility attributes relative to possible approaches for measuring performance.

3.3.2.3 Recommended Approach

There is no "best" approach for measuring the performance of a LLW disposal facility. Selection of an appropriate approach needs to begin with developing a general understanding of how the facility will perform by conducting systematic evaluation to identify important facility attributes and their relationship to performance. This initial analysis should be used to probe assumptions and uncertainties to determine the sensitivity to facility performance. The staff recommends using simple approaches that encourage broad examination of uncertainties (parameter and model) including an evaluation of the degree to which the uncertainties should be addressed and represented in assessment results. Although simple approaches are envisioned, it is anticipated that alternative models as well as parameter variations should be used to provide sufficient information to determine whether a probabilistic or deterministic approach is a more appropriate measure of performance.

3.3.2.3.1 Deterministic Analysis

Single estimates of performance often can be evaluated easily, but the selection of appropriate models and parameter values may be difficult. (The staff positions on policy issues (Technical Position 3.2) provide key guidance on what is and is not expected in developing models and parameter values.) When performance is measured against a single estimate, uncertainty is addressed by providing reasonable assurance that this estimate conservatively bounds performance. Given the uncertainties inherent in an LLW performance assessment, it is expected that bounding analyses will use simple modeling approaches, assumptions, and parameters that readily can be demonstrated as being conservative.

One approach would be to use bounding values in key areas of performance such as the amount of water entering the disposal units, release of radionuclides from disposal units, transport to receptor locations, and dilution of radionuclides within exposure pathway. Although it is not required that the bounding analysis use the most conservative values for all parameters and the most conservative models, a demonstrably conservative or bounding analysis should not make use of parameters and models that cannot readily be shown as leading to conservative results. Although the bounding analysis is expected to be a simple calculation involving a limited number of parameters and simple models, the support necessary to defend a bounding analysis will vary based on the characteristics of the facility and the nature of the analysis.

For example, at a facility relying on small releases and slow transport in the unsaturated zone (typical of some arid environments), site characterization and infiltration tests could be performed to understand and bound uncertainty associated with infiltration rates and unsaturated zone properties. This site information could be used to select a conservative infiltration rate and radionuclide solubility limits that, when combined with appropriate models for radionuclide transport and uptake, can be shown to provide a single conservative estimate of performance. At a different facility, where reliance may be placed on having a design with significant amounts of cementitious material to create a high pH environment lasting long periods of time, geochemical experiments could be performed to understand and

bound uncertainty associated with near-field solubility limits. Again, this information could be used to select conservative near-field radionuclide solubility limits for transport models to provide a single conservative estimate of performance.

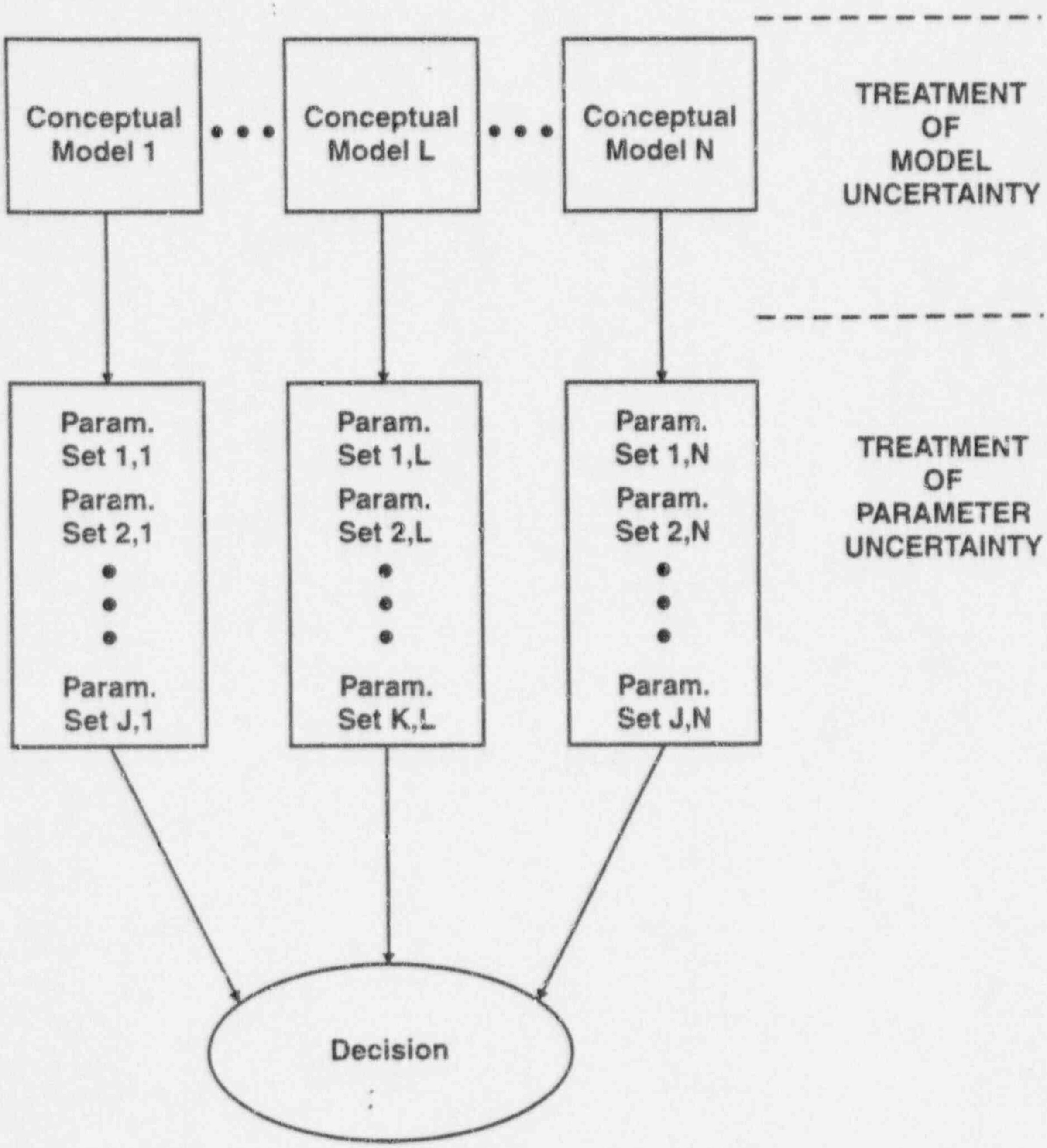
3.3.2.3.2 Probabilistic Analysis[12]

Simple, bounding analyses may not always be an appropriate measure because of the need to rely on conservatism in the analysis as a replacement for quantitatively evaluating uncertainty. As the complexity of the analysis and the number of parameters increase, it becomes very difficult to select a defensible single estimate of performance. An alternative approach is to develop more sophisticated models and more realistic parameter ranges that more explicitly quantify the uncertainty in performance estimates. In contrast to what may be appropriate for simple deterministic approaches, understanding the uncertainty associated with the results from more sophisticated models may require more sophisticated approaches for analyzing the uncertainty in results of the assessment. A formal, systematic uncertainty analysis (characteristic of probabilistic approaches) provides a tool to probe the conceptual models and parametric values, and furnishes a foundation for understanding and explaining the influence or impact of the assumptions and parametric values on the calculation of consequences.

The representation of parameter uncertainty is perhaps the most easily and commonly analyzed uncertainty. Parameter uncertainty is often evaluated using a Monte Carlo analysis or LHS where the input variables representing parameter uncertainty and the output of the model(s) are in the form of distribution functions (see Davis *et al.*, 1990). An output distribution is produced by evaluating the performance many times, using sets of input values based on random or Monte Carlo sampling of the input distributions. This approach is shown conceptually in Figure 5. This type of formal approach, however, does not necessarily require extreme amounts of site-specific data to specify parameter distributions. The specification of the parameter distribution should reflect the knowledge of the parameter or "degree of belief" rather than concentrate on rigorous statistical efforts to determine distributions. Precisely defined distribution functions may not provide significantly better insights than can be obtained using distributions that are selected using qualitative means such as expert opinion combined with a knowledge and understanding of available generic and site-specific data. This type of approach is most appropriate for an analysis with many parameters and can provide additional insights beyond analyses that vary a single parameter only. (Although single parameter variations can be useful in examining model sensitivity, their use in evaluating uncertainty in analyses involving many parameters is limited. The results of uncertainty analysis using single parameter variations can be misleading when the sensitivity of one parameter is not independent of the value of another parameter and the sensitivity of the output may not be constant over the range of variability of a particular

[12] Probabilistic approaches encompass a wide range of analysis techniques and methods. For the purposes of this BTP, probabilistic approach refers to the use of a formal, systematic uncertainty analysis to quantify the uncertainty, in performance estimates, caused by uncertainty in models and parameters. The staff does not recommend assigning probabilities to scenarios, which is characteristics of some probabilistic approaches.

Figure 5. Overall approach to uncertainty analysis in an LLW performance assessment (after Kozak *et al.*, 1993).


Conceptual Model 1
Conceptual Model L
Conceptual Model N
TREATMENT OF MODEL UNCERTAINTY
Param. Set 1,1
Param. Set 2,1
Param. Set J,1
Param. Set 1,L
Param. Set 2,L
Param. Set K,L
Param. Set 1,N
Param. Set 2,N
Param. Set J,N
TREATMENT OF PARAMETER UNCERTAINTY
Decision

parameter.)

Uncertainty in conceptual models is more difficult to evaluate. It is not generally possible to informally and *a priori* identify models and their associated parameter values that prove to be conservative throughout the performance assessment analysis. This is because of the complex relationships that exist within and between subsystem models of the system and the counter-intuitive relationships between parameters. When there are two or more equally reasonable and plausible conceptual models for the site, results of different conceptual models need to be compared and analyzed. Comparison of the results from different conceptual models provide a quantitative basis for evaluating the uncertainty and conservative nature of competing conceptual models.

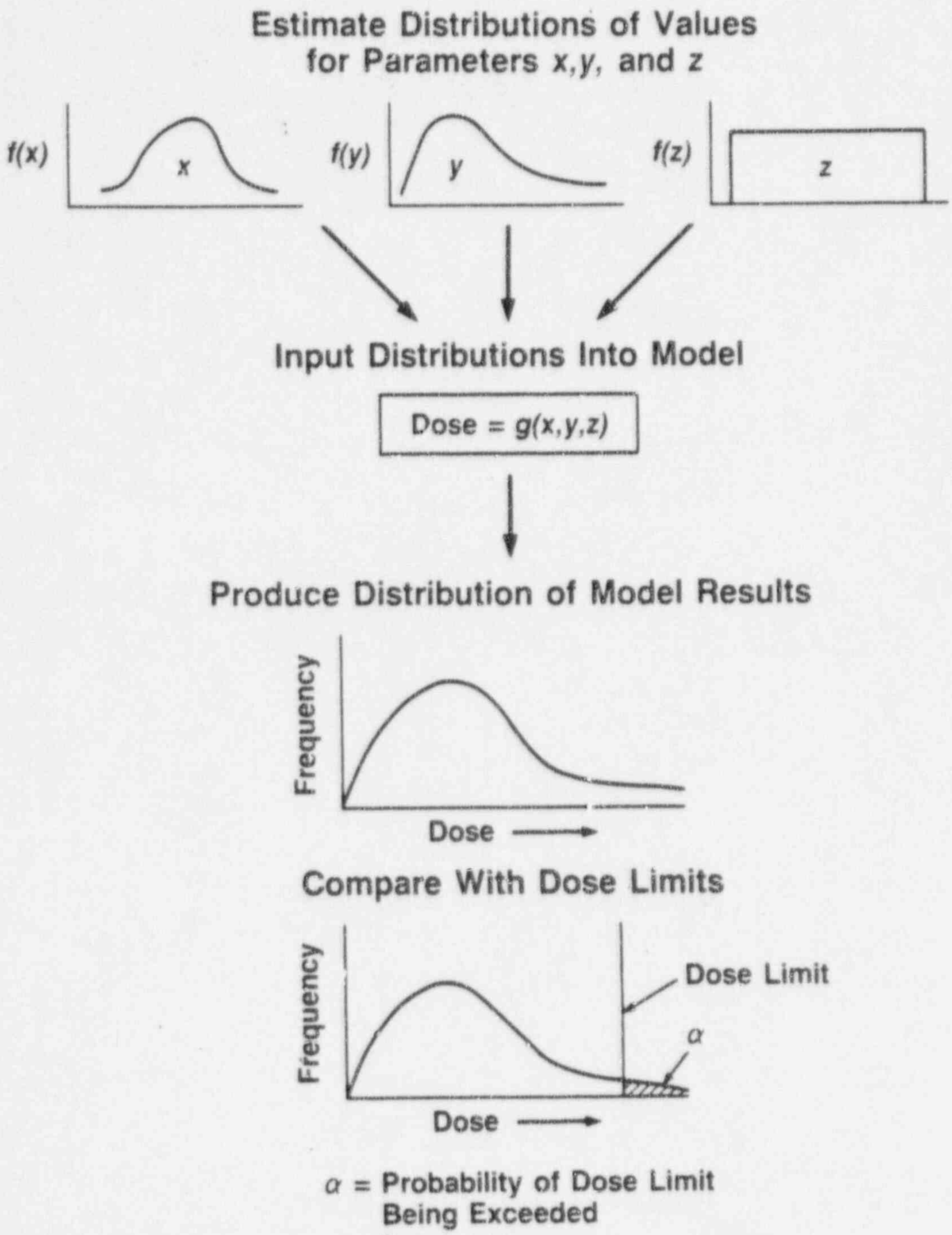
The analyst must weigh the results of all analyses and cogently present the evidence and arguments supporting or rejecting each model. Since the staff will evaluate the overall performance of the system, in part on the basis of the applicant's performance assessment (as well as on the basis of independent analyses), it is essential that the applicant present a reasonable, comprehensive, and persuasive interpretation of the results, in the context of the applicant's understanding of the site and disposal system. Thus, an uncertainty analysis that propagates parameter uncertainty through each credible model of the system, using Monte Carlo analyses or some similar technique, can provide a comprehensive examination of uncertainty and its effect on compliance demonstrations. Figure 6 (modified from Hoffman and Gardner, 1983) depicts how the results of analyzing multiple conceptual models and parameter sets are compared and used to make a decision on how adequately the design meets the requirements. In practice, the most conservative results should be used to measure performance. However, as noted in Technical Position 3.3.2.1.1, on model uncertainty, incredible events, highly-unlikely combinations of parameters, and unreasonable modeling assumptions should not be used.

3.3.2.4 Parametric Sensitivity Analysis

Sensitivity analysis plays an important role in performance assessment by identifying which model parameters are most important to performance calculations. This type of information can be useful in interpreting the results of uncertainty analyses. Similar to uncertainty analyses, sensitivity analyses can be performed at different levels of sophistication. The method should be selected based on the types of questions being asked and the sophistication of the models being examined.

Similar methods are used for both sensitivity and uncertainty analyses (refer to Technical Position 3.2.4). Although the methods are similar, the objectives of uncertainty and sensitivity analyses are different. The objective of the sensitivity analysis is to determine what parameters affect the model results most, whereas the objective of an uncertainty analysis is to determine how the uncertainty in model parameters affects the model results. Sensitivity analysis provides extremely useful input to uncertainty analysis by identifying the important parameters and assumptions in the models that can be used to focus the scope of the uncertainty analysis. For complicated modeling analyses, where there are many

Figure 6. Probabilistic approach for treating model and parameter uncertainty in an LLW performance assessment (after Kozak *et al.*, 1993).


Estimate Distributions of Values
for Parameters x,y, and z
f(x)
x
f(y)
y
f(z)
z
Input Distributions Into Model
Dose = g(x,y,z)
Produce Distribution of Model Results
Frequency
Dose
Compare With Dose Limits
Frequency
Dose Limit
α
Dose
α = Probability of Dose Limit
Being Exceeded

parameters and potential for counter-intuitive results, a better understanding of model sensitivities should be used before selecting a particular approach for analyzing uncertainty.

3.3.3 Infiltration

The primary objective of the performance assessment infiltration analysis is to determine the amount of water entering the disposal unit, and the amount of water available for replenishing the ground-water system (i.e., natural recharge). Determining the amount of water infiltrating into the disposal unit is needed in the source term analysis to determine the release rate of radionuclides from the disposal unit. Knowledge of recharge in the natural system is needed in determining the upper boundary condition for the ground-water flow and transport analysis. Infiltration is commonly defined as the entry of water into the soil profile or the cover surface of the disposal unit. However, as described in this document, the infiltration analysis also includes the subsequent movement of water through the soil profile or cover system and into the disposal unit itself and/or the ground-water system.

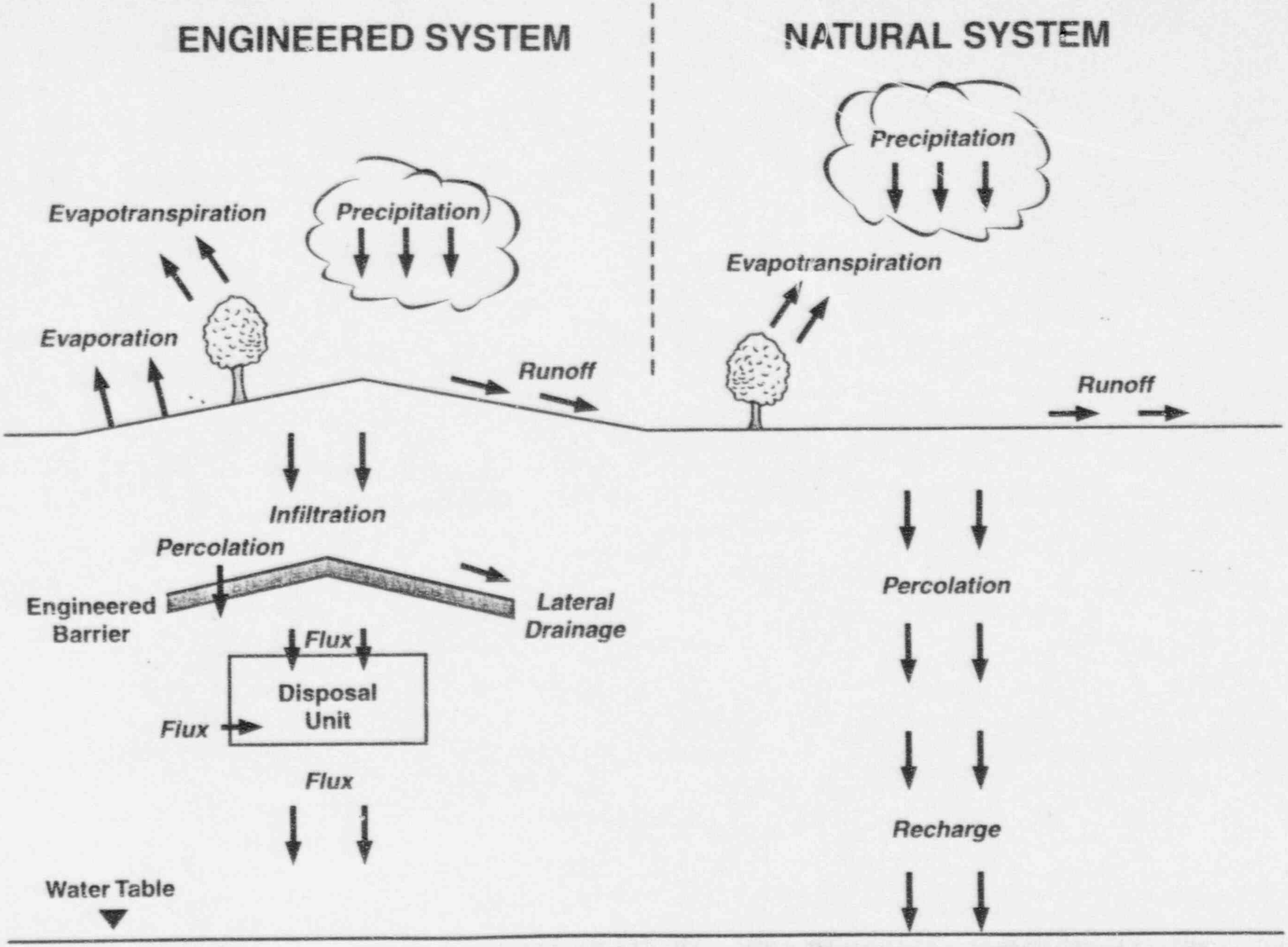
Figure 7 shows the various processes to consider in performing the infiltration analysis. Climate, soil properties, and vegetation are a few of the important parameters controlling infiltration. Each can vary spatially and temporally, and trying to account for this variability over the period of regulatory concern will involve a considerable amount of uncertainty. Several important considerations to weigh in undertaking the infiltration analysis are discussed below, followed by a general approach to the analysis that is designed to address these considerations without having to treat them in full.

3.3.3.1 Key Considerations in the Analysis

3.3.3.1.1 Temporal Variation in Processes and Parameters

Infiltration is influenced by highly transient processes of precipitation, runoff, drainage, evapotranspiration, and snowmelt that create special problems in analyzing infiltration in an LLW performance assessment. Capturing the true interaction of these highly transient processes may require an analysis at small time increments; however, this is problematic for performance assessment analyses that may cover many hundreds of years. Water budget analyses, which are commonly based on average monthly values, may underestimate the mean annual infiltration rate because months where evapotranspiration exceeds precipitation are assumed to have zero infiltration, even though there may be significant precipitation during parts of the month. Similarly, concluding that recharge at arid sites will be negligible because, on average, annual evapotranspiration exceeds annual precipitation is not conservative. This is because it is entirely possible for some recharge to occur following episodes of high-intensity precipitation. An analysis based on too large a time discretization could also lead to over-estimates of the infiltration rate because larger time intervals allow more time for the soil profile to receive a given influx of water. These examples highlight the importance of using short time intervals in the infiltration analysis. Smyth *et al.* (1990) reported that 1-hour or 6-hour incremental data may be required to define the subsurface response to climate, vegetation, and near-surface soils. However, it can be easily seen that even for an analysis using data on 6-hour increments, the data requirements will be

Figure 7. **Schematic showing an LLW disposal facility in relation to the components of the hydrologic cycle.**


ENGINEERED SYSTEM
NATURAL SYSTEM
Evapotranspiration
Precipitation
Evaporation
Runoff
Infiltration
Percolation
Engineered
Barrier
Lateral
Drainage
Flux
Disposal
Unit
Flux
Flux
Water Table
Precipitation
Evapotranspiration
Runoff
Percolation
Recharge

substantial for an analysis carried out for many hundreds of years. Even if the analysis is carried out at small time increments, consideration must be given to selecting the appropriate climatological or sequence of climatological data to use in the analysis.

Because site conditions and the physical properties of engineered barriers will not remain the same throughout the period covered by the performance assessment analysis, infiltration into the disposal unit may increase over time. For example, infiltration may be enhanced if the site experiences a change or loss in vegetation (Gee *et al.*, 1992; and Smyth *et al.*, 1990) and cover performance may be reduced by plant and animal intrusion, settling and slumping, or erosion. In addition, man-made materials such as concrete are expected to degrade over time in response to physical, chemical, and/or mechanical processes (Walton *et al.*, 1990). Thus, an analysis based solely on as-built and current site conditions may not be conservative and, therefore, some assumptions must be made about the performance of engineered barriers (see Technical Position 3.2.2), and future states of the site (Kozak *et al.*, 1990b). In addition, assumptions about how the site may change or engineered materials degrade are expected to affect the type of analysis required. For example, assuming that the concrete will degrade through fracturing may require consideration of fracture flow.

3.3.3.1.2 Spatial Variation in Parameters

Soil properties are expected to vary spatially over the area covered by the infiltration analysis. Variability in the physical properties of soil is important in determining infiltration rates. Gee *et al.* (1992) show how spatial variation in soil texture influences recharge. Variation in soil physical properties, unless accounted for, increases the level of uncertainty in the performance assessment infiltration analysis. Even for relatively uniform soils — for example within units of an engineered cover — physical properties can vary greatly from one place to another. As an example, hydraulic conductivity values measured in radon barriers of three Uranium Mill Tailings Radiation Control Act (UMTRCA) projects varied spatially between 1 to 2 orders of magnitude (Smyth *et al.*, 1990). Variations in natural soils may be even higher.

The dimensionality of the analysis should also be considered. Assuming strictly vertical, one-dimensional (1-D) flow should be conservative for most situations because it does not account for lateral drainage; however, under some conditions, this assumption may not be conservative. Covers designed for LLW disposal facilities likely will incorporate one or both of the following design features: a sloped surface to enhance runoff; and a sloped subsurface interface of coarse-to-fine grained soil to enhance lateral drainage. Under some circumstances this design could actually enhance water flux into the disposal unit. For example, Smyth *et al.* (1990) reported that surface runoff has been observed at the cover edge of several UMTRCA projects. If this accumulated water migrates back toward the disposal unit, which it could under some circumstances, the flux of water into the disposal unit will be larger than that assumed under strictly vertical, 1-D flow.

3.3.3.2 Recommended Approach

3.3.3.2.1 General Strategy

The approach the staff recommends for the infiltration analysis is to start with a simple conceptualization of the engineered system and the unsaturated (vadose) zone of the natural setting and progress to more complicated analyses, as appropriate, for measuring performance and evaluating the design. For example, in developing a conceptual model of the cover, the analyst may choose not to take credit for liners that may have a short life-span; such liners may provide an extra measure of protection, but may not be needed for demonstrating compliance. A simple analysis will facilitate testing several conceptual models over a range of parameter values. Figure 8 diagrams one approach that is similar to the integrated numerical model approach described by Smyth *et al.* (1990). The approach is designed so that sites with favorable hydrologic conditions can take advantage of these favorable conditions, whereas sites with less favorable hydrologic conditions will require greater reliance on the engineered system.

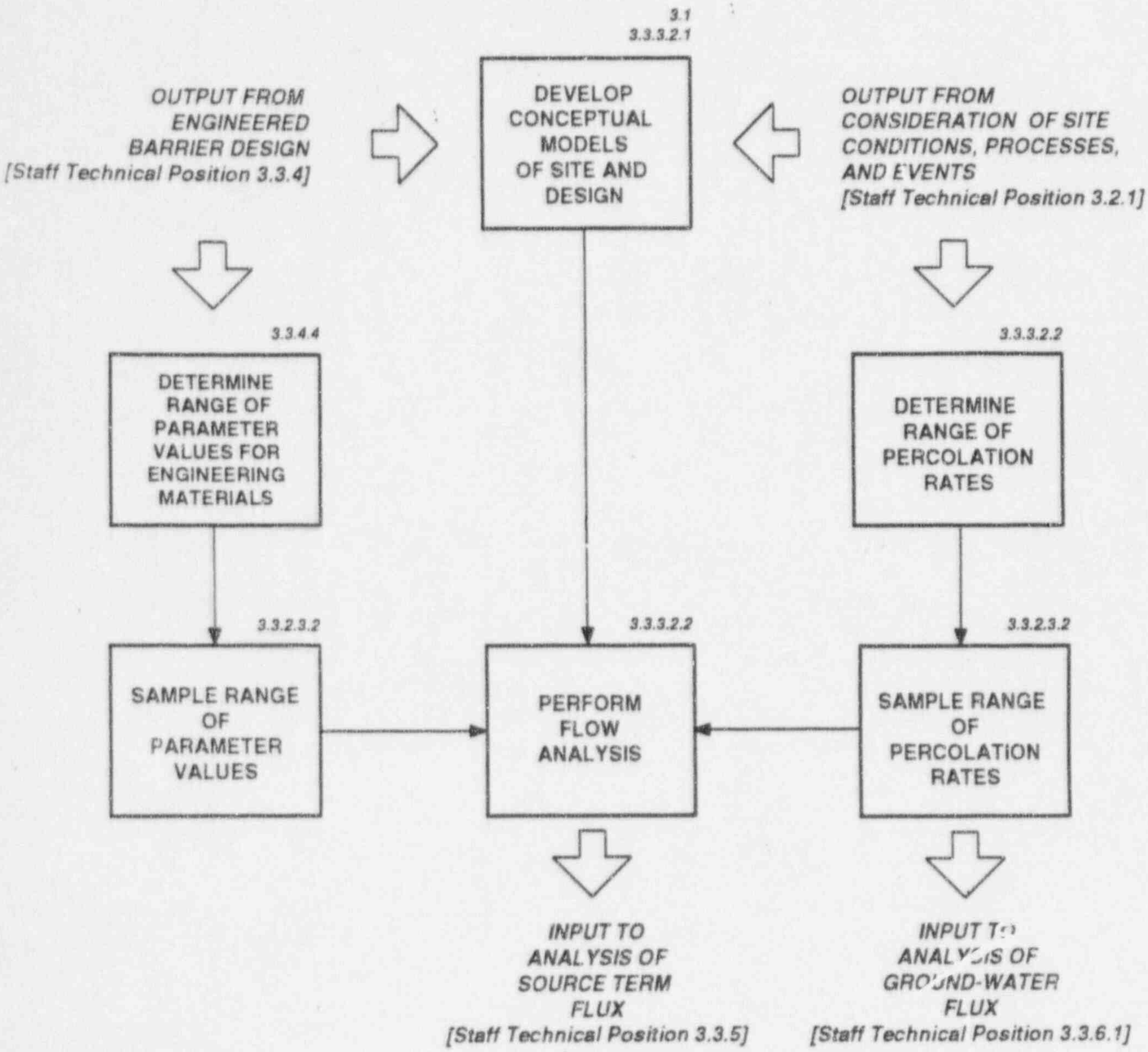
As discussed in Technical Position 3.3.2.1.2, a broad range of values should be used to characterize each parameter in the analysis. A range of values is used to capture the uncertainty in the parameter. For a bounding-type deterministic analysis, the analyst will have to determine the appropriate values to use in the infiltration analysis so as to bound the performance assessment results. The use of extreme values may not be conservative when placed in the context of the overall performance assessment analysis. That is, although a particular value may be conservative for the purpose of the infiltration analysis, it may not be conservative for the overall performance assessment results.

A key feature of the approach is how progressive stages of cover performance degradation over time are captured in the infiltration analysis by using ranges of percolation rates and hydraulic parameters for engineered materials. At each stage of cover degradation, hydraulic parameter values for engineered materials are developed to represent the state of cover degradation for the stage. Ranges are sampled based on their assumed statistical distributions, and the values taken are assumed to remain constant throughout the stage. At each subsequent stage, a new set of parameter distributions is sampled. The sampled percolation rate remains the same throughout all stages of the analysis. Determining sets of values for both percolation and hydraulic properties of engineered materials may require auxiliary analyses performed outside the integrated performance assessment analysis.

3.3.3.2.2 Analysis

The infiltration analysis can be viewed as consisting of two primary components. First, highly variable (temporally) processes are considered in determining a steady-state percolation rate. As depicted in Figure 8, this can be represented as a range of values. As previously stated, it may be best to determine this range through analyses outside the integrated performance assessment analysis. Second, the steady-state percolation rate is used as an upper boundary condition to model moisture movement through the cover and the ground-water system; this is depicted as the bottom, middle box in Figure 8.

Figure 8. Technical Position 3.3.2: Recommended approach to the LLW infiltration analysis. Numbers next to the process blocks refer to the technical position statements in Section 3.3.2.2.2 of the text.


3.1
3.3.3.2.1
OUTPUT FROM ENGINEERED BARRIER DESIGN [Staff Technical Position 3.3.4]
DEVELOP CONCEPTUAL MODELS OF SITE AND DESIGN
OUTPUT FROM CONSIDERATION OF SITE CONDITIONS, PROCESSES, AND EVENTS [Staff Technical Position 3.2.1]
3.3.4.4
DETERMINE RANGE OF PARAMETER VALUES FOR ENGINEERING MATERIALS
3.3.3.2.2
DETERMINE RANGE OF PERCOLATION RATES
3.3.2.3.2
SAMPLE RANGE OF PARAMETER VALUES
3.3.3.2.2
PERFORM FLOW ANALYSIS
3.3.2.3.2
SAMPLE RANGE OF PERCOLATION RATES
INPUT TO ANALYSIS OF SOURCE TERM FLUX [Staff Technical Position 3.3.5]
INPUT TO ANALYSIS OF GROUND-WATER FLUX [Staff Technical Position 3.3.6.1]

Given the potentially long periods over which the performance assessment analysis is likely to be carried out, use of a constant percolation rate is desirable. Use of a constant percolation rate is justified because as water moves below the zone of influence of plant roots, the requirement for capturing the transient nature of the hydrologic processes occurring near the land surface (e.g., precipitation, evapotranspiration, runoff, etc.) becomes less important; as a result, the flux of water below this zone can be assumed to be at a steady rate. Therefore, in the proposed approach, this "steady rate" of water or percolation is used in determining the upper boundary condition of the flow analysis. This percolation rate can be considered as equivalent to natural recharge and can therefore be used to establish the upper boundary condition for the ground-water flow and transport analysis.

Because of uncertainty in the determined percolation rate, the analyst should consider a range of parameter values in the analysis. The range will need to be broad enough to represent the analyst's confidence in the value. Once the range and distribution are established, values can be sampled for use in the flow analysis.

In determining the range of percolation rates, the analyst should consider the effects that discrete high-intensity events, and various prolonged wet periods might have on the mean annual percolation rate. In general, prolonged periods (i.e., seasonal or annual) of higher than normal precipitation have been found to result in more infiltration than short-duration, extremely high-intensity storms. However, the effects of high-intensity, short-duration storms should not be overlooked, because in some settings they may be the principal source of infiltration. The analyst should consider the effects melting snow that accumulated on the site may have on infiltration. The analyst should also try different conditions to determine the melting effect of snow on the percolation rate. Because of the uncertainty in predicting climatic changes, the staff does not recommend considering long-term climatic changes in the analysis (see Technical Position 3.2.1.2); however, variations in weather conditions should be considered, as discussed above. Finally, the analyst should consider the effects of having no vegetation on the cover surface of the disposal unit, in case the vegetation later dies off.

One suitable method for determining the range and distribution of percolation rates is the method used by Smyth *et al.* (1990) in their analytical stochastic analysis of an UMTRCA cover. In their analysis, percolation rates were assumed to be uniformly distributed. The range in values was derived by estimating the minimum and maximum possible recharge rates. In general such an approach should be conservative (for the infiltration analysis) since recharge rates are expected to have either a gamma or log-normal distribution, based on previous works that have shown climatic data to be best represented by a gamma distribution (Richardson and Wright, 1984), and both hydraulic conductivities and infiltration rates to be approximately log normally distributed (Cook *et al.*, 1989).

Another suitable method, especially for arid areas, is to use the natural recharge rate determined from field tests conducted at the site. Gee and Hillel (1988) discuss a number of methods for determining natural recharge and some of the considerations of each method. Of these methods, lysimetry and tracer tests appear to be most reliable for estimating natural

recharge at an arid site. These methods could provide an estimate of the expected recharge or percolation rate; however, the analyst will have to establish a justifiable range about this expected value, especially for sampling in a probabilistic performance assessment analysis. Kozak *et al.* (1990b) recommend using several field methods, as opposed to a single method. Each method used should have data input independent of the other methods.

For humid sites (i.e., greater than 500 millimeters/year of precipitation), a range of percolation rates can be estimated through the use of water balance analyses. For such analyses, the analyst should use National Weather Service and/or the USGS climatological data from nearby stations to augment site data. The data record for the analysis should cover 20 to 50 years (Smyth *et al.*, 1990). It is recommended that the time interval for water balance analyses be no greater than average daily values (i.e., water balance analyses based on average monthly or annual input values are not recommended). The average of the mean annual infiltration rates, determined from the water balance calculations, can be used as an estimate of the percolation rate to be used in the analysis. Statistical deviations about this mean value can be used in determining an appropriate range. The analyst should ensure that the sequence of the climatological data used in determining the range in percolation rates is appropriate considering the timeframe of the analysis (i.e., selection of climatological data that represent significant dry periods is not advised). In general, results from water balance calculations are more sensitive to uncertainties in the input components for sites in arid and semi-arid areas than for sites located in humid areas (Gee and Hillel, 1988). Therefore, it is advisable to exercise considerable caution in using water balance calculations for sites located in arid or semi-arid areas.

Lastly, when the cover is assumed to be intact, the amount of water transmitted through the cover may be sufficiently small so that the analysis can be simplified with some conservative assumptions. For example, the analyst may assume full saturation for the clay barrier and use the saturated hydraulic conductivity of the barrier as an estimate for the percolation rate.

For the second step in the analysis, the steady rate of water, determined from the percolation/natural recharge analysis, establishes the upper boundary condition for analyzing flow through the remainder of the cover. For the native soils, recharge can be used directly in establishing the upper boundary condition for the ground-water flow and transport analysis (see Technical Position 3.3.6.1). Because of the expected spatial variation in hydrologic properties of cover materials, the analyst should use a range of values. Distributions for the parameters for the engineered system should be based on specific values representing the median of the respective parameter distributions for each of the three phases of facility performance (i.e., design, degrading, and degraded performance, as discussed in Technical Position 3.3.4.4). The selection of the functional form of the distribution should be based on the type of distribution typically observed for that parameter. Values can be sampled from the assumed distribution and treated as an effective parameter in the analysis. Because the potential number of parameters to be sampled could become fairly large (depending upon the complexity of the cover system), the analyst should carefully consider the correlation of the various parameters. If parameters are correlated, it may be possible to use a lumped

parameter in the analysis and reduce the number of parameters to be sampled. Parameters that can be specified can be described by constants.

The cover material is expected to degrade with time (see Technical Position 3.2.2, "Role of Engineered Barriers"); therefore, the hydrologic parameters used in the analysis should also encompass expected temporal changes. In the approach outlined in Figure 8, degradations of materials are handled through changes in their hydraulic properties. In this way, the materials are assumed to change in a step-wise fashion in that new parameters are sampled to reflect a progression in degradation of the engineered components of the disposal unit.

The staff recommends treating materials as an equivalent porous continuum; therefore, explicit modeling of fracture flow is not required for materials that are susceptible to fracturing. For materials expected to undergo fracturing, the degree of fracturing expected should be captured by the range of hydraulic parameters assumed when these materials are expected to degrade. Treating the material as an equivalent porous continuum eliminates the need for making detailed predictions about the geometry and nature of the fractures. In addition, assuming an equivalent porous continuum is in general agreement with the approach recommended for analyzing the source term, whereby it is assumed that the influx of water into the disposal unit comes into contact with the bulk of the waste.

In considering degradation of engineered materials, the analyst will need to consider the degradation of not only the clay barrier, but also the degradation of other constituents within the cover that are important to limiting infiltration. For example, over time, drainage layers may become clogged, and therefore lose their effectiveness in transmitting water away from the disposal unit.

The analyst should consider the influence of multi-dimensional flow; this is needed to ensure that accumulated water at the cover edge does not reach the disposal unit. Accumulated water at the edge may produce a larger flux of water into the disposal unit than that occurring vertically at the top of the disposal unit. Determining the potential occurrence of such a phenomenon will likely require a multi-dimensional analysis. However, once it has been determined that such accumulated water could migrate into the disposal unit, the effects of this can be accommodated within a simple 1-D or quasi 2-D analysis used as part of the performance assessment analysis.

3.3.4 Engineered Barriers

The objective of the engineered barrier (system) analysis in LLW performance assessment is to establish model representations of the physical dimensions and characteristics of designed engineered features, and to determine the ranges of parameter values that would reasonably represent the behavior of the features with the passage of time. The following discussion addresses the major issues relevant to evaluating the performance of engineered barriers, and describes a process that can be used to establish parameter values of materials in engineered barriers for use in an LLW performance assessment. A methodology for evaluating the characteristics and modeling engineered barriers in the performance assessment is depicted in Figure 9.

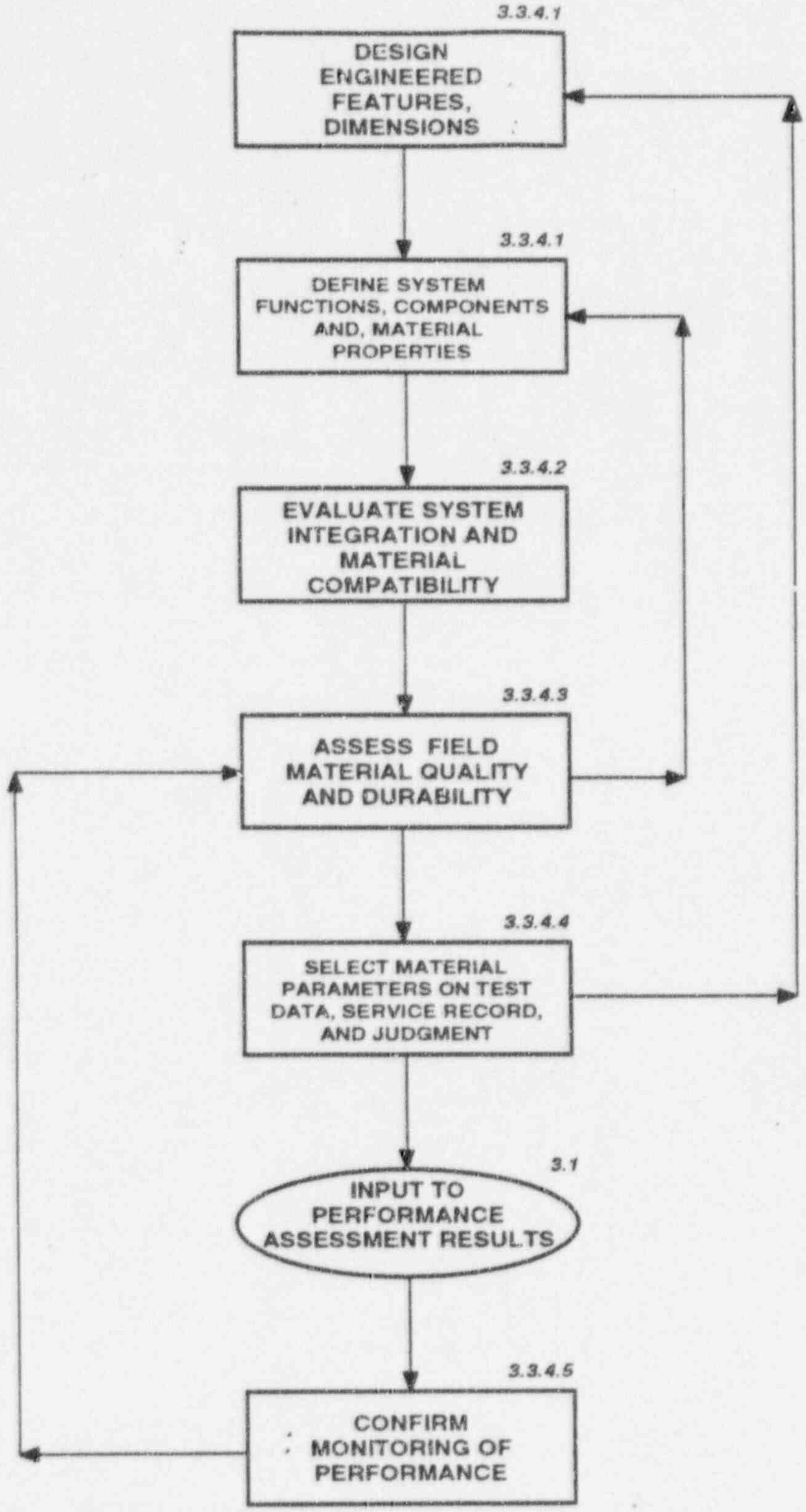
3.3.4.1 Features and Dimensions of Engineered Barrier Systems

Engineered barriers are components and systems designed to improve the waste retention capability of a land disposal facility. The considerations related to physically describing the features of the engineered barriers in performance assessment are the same as those inherent in their actual design. These design considerations are described in detail in Chapter 3 of NUREG-1200 ("Design and Construction"), and are controlled primarily by the requirements of established engineering practice and building codes. The design concept of a disposal unit for an LLW disposal facility (layout and physical dimensions of a vault system, etc.) is typically documented and depicted in sketches and drawings. The descriptions should identify the materials and their arrangement in a disposal unit including spatial variations (i.e., horizontally and vertically). This information defines the spatial relationships among the various types of materials that are used in a facility and provides the information that is needed to model the physical dimensions of engineered barriers. Not all design features will necessarily be reflected in, or qualify for, consideration in performance assessment as engineered barriers. The applicant should define which components and associated materials are intended to help meet the performance objective and thus are being considered as engineered barriers in the performance assessment. It is likely that the results of preliminary (auxiliary) analyses will be used to assess the need for additional performance enhancements that may, in turn, dictate the use of improved or additional engineered barrier systems. In this manner, design features and engineered barriers would evolve from important conclusions arising from performance assessment results.

3.3.4.2 Integration and Interaction of Materials

An understanding of the nature of materials in engineered barriers, their make-up, and their interactions is needed in performance assessment, for estimating material longevity and for developing parametric values that represent the behavior of engineered barriers with time. Once the various materials that make up the engineered barriers and their spatial relationships are described, it will be necessary to evaluate how their integration into the composite system affects facility behavior. Presumably, each material that constitutes part of the design is selected either for fulfilling the regulatory requirements or for some utilitarian purpose such as constructability. Factors that need to be considered in this process include:
(a) compatibility among materials that may come in contact with each other, either directly

Figure 9. Technical Position 3.3.4: Recommended approaches to LLW performance assessment modeling — Methodology for modeling engineered barriers performance. Numbers next to the process blocks refer to the technical position statements in the text.


3.3.4.1
DESIGN ENGINEERED FEATURES, DIMENSIONS
3.3.4.1
DEFINE SYSTEM FUNCTIONS, COMPONENTS AND, MATERIAL PROPERTIES
3.3.4.2
EVALUATE SYSTEM INTEGRATION AND MATERIAL COMPATIBILITY
3.3.4.3
ASSESS FIELD MATERIAL QUALITY AND DURABILITY
3.3.4.4
SELECT MATERIAL PARAMETERS ON TEST DATA, SERVICE RECORD, AND JUDGMENT
3.1
INPUT TO PERFORMANCE ASSESSMENT RESULTS
3.3.4.5
CONFIRM MONITORING OF PERFORMANCE

or indirectly through material transport processes within the engineered barrier system; (b) the manner in which the disposal facility is to be constructed, including how construction joints, changes in geometry, penetrations, etc., may affect system behavior; (c) the effect that failure of a design feature or some portion of an engineered barrier would have on the overall behavior of the barrier; and (d) how the degradation of material properties affects barrier performance over time. The purpose of this integration step is to start the analyst through a logical thought process, to ensure that all relevant materials and conditions that could affect the behavior of the waste disposal system over the design life of the engineered barriers are considered.

3.3.4.3 Construction Quality and Testing

The quality level to be required and maintained during the design and construction of a disposal facility should be reflected in the parametric values for engineered barriers derived for use in performance assessment. Before construction of the disposal facility, the quality level of the various material and construction specifications that will be documented in the license application can be used by the analyst. It would be necessary, however, to conclude that the quality level being proposed is attainable and that it is supported by an acceptable QA program. Provisions also should be made in performance assessment for the fact that the actual level of quality achieved in the field may be different and possibly lower than that assumed during the design and analysis phase of the project. If this has not been considered in the original design, by allowing for design margins, appropriate parameter distributions in a performance assessment will need to be modified to reflect as-built conditions. For example, it is expected that the permeability of the various engineered barriers will be a key parameter in the performance assessment. Therefore, it may be necessary for appropriate controls to be initiated in the field during and after construction, including testing, to verify permeability values for design and in performance assessment. Testing of in-place reinforced concrete barriers, for example, including areas with discontinuities, should include tests for hydraulic conductivity. Field permeability testing should also be performed on other materials and engineered barriers that are relied on in performance assessment.

3.3.4.4 Model Input

After proceeding through the initial three steps of this methodology, discussed above, the analyst should have sufficient information on the characteristics of engineered barriers from which to base reasonably bounding estimates of their material properties necessary for the performance assessment. These steps include: (a) identifying engineered barriers, systems, and materials used in the disposal unit; (b) appraising compatibility and interactions among materials; (c) evaluating material quality and durability, and system behavior; and (d) assessing the effect of construction quality. In carrying out the recommended methodology, the analyst should review sources of information on engineered barrier material properties and performance to be certain that they include:

(a) comparable historical laboratory and field service data, including consideration of:
- (i) compatibility with current LLW disposal conditions; and
- (ii) compatibility of the test methods and procedures; and

(b) the analytical methods for projecting service life performance, including:
   (i) capability of addressing synergistic effects; and
   (ii) the ability to extrapolate service life and performance characteristics.

In determining the service life of engineered barriers, including the parameter values and the confidence levels in those parameters influencing physical performance, previous engineering experience and knowledge about the application and long-term behavior of specific materials need to be considered. Some materials, such as synthetic waterstops, have service histories of no more than 100 years. The service histories of other materials (e.g., clay, sand, and gravel) is well known from their behavior in the environment and from proven construction experience.

The ranges of parameter values to represent the performance of engineered barrier materials, over time, may be determined by dividing engineered barrier performance into three phases. The first phase is the service life or performance period, when engineered barriers would perform as designed. The occurrence of certain natural events (e.g., seismic and meteorological) and resulting imposed loads that the facility must be designed to withstand, are factored into the design of the disposal facility (so-called "design-basis" natural events are defined in Chapter 3 of NUREG-1200). Once it has been determined that the requirements for disposal site stability have been met, it can be assumed that engineered barriers will remain stable against design basis events over their service live. The second phase, following the service life period, represents a time of decreasing engineered barrier function from ongoing processes of degradation. The third or final phase represents performance where complete degradation has occurred. Complete degradation means loss in intended design function and a return to those constituent materials shown to be resistant to physical, chemical, or biological processes, and is not meant to imply total structural instability and the creation of void spaces. For example, complete degradation of concrete would assume a return to the constituent sand and gravel aggregates, whereas, for a degraded clay-cover soil, the clay soil particles would remain, but at a loss in intended engineering properties. The selection of parameters for model input for a degraded barrier is very much influenced by the availability of information and data on material quality and durability. Because the performance assessment timeframe is much longer than actual material performance records, engineered design lives, and the period of active institutional control, it is necessary to assume conservative material properties for degraded engineered barriers.

It is expected that, in the first phase, the service life periods of different barriers will vary significantly because of the inherent diversity and variability of materials used to construct engineered barriers. This would need to be accounted for in performance assessment. As an example, based on engineering judgment, the hydraulic conductivity for the low-permeability portion of the cover, such as a clay layer, may range from 1×10^{-8} to 1×10^{-7} centimeters/second over its service life. Its service lifetime may be established at 500 years because, for example, it is determined that site conditions would ultimately allow tree roots to penetrate the clay layer at 500 years. Similarly, the hydraulic conductivity over the service life of a reinforced concrete vault may be estimated to range from 1×10^{-11} to $1 \times$

10^{-9} centimeters/second. If, for example, it is determined that site conditions could lead to slowly developing differential settlement under structural loading and ensuing concrete cracking 100 years after site closure, then the service life of the disposal vault would be chosen at 100 years.

For the second and third phases of performance after the service life phase, new sets of parameter values would be established for barrier materials, first to represent engineered barriers in the process of degrading and then to represent them after they have completely degraded. Thus, to represent variations in the behavior of clay after 500 years, when tree roots have penetrated, or of cracked vault concrete beyond 100 years, additional hydraulic conductivity distributions for the respective barriers would have to be determined. In preliminary modeling of engineered barriers, the time increment can be considered as a step function by introducing, at the beginning of each phase of barrier performance, the set of unique parameter distributions representing the performance of the barrier over the respective phase. In later iterations of the performance assessment, continuous time functions may be established, based on as much actual data as are available.

3.3.4.5 Post-Construction Monitoring and Evaluation

The range of values used in design must also reflect what is achievable in the field after various materials, configurations, and resulting engineered barriers are integrated into the disposal facility. Once a disposal unit is ready for operation, it will be necessary to verify that the actual as-built parameter values are within the design range used in the performance assessment. If the as-built values are less favorable and outside the range considered as initial conditions in the design, additional supporting studies to update the performance assessment may be required. The monitoring of a facility's post-construction behavior is typically intended to build confidence in fulfillment of design expectations, by obtaining confirmatory records of the disposal facility's successful performance. Monitoring to verify satisfactory performance is accepted practice and is not normally meant to allow a licensee to take greater credit and to reduce safety margins. During the design and construction stage of facility development it may be necessary to plan for and implement physical arrangements and instrumentation needed for monitoring the relevant parameters previously defined by the designer (White *et al.*, 1990; and Marts *et al.*, 1990).

3.3.4.6 Use of Engineering Judgment

Predicting the service life of the engineered features of the LLW disposal facility will, by necessity, be based on the results of accelerated material testing and mathematical modeling. The staff does not expect potential applicants to independently develop this information. Rather, the staff expects that an applicant will carefully review the literature and select values

(or ranges in values) for the material property parameters to be considered as part of the LLW performance assessment. Thus, in selecting the values for the needed engineering parameters, the applicant is expected to evaluate and interpret the scientific knowledge base as it relates to materials performance, to the extent that this knowledge base exists. For the purposes of this guidance, the analysts' efforts to synthesize sometimes disparate and often conflicting sources of information (or data) on materials performance into an integrated picture can be referred to as *engineering judgment*.

As with all complex technical analyses, engineering judgment, usually informal and implicit, is used routinely to supplement and interpret this information, indeed, even to determine how to obtain the data or perform the analyses. The staff believes that its ability to evaluate a potential LLW license application will, in large measure, depend on the transparency with which data are collected, analyzed, and interpreted, and safety-related decisions are made. Therefore, the staff believes that it is important for the analyst to document the rationale and basis for the engineering judgments. The reasons for documenting these engineering decisions are: (a) to indicate the current state of knowledge about material properties and service life; (b) to demonstrate that the parameter values selected are reasonable and conservative, and consistent with the current state of knowledge; (c) to permit the analysis to be independently confirmed; and (d) to provide a basis for updating assessments to reduce uncertainty in the analysis.

3.3.5 Source Term and Waste Type

The objective of a source term analysis is to calculate radionuclide releases from the LLW disposal units as a function of time. These radionuclide release rates can then be used as input for transport models that estimate offsite releases for the facility. Radionuclide releases from LLW facilities are typically liquid or aqueous releases; however, release of certain radionuclides disposed of at LLW facilities can occur in the gaseous phase. Although liquid releases can be significantly constrained by considerations of the flux of water entering a disposal unit, gaseous releases are relatively unconstrained because of the significantly higher rates for gaseous diffusion and advection compared with diffusion and advection of radionuclides in the liquid phase. Gaseous and liquid releases will often be analyzed separately in LLW performance assessment analyses because of the significant differences in the nature of the releases, and because the limited impact on performance of the gaseous release readily lends itself to a simple bounding analysis. Therefore, source term modeling of liquid and gaseous releases are discussed separately.

Gaseous release of radionuclides, for those waste streams with gaseous radionuclides, will be governed by the container lifetime and design (e.g., container vents could allow gas to diffuse out). Technical Position 3.3.5.7.2 presents approaches for bounding calculations of gaseous release to be used to determine if further consideration is warranted. The remaining technical positions in this section concentrate on more sophisticated approaches and assumptions used for understanding liquid release processes. The source term analysis for liquid release uses the flux of water into the disposal unit, calculated from the infiltration

analysis, to estimate radionuclide releases (the source term) from the disposal unit(s), which are then used to analyze environmental transport.

When selecting modeling approaches for estimating the liquid releases, one must consider a number of disposal unit features and environments such as the radionuclide inventory, waste types, waste form and type, waste containers, backfill, and chemical conditions. Estimates of releases that rely on specific performance from these features will require data and technical support commensurate with their importance to performance. Simple modeling approaches, which are based on the general behavior of the waste form and a general understanding of the chemical environment within the disposal unit, will require less sophisticated analyses and support than approaches that put more reliance on understanding complex processes. It is recommended that a screening analysis, which identifies the important radionuclides that need to be included in the analysis for comparison with the regulatory limit, should be performed to limit the scope of radionuclides to be considered. A schematic depicting the general considerations or decisions that could be required in a source term analysis is shown in Figure 10. The following discussion provides guidance on the simple approaches that can be used to address these general considerations.

3.3.5.1 Inventory of Radionuclides in LLW

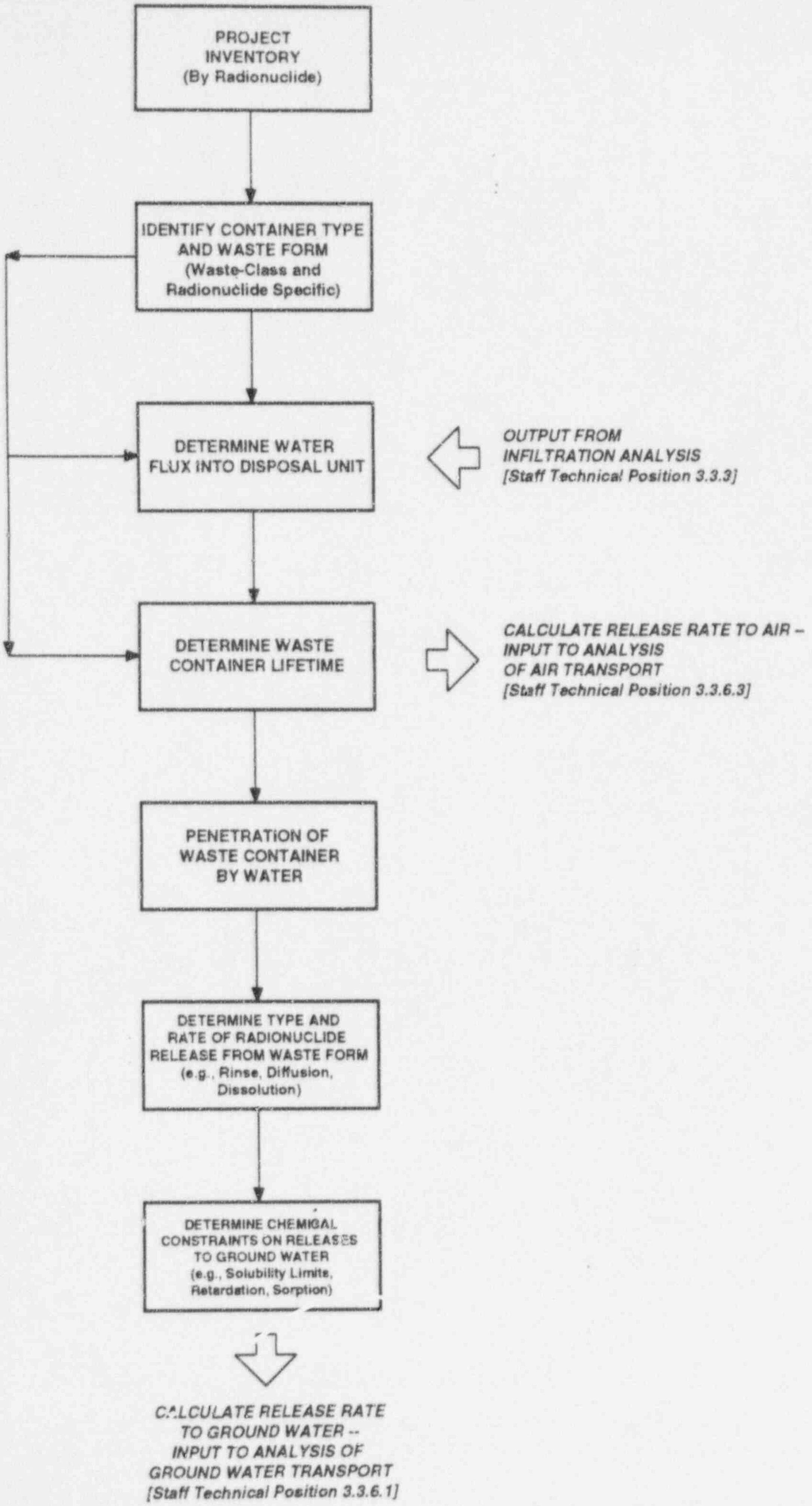
3.3.5.1.1 Issues

Assumptions regarding the characteristics of the radionuclide inventory can have a significant impact on the determination and selection of modeling approaches appropriate for representing the source term. Radionuclide inventories need to be addressed on a facility-specific basis. That is, the anticipated distribution of specific radionuclides in the LLW disposal facility inventory must be estimated by waste class (Classes A, B, and C); waste type; waste form; waste stream; and waste container. This information provides a basis for selecting an initial approach for source term modeling. The necessary level of detail of this information will need to vary with the modeling approaches under consideration. For example, the distribution of radionuclides among different waste types (e.g., dewatered ion-exchange resins, activated metals, dry solids, dry active wastes, etc.) can be very important because of the potential for significant variation in release rates from the various waste types. In addition, the solubilities and half-lives of the radionuclides under consideration can affect the selection of source term models. Also, consideration of specific waste containers (e.g., HICs) which can be relied on to delay initial releases of radionuclides, might be effective for reducing the releases of short-lived radionuclides.

3.3.5.1.2 Recommended Approach

The applicant should provide a description of the inventory, waste form, waste type, and waste container assumptions used in the performance calculation. Moreover, the applicant should use assumptions consistent with LLW expected to be disposed of at its site. Despite the uncertainty in predicting future inventories, waste streams, and disposal practices, the performance assessment needs to contain a thorough description of the LLW quantities and disposal assumptions.

Figure 10. Calculational considerations in estimating LLW source term releases. Note that the calculational steps and parameters can be specific to a waste class, waste type, and stream, or to an individual radionuclide.


PROJECT INVENTORY (By Radionuclide)
IDENTIFY CONTAINER TYPE AND WASTE FORM (Waste-Class and Radionuclide Specific)
DETERMINE WATER FLUX INTO DISPOSAL UNIT
OUTPUT FROM INFILTRATION ANALYSIS [Staff Technical Position 3.3.3]
DETERMINE WASTE CONTAINER LIFETIME
CALCULATE RELEASE RATE TO AIR – INPUT TO ANALYSIS OF AIR TRANSPORT [Staff Technical Position 3.3.6.3]
PENETRATION OF WASTE CONTAINER BY WATER
DETERMINE TYPE AND RATE OF RADIONUCLIDE RELEASE FROM WASTE FORM (e.g., Rinse, Diffusion, Dissolution)
DETERMINE CHEMICAL CONSTRAINTS ON RELEASES TO GROUND WATER (e.g., Solubility Limits, Retardation, Sorption)
CALCULATE RELEASE RATE TO GROUND WATER -- INPUT TO ANALYSIS OF GROUND WATER TRANSPORT [Staff Technical Position 3.3.6.1]

Significant radionuclides present in LLW should be provided by volume and activity levels and identified by: waste class; waste type (e.g., ion-exchange resins, dry active wastes, and dry solids); waste form (e.g., cement-solidified, activated metals); waste stream; and waste container for each type of generator (e.g., utility, medical, academic). LLW containing chelating agents (e.g., decontamination waste) needs to be identified separately, because of the concerns of 10 CFR 61.2 and 61.20 regarding waste forms containing chelating agents. Particular attention should also be given to: identifying long-lived radionuclides with a high potential for mobility (e.g., ^{14}C, ^{36}Cl, ^{99}Tc, ^{129}I, and certain alpha-emitting transuranics such as plutonium-239 (^{239}Pu) and neptunium-237 (^{237}Np)). In addition the inventory needs to include radionuclides with a relatively high dose conversion factor (DCF) and/or significant ingrowth of daughter radionuclides (e.g., ^{238}U and ^{232}Th).

Information on commercially generated radionuclide distribution by waste generators, waste class, waste stream, and waste form is available from shipping manifests (see Roles, 1990 and Cowgill and Sullivan, 1993) and from DOE's National Information Management System managed by the Idaho National Engineering and Environmental Laboratory.[13] Specific inventory information for a performance assessment may be obtained from surveys of waste generators within the compact or State and projections of changes in waste streams over the lifetime of the facility (e.g., for anticipated reactor decommissioning). The Commission recently amended its regulations at 10 CFR Part 20 to improve LLW manifest information and reporting (NRC, 1995). Guidance to complete NRC's uniform LLW manifest is presented in NUREG/BR-0204 (NRC, 1995).

3.3.5.2 Screening Methods to Identify Significant Radionuclides

3.3.5.2.1 Issues

The objective of preliminary screening of the LLW facility inventory is to identify radionuclides to be included in the performance assessment and eliminate insignificant radionuclides from further analysis. The use of a screening approach to determine these key radionuclides could involve a number of possible approaches and also will likely involve disciplines other than the source term (e.g., ground-water transport and dose). A tiered approach, which starts with the highly conservative inventories and releases mechanisms and progresses to a less conservative approach, is recommended. Regardless of the approach, justification would be required to explain the rationale for eliminating radionuclides from the analysis.

3.3.5.2.2 Recommended Approach

The following are acceptable screening approaches to determine which radionuclides in the facility inventory need to be considered further in the LLW performance assessment.

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[13] Administered by the National Low-Level Radioactive Waste Management Program, Idaho National Engineering and Environmental Laboratory, P.O. Box 83415, Idaho Falls, ID 83415. The system administrator is currently Ron Fuches, Telephone: 208/526-9717.

(a) Eliminate radionuclides, with half-lives less than 5 years, that are not present in significant activity levels and do not have long-lived daughter products (or are themselves not daughters of a longer-lived parent).

(b) Perform a dose calculation that assumes the waste container, waste forms, backfill, or other retardation methods are completely ineffective in delaying or retaining radionuclides within the disposal units. All radionuclides are assumed to be available for radionuclide transport in soil to the ground-water system, and with subsequent transport to the average member of the critical group by all exposure pathways, including drinking water. Important radionuclides will be determined by calculating the transport of the radionuclides in soil and ground water, with an acceptable radionuclide transport model, using conservative, radionuclide distribution coefficients to retard radionuclide movement in the soils. Radionuclides with an estimated maximum dose less than 1 percent of the Part 61 dose requirements can be eliminated from further performance assessment calculations. Appropriate computer models, such as *PAGAN* (Chu *et al.*, 1991), would be useful to make this type of screening calculation.

3.3.5.3 Waste Form and Waste Type

The physicochemical properties of the waste form and waste type will determine the release mechanism(s) for a given radionuclide inventory. Aqueous release, once the container degrades, is controlled primarily by the waste form and waste type. Radionuclide release from various waste forms such as cement-solidified waste (diffusional release) and activated metals (dissolutional release) may vary significantly from waste forms that have only surface contamination and are characterized by a "wash-off" or rinse release. Understanding specific release mechanism(s) that retard release from specific waste forms can be extremely important, depending on the inventory, in developing appropriate source term release models.

3.3.5.3.1 Issues

The minimum requirements that all waste forms must meet, to be acceptable for near-surface disposal, are given in 10 CFR 61.56(a). In addition to these minimum requirements, certain wastes (i.e., Classes B and C wastes, and Class A waste that is to be co-disposed of with Classes B and C waste) must be stabilized (structurally) and meet the requirements of 10 CFR 61.56(b). Stability is defined in terms of the ability to keep dimensions and form under disposal conditions. Stability can be provided by the waste form (e.g., activated metals); by processing the waste to an acceptable form (e.g., cement solidification); placing the waste in a HIC; or by the disposal unit itself (e.g., vault disposal). Note that stability does not imply that the waste form will not release radionuclides, nor that its container is water-impermeable for the same length of time that it is stable. Waste form stability is a component of the systems approach, to Part 61, which supports the goal of minimizing water contact with waste. However, the relationship of waste form stability requirements and release rate from the waste form is not necessarily straightforward. Assumptions with respect to the release of radionuclides need to be justified based on properties of the waste form and chemical environment in the disposal unit.

The staff is aware of the following four broad categories possible for characterizing the release of radionuclides from the waste form: (a) rinse release; (b) diffusional release; (c) dissolutional release; and (d) sorption coefficient or K_d release. A rinse release or wash-off occurs when infiltrating water removes or washes radionuclides from the surface of the waste form (e.g., appropriate for Class A waste consisting of lab trash, clothing, plastics, etc.). A diffusional release results when the release of radionuclides is limited by diffusion through a porous waste form such as cement (e.g., cement-stabilized waste form). A dissolutional release occurs when the release is controlled by the corrosion rate of a metal waste form (e.g., activated metals). Certain waste types may be characterized by a K_d or sorption release when a radionuclide is bound or sorbed onto a surface such that radionuclide release is characterized by a distribution coefficient or K_d (e.g., ion-exchange resins that are selected for their sorption properties). Additionally, all releases can be moderated to some degree by solubility limits for the particular radionuclide and particular chemical environment of the disposal unit (see Technical Position 3.3.5.6 for discussion on solubility limits).

The variation of waste forms and waste types both within and between the waste classes can result in significant variation in overall releases from the facility. Applicants should, therefore, identify the waste generators and waste streams anticipated for disposal, to make appropriate assumptions regarding inventory waste forms and waste types. During facility operation, waste form and waste type assumptions should be updated and the performance assessment calculations redone if significant deviations occur between these assumptions and the characteristics of waste being disposed. At the time of facility closure, the performance assessment calculation will use the actual inventory and disposal methods based on manifest data to update the waste form and waste type assumptions.

3.3.5.3.2 Recommended Approach

LLW inventories will typically involve a large variety of waste forms and waste types, which may complicate the selection of an appropriate approach for estimating waste form release. A simple, conservative approach for the performance of waste forms and waste types should be used initially. A more sophisticated, less conservative, approach could be used for particular waste streams and radionuclides where the simple approach produced unacceptable results. Less conservative analyses generally will involve more support to justify their use for a particular application and therefore should be used on an as-needed basis. Homogenization of the disposal unit, by allowing globally assigned percentage releases by the various mechanisms and radionuclides (e.g., 60 percent rinse release and 40 percent diffusional release for a particular radionuclide), is an example of a simple approach that is acceptable if it is supported by site-specific inventory information. The wash or rinse release model would generally be conservative in all cases; however, the very conservative nature of this approach limits its overall utility. Knowledge about the particular waste forms and waste types being disposed of may be useful for selecting approaches that limit waste form release because of consideration of specific characteristics of the waste form and waste type such as low permeability of a cement-solidified waste, corrosion rate of activated metals, and sorption on an ion-exchange resin.

Generally more is known about the releases of radionuclides for Classes B and C waste forms than for Class A, particularly for solidified waste streams where a diffusional release may be appropriate. For solidified waste forms, release of radionuclides may be diffusion-controlled and can be quantified by the American National Standards Institute/American Nuclear Society (ANSI/ANS) leach test (ANSI/ANS, 1986) that is incorporated in NRC's technical position on waste form (NRC, 1991c). However, the effectiveness of diffusion control of waste form release rates over long time periods (hundreds of years) will be limited by the eventual degradation of a cementitious waste form and subsequent increase in the diffusion coefficient.

Ion-exchange resins and activated metals are examples of waste forms that require a chemical reaction before release of radionuclides from the waste form. Ion-exchange resins were selected by industry because of their sorption properties, and they probably wouldn't freely release all their sorbed nuclei at once (i.e., in a rinse release). However, little is known about the release of nuclei from these materials over long timeframes, in a setting such as an LLW disposal site. Release of radionuclides from the ion-exchange resin is often estimated by considering the distribution coefficient for the individual radionuclide in the ion-exchange resin. However, to take credit for some kind of partitioning properties for the resins, while seemingly reasonable, would be highly uncertain over extended timeframes without specific experimental and site-specific chemical data. Release of radionuclides from activated metals could be controlled by the corrosion rate of the metal except where the surface has removable contamination.

Solubility limits are an extremely important consideration when selecting specific modeling approaches. Solubility limits, especially in the high-pH environment of a cement-buffered disposal unit, may be very useful in limiting release of radionuclides and thus reducing the need for characterizing waste form release rates. However, the complex and transient nature of the waste types and of the disposal unit chemistry exacerbates the difficulties in obtaining reliable solubility limits and requires that uncertainties must be addressed. Selection of the solubility limits for most radionuclides should be conservative under the anticipated conditions and is discussed in the technical position, below.

3.3.5.4 Waste Container

3.3.5.4.1 Issues

Waste containers can improve overall performance by delaying the release of radionuclides, allowing short-lived radionuclides to undergo significant decay, while the container remains leak-proof. Containers for LLW typically consist of carbon-steel drums, low-specific activity (LSA) steel liners, or HICs. Each container will have its own characteristic lifetime, during which it would be considered "leak-proof," which would have to be justified for the particular application. Manifest information can provide data on the distribution of LLW by waste container type(s). In some cases, it may be possible to estimate or infer LLW distribution by container. For example, Class A wastes are generally disposed of in LSA boxes or "55-gallon" drums; Class B wastes are generally disposed of in HICs; and Class C wastes are generally disposed of in liners (e.g., activated metals) or HICs.

The structural stability requirement of 10 CFR 61.56(b) can be provided by processing the waste (e.g., solidified in cement) or placing the waste in a container (e.g., HIC) that provides the stability. Examples of materials used in construction of HICs include: Ferralium-255; stainless steels; metallic fiber-reinforced concrete with polyethylene inner shell; polymer-impregnated concrete; high-density polyethylene (HDPE); or combinations of these. HDPE HICs, containing Classes B and C wastes, are placed in concrete overpacks for additional stability.

There is considerable uncertainty and argument as to the length of time that these containers will provide isolation from the environment. Initial performance assessment analyses should investigate the impact, on facility performance, of the length of time HICs would provide integrity against water penetration. The uncertainty concerning the "leak-proof" performance lifetime of the HICs would tend to increase as the performance lifetime increases. Assumptions regarding long-term "leak-proof" performance of containers will need to be justified for the chemical characteristics of the disposal unit and the container design. Additionally, the importance of the integrity of a container to keep water out must be viewed relative to the effectiveness of other engineered barriers (e.g., cover and concrete vault) to reduce infiltration into the disposal unit. An assumed long container lifetime for a HIC could have a profound effect on the facility performance when its lifetime significantly exceeds the effective lifetime of other barriers to infiltration, such as the cover. On the other hand, the lifetime of other containers (e.g., 55-gallon steel drums), with relatively shorter lifetime compared with HICs, could have very little effect on performance, because they will have degraded long before engineered barriers are compromised relative to water flow.

3.3.5.4.2 Recommended Approach

Estimations of container lifetimes generally focus on HICs that are made of corrosion-resistant materials or carbon-steel containers (e.g., 55-gallon drums, LSA boxes). For carbon-steel containers, a time-averaged corrosion rate has been proposed as one possible approach for estimating container lifetime (Sullivan, 1993). However, general corrosion failure of carbon-steel containers is anticipated to result in short lifetimes (i.e., mean lifetimes on the order of tens of years), which provides little performance enhancement. Therefore, it is recommended that carbon-steel containers be given no credit for delaying releases because of the anticipated short lifetime relative to either the lifetime of other engineered barriers such as the cover or the institutional control period. Additionally, significant justification might be necessary to support long lifetimes (e.g., lifetimes greater than 50 years) for carbon-steel containers, without commensurate benefit to overall performance. For example, the chemistry of corrosion processes in soil is generally based on a generic database, the use of which could lead to large uncertainties in the predicted corrosion rates (see Sullivan and Suen, 1989). The effects of internal corrosion by the waste streams would also have to be considered when determining container lifetime.

The length of time a HIC provides isolation of the waste from the environment could be substantially longer than carbon-steel container lifetimes as well as other engineered barriers and thus potentially be an important factor in delaying releases. Justification will be

necessary to support the length of time credit is taken for water not contacting waste inside the HIC. After this period of performance, a conservative assumption would be that the container can no longer prevent releases of radionuclides. Generally, a simple model for HICs will treat HICs as a group such that there are no releases before water entering the HICs and after this "failure" time, the HICs do not offer any reduction in radionuclide releases. Thus, the technical basis for defining the waste container "failure" time needs to be provided. For example, an adequate technical basis could include: (a) an NRC-approved topical report;[14] (b) specific information on the features that inhibit water movement into the HIC; and (c) specific information on the HIC that relates its designed stability properties to its ability to keep water out of the waste. Sophisticated models, which attempt to take credit for the distributed or partial failure of individual containers, may result in lower estimates for release rates, but will require the applicant to provide additional details supporting the technical basis for the assumed credit.

Similar to the approach recommended for partitioning the release mechanisms, it would be acceptable to "homogenize" the waste containers of the disposal unit by assigning a percentage of containers by waste class (e.g., for Class C waste, 60 percent are contained in HICs and 40 percent are contained in liners), if it is supported by site-specific inventory information. The location of LLW within a disposal facility, by waste class, may also be an important consideration in any LLW performance assessment. However, the locations and relative positions of individual containers within each waste class in the disposal facility need not be considered in any performance assessment, unless an applicant believes this level of detail is important.

3.3.5.5 Source Term Models

Selection of appropriate modeling approaches for estimating radionuclide releases from the disposal unit will need to consider the processes affecting container lifetime, release rates, and solubility limits. Any particular approach should be tailored to the characteristics of the facility and the level of sophistication necessary to demonstrate compliance. For example, one facility may require only solubility limits to demonstrate compliance, whereas another may need to consider a release rate and solubility limits. The appropriateness of any particular approach is not a generic issue and can only be determined based on the characteristics of the facility (i.e., inventory, design, and site). Once a modeling approach is selected, both generic and site-specific information may be useful in assigning parametric values within the model(s) and supporting specific approaches.

A variety of source term models have been developed in recent years and are compared and discussed in the following references: Kozak *et al.* (1990a, 1989a, 1989b); Sullivan (1991); and Kozak *et al.* (1993). *BLT* (**B**reach, **L**each, and **T**ransport) and **DUST** (**D**isposal **U**nit **S**ource **T**erm) were developed for NRC by the Brookhaven National Laboratory (Sullivan

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[14] Or, in the case of LLW disposal facilities licensed by Agreement States, following the guidance established by the designated regulatory authority.

and Suen, 1989; Sullivan, 1993; MacKinnon, 1995; and Sullivan, 1996) to provide comprehensive analytical capabilities (e.g., individual containers within a disposal unit can be evaluated) and to consider container lifetimes, release rates, and solubility limits. *NEFTRAN II* (**NE**twork **F**low and **TRAN**sport — Olague *et al.*, 1991) can be used to implement a simpler approach, which considers the entire disposal unit rather than individual containers, to account for the effects of container lifetime (a single lifetime for all containers in a disposal unit); release rate (a single leach rate for all waste); and solubility limits (solubility limit is element-specific). Solubility limits for radionuclides are common to all three models. It is extremely important to use solubility limits appropriate to the facility being analyzed. Because of its potential importance to performance, Technical Position 3.3.5.6.1, below, provides a detailed discussion on this subject.

3.3.5.6 Chemical Environment

The chemical environment within the waste disposal facility may have significant, long-term impacts on the releases of radionuclides from the waste and subsequent transport out of the disposal unit. Consideration of this chemical environment is important for two specific areas within the source term model: (a) if credit is being taken for solubility limits of radionuclide species in the aqueous phase; and (b) if credit is being taken for retardation coefficients specific to the materials within the disposal units. An understanding of the chemical environment within the disposal units is also important if the source term model is based on empirically derived radionuclide release rates or other release mechanisms from laboratory or field studies. Another important consideration is that a disposal system could be engineered to have specific chemical properties that will buffer, over long time periods, the overall chemical state of the system, which would result in facility-specific radionuclide solubilities and retardation coefficients for the performance assessment.

3.3.5.6.1 Considerations and Issues

Application of source term models, which make use of release rates or solubility limits to improve the radionuclide containment of the facility, can be highly uncertain because of a lack of knowledge of the chemical conditions that might occur inside a disposal unit. Chemical considerations that are important for assessing the releases of radionuclides from the LLW disposal facility include: (a) chemical conditions inside the disposal units that could affect solubilities, diffusion, corrosion rates, and sorption properties of radionuclides (e.g., Ph, redox potential, ionic strength, buffer capacity, chemical composition, speciation, complexation, etc.); and (b) potential chemical changes (e.g., oxidizing to reducing conditions) over time, that could affect releases of long-lived radionuclides.

One key issue is to develop an understanding of the chemical environment that may occur in the disposal units so that reasonable and conservative assumptions with respect to radionuclide solubility limits or retardation coefficients for the backfill material may be made. The chemical environment at different points within a disposal unit could be highly uncertain over the performance period, because of the heterogeneous nature of LLW. However, depending on the design of the disposal facility and the methods used to stabilize and dispose of the LLW, a concrete vault disposal system could contain large amounts of

calcium hydroxide and calcium silicate mineral phases in various components of the system (e.g., cementaceous waste forms, concrete overpacks, grout backfill, and the structure itself) which could have a strong buffering effect on the overall chemical state of the system. Thus, uncertainty of specific solubility limits and/or retardation coefficients might be reduced in a performance assessment for such a system.

A second key issue is the applicability to vault systems of existing data on solid phase/aqueous phase partition coefficients derived from existing field and laboratory studies. This is important, because most St... and compacts are developing concrete vault disposal facilities rather than trench disposal facilities. Geochemical field, laboratory, and modeling studies, that have been carried out for LLW trench disposal sites show that, in general, the solutions are reduced relative to ambient ground water, and that significant increases in major ion concentrations, and dissolved organic species occur (Serne *et al.*, 1990; and references therein). A better understanding of the potential chemical conditions that may exist in a concrete vault will help determine if empirically based release models derived from studies of: (a) trench systems; or (b) field lysimeter studies (Rogers and McConnell, 1993; McConnell *et al.*, 1994; and McConnell *et al.*, 1996); and/or (c) laboratory leaching experiments using actual LLW (Akers *et al.*, 1994a,b; and Serne *et al.*, 1996) are conservative for a performance assessment of a concrete vault system.

A third key issue is to determine if certain materials, such as a specialized backfill or special concrete formulations, can be used to chemically condition the environment within disposal units. The goal in such an approach would be to chemically engineer the system to have certain specific properties that limit the potential mobility of particular radionuclides, especially radionuclides that may be present in releases as anions (e.g., ^{129}I and ^{99}Tc).

Empirical release models based upon partition coefficients derived from trench disposal systems are not appropriate for concrete vault systems. The Part 61 DEIS (NRC, 1981) used release factors (i.e., partition coefficients) based on ratios of measured radionuclide leachate concentrations to estimated radionuclide inventories in disposal trenches at Maxey Flats (Kentucky) — for ^{3}H, cobalt-60 (^{60}Co), strontium-90 (^{90}Sr), cesium-137 (^{137}Cs), $^{238/239}$Pu and americium-241 (^{241}Am) — and West Valley (New York) — for ^{14}C and ^{238}U (Oztunali *et al.*, 1981). The use of the Maxey Flats/West Valley partition coefficients implies a certain set of chemical conditions, for the disposal units, that must be justified in terms of conditions that are likely to occur in the system(s) being analyzed. For the Maxey Flats/West Valley trench leachates, near neutral pH and strongly anoxic conditions result in the leachates being supersaturated with respect to certain carbonate and sulfide phases (Dayal *et al.*, 1986; and Weiss and Colombo, 1980). Thus, if these systems have achieved a state of equilibrium, then the concentrations of radionuclides in solution represent both mobilization from the waste forms and removal as precipitates in secondary solid phases. A different set of chemical conditions or waste types may result in significantly different equilibrium concentrations of radionuclides in solution than would be predicted from the ratios. For example, the trench leachate concentrations of ^{238}U at West Valley are consistent with U(IV) solubilities in a reducing environment. If it is likely that oxidizing conditions will eventually

prevail in a proposed disposal system, then the Maxey Flats/West Valley partition coefficients are not appropriate as the solubilities of U(VI) are several orders of magnitude higher than for U(IV). Similar arguments apply to other radionuclides that are relatively immobile under reducing conditions, but relatively mobile under oxidizing conditions.

Another related problem is that the Maxey Flats/West Valley partition coefficients for certain radionuclides are derived from other radionuclides. Thus, ^{129}I and ^{99}Tc are assumed to be 10 percent of the ^{3}H ratio; nickel and iron are assumed to be the same as Co; niobium is assumed to be 75 percent of Co; and neptunium and curium are assumed to be the same as for Pu. The applicant would have to justify these assumptions and show that they are appropriate and conservative for the potential chemical conditions inside the proposed disposal units.

A more critical problem area for using the Maxey Flats/West Valley partition coefficients is that the true waste inventories in the trenches are considerably uncertain and the waste types disposed of at Maxey Flats/West Valley are not typical of current wastes. If the waste inventories are overestimated then the partition coefficients may be underestimated by large amounts. Therefore, even if the chemical environment issues discussed above can be resolved, the use of the Maxey Flats/West Valley ratios presupposes a knowledge base about the radionuclide inventories that cannot be supported.

3.3.5.6.2 Recommended Approach

Initial analysis should make use of simple, conservative models and assumptions before implementing more sophisticated techniques, which may require additional information to justify a less conservative approach. Conservative solubility limits could be set within reasonable bounds, given some consideration to the waste form and water quality chemical factors such as pH. After initial calculations, it might prove useful to examine in further detail the chemical conditions of the system (e.g., redox state, chemical composition, and ionic strength of water) to better understand the influence on solubility limits, corrosion rates, and release rates. Technical Position 3.3.5.6.3.2 provides information on available models for performing geochemical calculations.

The following technical approaches are acceptable for treating chemical characteristics in LLW performance assessments:

(a) A rinse-release model is used and no credit is taken for engineered controls on chemical characteristics, including backfill, chemical barriers, and geochemistry considerations. This is the most conservative approach.

(b) Credit is taken for the chemical conditions inside the disposal units to justify specific solubility limits, retardation coefficients, and corrosion rates. Sufficient justification must be presented for specific chemical conditions (e.g., redox conditions, pH). The justification may be based on experimental data, and/or the use of field data, where appropriate, in conjunction with geochemical modeling.

(c) If backfill materials or chemical barriers are used to retard the release of radionuclides to the ground water, sufficient justification must be provided that the sorptive properties of the material would be appropriate for the chemical environment of the disposal facility. The justification may be based on the distribution coefficient approach, experimental studies such as field lysimeter investigations, and laboratory studies, combined with geochemical modeling.

3.3.5.6.3 Development of Site-Specific Parameters and Models

There are several issues and concerns that need to be addressed in developing site-specific values and geochemical models for use in source term analyses. Similar considerations also apply to developing site-specific K_ds and geochemical models for input to the ground-water transport analysis. Of particular importance for the latter are the conditions and properties and models of the geologic strata most likely to be involved in radionuclide transport to the average member of the critical group.[15]

3.3.5.6.3.1 Radionuclide Distribution Coefficients

In general, performance assessments take credit for retardation in the transport of radionuclides. Development of retardation or K_ds for a specific application, whether inside the disposal units or in the unsaturated and saturated zones, should use an iterative approach. In recent years, literature reviews of K_d information for a large number of radionuclides and conditions have been developed (Baes and Sharp, 1983; Berry, 1992a,b,c; Isherwood, 1981; Looney *et al.*, 1987; Sheppard and Thibault, 1990; and Turner, 1995). The information from these and other K_d databases, and reviews will be useful in developing an initial range of K_ds appropriate for the site and disposal units. In the early stages of the iterative process, these initial ranges may be overly conservative but will be useful for identifying the most important radionuclides. In the latter stages of the iterative process, site-specific data could be developed for key radionuclides and would supplement information in the literature.

For sites where soil geochemistry will dominate the near-field environment compilations of soil, K_ds will be useful (e.g., Baes and Sharp, 1983; Sheppard and Thibault, 1990). Detailed information on K_ds reported in the Sheppard and Thibault paper are published in an Atomic Energy of Canada Report (see Thibault *et al.*, 1990). For disposal systems where large amounts of cementitious materials will be present, the applicant may need to consider K_d values measured on these types of materials. This will be a more limited data set than for soils and rocks, but information is available in a variety of publications and abstracts (e.g., Allard, 1985; Berry, 1992a,b,c). In addition, the staff has recently compiled information on sorption coefficients in the high-pH environment that is likely to dominate for long periods of time in a concrete/grout disposal system (Krupka and Serne, 1996).

Because the K_ds reported in these data bases cover many orders of magnitude, it will be

[15] The critical group is defined as the group of individuals reasonably expected to receive the greatest exposure to radioactive releases from the disposal facility over time, given the circumstances under which the analysis would be carried out. See Technical Position 3.3.7.1.

important to evaluate the specific information on the experimental conditions, soil types, and other variables under which the K_ds were measured. This type of information will be important in determining the appropriateness of applying these "generic" K_ds to the specific site conditions and will help in narrowing the ranges of values. A number of parameters reported for the measured K_ds may need to be considered and evaluated to bound the uncertainty in the K_d values. These parameters are likely to be facility-dependent, but may include: time of the experiment; solution pH; redox poise of the solution; nuclide concentration; major ion concentration and ionic strength; reduced iron content; vault-water versus ground-water chemistry; water/soil ratio; backfill and structural material variations; soil mineralogy and composition (e.g., clay content); batch experiments versus column experiments; and filtration method versus centrifugation.

Facility- and site-specific K_ds can be determined for a few radionuclides when necessary to help bound the uncertainty in the literature data with respect to specific site and facility conditions. Experiments would be carried out to measure these specific K_ds in the site characterization phase of the program. Representative vault water (if the anticipated chemical composition differs from that of the ground water) and representative disposal unit materials (e.g., concrete, backfill, etc.) will need to be used in the experiments. In general, either batch or column experiments would be appropriate (e.g., ASTM D-4319-83 (American Society of Testing and Materials, 1984)). However, detailed guidance on measuring K_ds under appropriate experimental conditions for site-specific applications is not provided in this technical position.

3.3.5.6.3.2 Geochemical Modeling of a LLW Disposal Facility

It is difficult to predict, *a priori*, what the aqueous chemistry inside a disposal unit will be without some knowledge of the main reactive components of the disposal system. The applicant needs to develop a conceptual model of the chemical conditions inside the disposal unit, if credit is being taken for a release model that is dependent on specific chemical conditions. For example, if the applicant wishes to take credit for specific solubility limits and/or sorption coefficients, then the values selected must be consistent with the conditions that are likely to occur in the disposal units.

As noted above, chemical conditions in concrete vaults may not be similar to trench conditions from which the leachate/solid partition coefficients were developed for the Part 61 *IMPACTS* analysis methodology (Oztunali and Roles, 1986). In general, if the applicant is relying on a source term model, in the performance assessment, that is based on field and/or laboratory data for radionuclide releases, then there is a need to develop sufficient justification to support the application of such data toward a specific site and facility. If the applicant is relying on a chemically engineered disposal system to retard specific radionuclides, then it must present information and modeling results that support the designed properties of the proposed system.

Geochemical modeling of expected disposal facility chemical conditions, determination of the potential chemical state in the disposal units, and comparison with models of and data from

field and laboratory studies, can be done to build confidence in the use of specific release models. Site characterization data (e.g., water chemistry, soil and backfill chemistry, etc.: see Chapter 2.6 ("Geochemical Characteristics") in NUREG-1200) must be obtained for both the natural site and engineered facility. Geochemical calculations (e.g., speciation, solubilities, and sorption) may be carried out using presently available codes such as *MINTEQ* (Felmy *et al.*, 1984); *MINTEQA2* (Allison *et al.*, 1991); *EQ3/6* (Woolery, 1992a,b; Woolery and Daveler, 1992c; and Daveler and Woolery, 1992); *PHREEQE* (Parkhurst *et al.*, 1980); *PHRQPITZ* (Plummer *et al.*, 1988); and *WATEQ4F* (Ball and Nordstrom, 1991). For a review of these codes and confirmatory studies see Bassett and Melchior (1990). The purpose of this type of modeling is to support the use of specific values and ranges of values within the performance assessment source term model.

3.3.5.7 Gaseous Releases

Some of the radionuclides present in LLW can be released from the LLW disposal facility in the gas phase. Gaseous radionuclides would be available for release immediately and completely after breach of the container, or may be released more slowly if the HIC design incorporates vents. For LLW buried below the ground, advective and diffusive migration to the ground surface and subsequent release to and transport in the atmosphere to locations downwind from the disposal facility, may conceivably contribute a non-trivial fraction of the total effective dose equivalent for the average member of the critical group.

3.3.5.7.1 Considerations

The most important radionuclides that must be considered and evaluated for gaseous release include; ^{14}C, ^{85}Kr, ^{222}Rn, ^{3}H and ^{129}I. These five radionuclides may be present in LLW facilities in a variety of waste streams and waste forms. Carbon-14 is expected to be present in dry solids, DAW (dry active waste), sorbed aqueous liquids, activated metals, and animal carcasses (Roles, 1990). Tritium is expected to be present in dry solids, DAW, sorbed liquids, oils, and animal carcasses. Both ^{14}C and ^{3}H could be released in the gaseous phase by several mechanisms, including: (a) microbial degradation of specific waste streams; (b) changes in oxidation/reduction conditions within the disposal facility over time; or (c) by leaching and volatilization mechanisms involving varying pH and other water chemistry considerations. Krypton-85 is disposed of as gas in sealed containers that will degrade over time. Radon-222, having a half life of only 3.8 days, is present in the disposal facility as a daughter product of ^{226}Ra ($t_{1/2}$ = 1760 years). The latter is present both from disposal of waste containing ^{226}Ra, and from the decay of ^{238}U in LLW.

3.3.5.7.2 Recommended Approach

A screening method is recommended to determine if gaseous release of the radionuclides ^{14}C, ^{85}Kr, ^{222}Rn, ^{3}H and ^{129}I in the disposal facility inventory might contribute significantly to the dose to the average member of the critical group. The screening approach would assume: (a) all the containers simultaneously fail, resulting in a puff release; and (b) the entire inventory of ^{14}C, ^{3}H, ^{85}Kr, ^{222}Rn, and ^{129}I in the disposal facility is available for release in the gaseous phase to the surface in a short period of time that conservatively bounds the problem

(e.g., 1 year). If ^{14}C and ^{3}H appear to be important contributors to the TEDE to the average member of the critical group, it may be possible to estimate the fractions of ^{14}C and ^{3}H released through the gaseous pathways relative to the total inventories of these radionuclides. The decay of short-lived radionuclide (e.g., ^{85}Kr, ^{3}H) inventory activities to much lower activity levels over the 300-year lifetime of the BGVs and EMCBs is also acceptable for screening. Details on the transport of gaseous radionuclides in the atmosphere can be found in Technical Position 3.3.6.3 ("Air Transport").

Because the screening analysis does not account for partitioning of radionuclides between gas and liquid phases, the entire inventory of radionuclides released to the atmosphere would still have to be considered available for ground water transport. A realistic and defensible generation rate and partitioning between gaseous and aqueous radionuclide species would have to be justified if the applicant desires to take credit for partitioning as a means of reducing the inventory available for release to either ground water or air.

If needed, more realistic release rates for ^{14}C, ^{3}H, ^{85}Kr, ^{222}Rn, and ^{129}I might be obtained from a recent study of mechanistic gas phase releases of radionuclides from individual LLW streams (Yim, 1994). This study simulates the evolution and production of radionuclide gas from LLW and estimates release rates to the atmosphere from LLW. Release rates may also be obtained from actual gaseous release data for the West Valley LLW disposal site (see Matuszek, 1982; Matuszek and Robinson, 1983; and Kunz, 1982 and references therein). However, a number of assumptions must be evaluated to determine the applicability of these release rates to a specific facility. For any particular LLW facility, the chemical conditions that govern the release processes and chemical form of the radionuclides are most likely different from the conditions at the West Valley trenches (Francis *et al.*, 1980; Kunz, 1982; and Dayal *et al.*, 1986). Partitioning of radionuclides between air and water is not explicitly considered; however the release rates based on the West Valley trench data implicitly take this into account. The release rates for West Valley (Kunz, 1982), when properly scaled, may represent a conservative estimate of release for a range of future LLW facilities based on the significant differences in West Valley waste disposal practices and anticipated facility designs (e.g., concrete vaults) and the forms and types of waste disposed. Nevertheless, the applicant would have to justify such an assumption. This can be done by examining the waste streams or waste forms to identify the extent of LLW most likely to undergo physical or chemical changes that would result in gas phase release of radionuclides.

More complicated analyses may include: determining radionuclide gaseous production rates by waste class, waste stream, and waste form from the LLW inventory; more sophisticated consideration of container failure; consideration of different mechanisms influencing gaseous releases (e.g., microbial, aerobic, anaerobic, radiolytic); and partitioning of the radioactive gases between aqueous and gas phase. In a concrete vault disposal system with a large amount of internal concrete (e.g,. in overpacks, grout backfill and so forth), the applicant may need to consider the effects of the high-pH and large amounts of calcium (Ca) present to take credit for the precipitation $^{14}CO_2$ as calcium carbonate ($CaCO_3$).

3.3.6 Transport Media

Radionuclides released from an LLW disposal site are transported in the general environment by ground water, surface water, and air. Transport media may be linked to radionuclide doses directly, such as through the consumption of contaminated well water, or indirectly through pathways composing the food chain. How radionuclide transport should be analyzed is influenced by the requirement for assessing annual dose to the average member of the critical group. This requirement implies: (a) selecting the maximum concentrations over the entire time and spatial domain of interest in the general environment that might be inhabited by a member of the critical group; and (b) integrating radiation exposures over a period of 1 year, rather than deriving a dose rate from radionuclide concentrations at specific times.

Approximations of properties and behaviors of complex radionuclide transport systems are depicted in site-specific conceptual models for analyzing radionuclide transport at LLW facilities. The complexity of conceptual models — features and processes modeled and how they are represented — and solution approaches to site-specific modeling, should be based on compliance demonstration needs. Development of conceptual models is the second step in the recommended LLW performance assessment process described in Technical Position 3.1 of this NUREG. Guidance presented in Technical Position 3.1, and in Technical Positions 3.3.2.1.1 and 3.3.2.1.2 (on treating model and parameter uncertainty) should be followed when analyzing media transport.

3.3.6.1 Ground Water

The objective of the ground-water flow and transport analysis is to assess radionuclide concentrations in the ground water at receptor points (i.e., human access locations) consistent with the exposure pathway assumptions for assessing the TEDE to the average member of the critical group.

3.3.6.1.1 Considerations

Available hydrogeologic and geochemical site characterization data must be evaluated and abstracted to form a simplified representation of the ground-water flow and transport system. This abstraction should consider all relevant conditions, processes, and events present at the site as well as any cause-effect relationships. Geometry of a modeled system will be defined by site geologic and hydrogeologic characteristics such as stratigraphy, faults, ground-water flow boundaries, and zones of ground-water recharge and discharge. Processes modeled will be selected from among the physical and chemical phenomena affecting ground-water flow and transport. Physical processes represented in a conceptual model may include advection, dispersion, and diffusion. Although advection will probably be the predominant means of transport — dispersion is probably not very important at disposal site scale -- the analyst may decide to account for dispersion in the analysis. Geochemical processes include sorption, precipitation, complexation, and redox reactions. However, the influence of some of the geochemical processes on transport may be extremely difficult to evaluate.

In simplifying the analysis, the analyst will have to determine how best to represent the

spatial variation of hydrologic parameters used to characterize features and processes included within the analysis and some consideration must be given to the appropriate analytical approach and dimensional representation to include. Detailed ground-water flow and transport modeling may be performed as needed to provide the analyst with sufficient insight to support simplification of the conceptual flow system while retaining features important to overall performance. These modeling activities commonly are called auxiliary analyses because they support, but are not part of, the final systems model.

In assessing the dose to the average member of the critical group, the analyst will have to consider radionuclide concentrations in ground water at all potential points down-gradient from the disposal unit where a human could come into contact with the contaminated water. This means that both existing (i.e., current) and hypothetical ground-water discharge points will have to be considered. Such discharge points could include streams, pumping wells, springs, and seeps. An analysis based solely on existing discharge points will likely be non-conservative because, over the long timeframes covered by the analysis, additional human access locations may develop closer to the disposal unit. Therefore, the analysis will likely involve a hypothetical well, and the analyst will have to make some assumptions in terms of where to assume that the well is located. In addition, the analyst will have to make certain assumptions regarding pumping well design and construction. Design features, such as well depth and screen length, are important in terms of determining how much water is available for dilution and how much of the plume will be captured by the well.

3.3.6.1.2 Recommended Approach

For this analysis, the staff recommends using the approaches to developing conceptual models discussed in Technical Position 3.1, and approaches treating model and parameter uncertainty discussed in Technical Positions 3.3.2.1.1 and 3.3.2.1.2. Auxiliary analyses may be useful in identifying important processes to be considered in the conceptual model as well as in filling-in data gaps. Although regulatory compliance is based on the annual dose to the average member of the critical group, the staff recommends that the ground-water transport analysis provide concentrations in well water at the site boundary that would have the composite concentrations of radionuclides resulting in the highest dose. For conservatism, the analyst should consider all points on the disposal site boundary as potential pumping well locations. The analyst can assume that the design of the pumping well is consistent with the design of other wells common to the region in which the site is located. Because the well is treated as a pumping well,[16] the analyst should initially assume that the well will yield sufficient water of adequate quality to provide the annual water requirements assumed as part of the overall dose analysis. For example, if the well is assumed to supply water for irrigation and drinking, the amount and quality of water assumed to be pumped should meet the need of these two requirements. If analyses of the hydrogeologic system suggest that a well would not satisfy the water requirements of the hypothetical user, the scenario

[16] As opposed to a monitor well — with a capture zone that can be assumed to be at steady-state conditions.

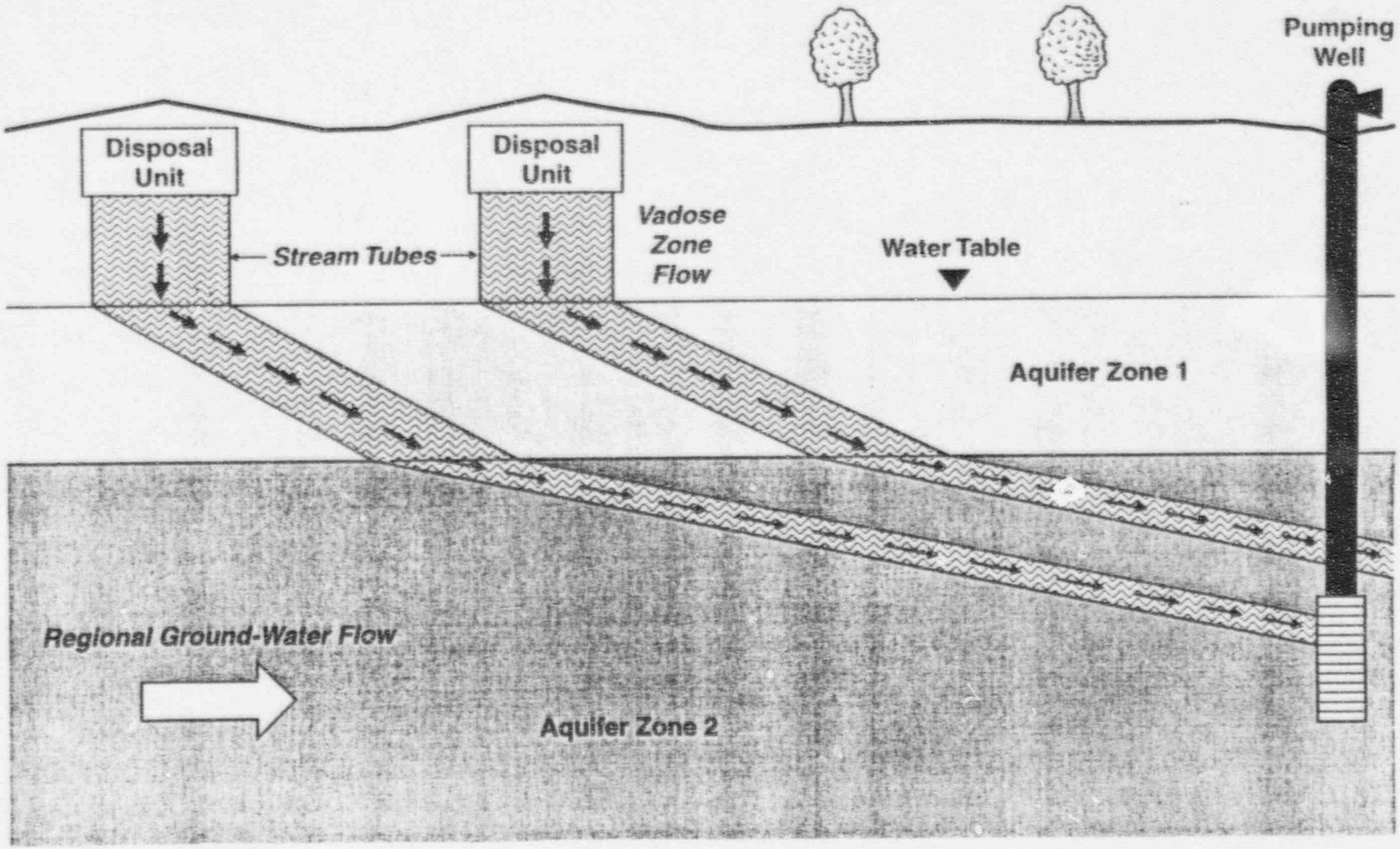
controlling the annual water requirements may need to be adjusted by considering the availability of water from other sources.

As a generally applicable approach for simulating radionuclide transport in ground water, the staff recommends streamtube analyses. This approach envisions a family of steady-state streamtubes connecting discrete radionuclide sources (i.e., disposal units) to the water table, the pumping well, and possibly any other location where ground water discharges to surface water. As an example, Figure 11 depicts a hypothetical disposal system and hydrogeologic environment, including two aquifers and a pumping well. For this hypothetical example, the streamtubes associated with each discrete source (a disposal vault) consist of a vertical segment from the disposal vault to the water table, continuing through Aquifer 1 to Aquifer 2. For sites with relatively thin unsaturated zones, travel time from the disposal vault to the water table will not afford a significant amount of radioactive decay. Therefore, the analyst may ignore the travel time through the unsaturated zone. The streamtubes should more-or-less correspond with the direction of regional ground-water flow. To justify the location and properties of streamtubes, auxiliary analyses of the ground-water flow system may be needed. In this example, the vertical extent of one streamtube and a portion of another are intercepted by the pumping well. Within streamtubes, solute transport is modeled as advection with the moving water, and dispersion in the direction of flow. Typically, the analysis should account for radioactive decay and daughter in-growth.

The radionuclide flux from each source is diluted by the flux of clean ground water within each streamtube. Transport through streamtubes ignores reduction in the concentration of radionuclides from dispersion normal to the flow direction (transverse dispersion). The significance of transverse dispersion is limited by the short distance between the radionuclide source and the pumping well, and because the analysis evaluates the concentration of radionuclides in water discharged by a pumping well rather than at points within the aquifer. Ground water captured by the pumping well may consist of both a portion of a plume or plumes contaminated with radionuclides and uncontaminated water. The concentration of radionuclides in water discharged by the pumping well may therefore be diluted with uncontaminated water. Auxiliary analyses should be conducted to estimate the contribution of radionuclides derived from the total volume of water withdrawn by the pumping well. In other words, the pumping well averages the concentration, based on the relative proportions of contaminated and uncontaminated water pumped. Thus, proper treatment of how the pumping well influences ground-water flow captures contaminant plumes is essential to approximating radionuclide concentrations in water pumped from the well.

Analysts, most likely, will wish to account for radionuclide retardation in the ground water system. Soil and rock characteristics such as pH, organic content, texture, and mineralogy control radionuclide retardation in ground water. Distribution coefficients (K_ds), which express the partitioning of an ion species between the solution and the solid adsorbing phase, are commonly used to describe radionuclide migration rates in transport analyses. Because of the general significance of retardation to the results of radionuclide transport analyses, use of site-specific K_d values for important radionuclides is recommended. However, retardation

Figure 11. Conceptualization showing potential streamtube pathways to pumping well in ground-water flow and transport analysis.



Disposal Unit
Disposal Unit
Stream Tubes
Vadose Zone Flow
Water Table
Pumping Well
Aquifer Zone 1
Regional Ground-Water Flow
Aquifer Zone 2

will, in most cases, have a minimal effect in reducing doses from long-lived radionuclides, because of their half-life and the short distance traveled. For the most part, radioactive decay of the short-lived radionuclides can be achieved before they leave the disposal unit. Thus, their decay through the groundwater pathway should have a minimal effect in reducing doses. Therefore, to account for specific geochemical processes that lower radionuclide concentrations in ground water, especially those that permanently remove radionuclides from ground water (i.e., irreversible sorption and chemical precipitation), supporting auxiliary analyses in geochemistry will likely be needed. Therefore, it is recommended that analysts not consider such processes when performing ground-water transport analyses unless their inclusion would be highly beneficial to making a successful demonstration of compliance with the dose requirement. Technical Positions 3.3.5.6.3.1 and 3.3.5.6.3.2 provide additional guidance on the use of K_ds and geochemical modeling in performance assessment.

3.3.6.2 Surface Water

The objective of the surface-water transport analysis is to assess radionuclide concentrations in surface water at human access locations consistent with exposure pathway assumptions for assessing the TEDE to the average member of the critical group. Furthermore, the surface-water analysis needs to be consistent with the water use and pathway exposure assumptions considered in assessing the TEDE from ground water. For example, if ground water is shown to be the principal domestic water-use pathway for the disposal site, then the amount of surface water used for domestic purposes should account for the amount of ground water already incorporated into the analysis. As in assessing dose for the ground-water pathway, the average member of the critical group resides at or near the disposal site boundary.

For purposes of this guidance: (a) a facility that is constructed above natural grade and mounded with earth (EMCB) is considered to perform as a BGV; and (b) the design of covers for below-ground disposal facilities will preclude exposure of waste at the surface by erosion where it would be subject to overland transport.

3.3.6.2.1 Considerations

Surface-water bodies can become contaminated with radioactivity by overland flow across a disposal site following exposure of the waste by erosion, or by the discharge of seeps and springs contaminated with leachate percolating from an LLW disposal facility (see Figure 13). For radionuclide transfer overland, contaminated runoff entering a stream may undergo immediate dilution; however, radionuclides deposited on the ground may become incorporated into plant or animal tissue, or be subject to further overland transport through successive episodes of erosion and deposition. The transfer of radionuclides via overland flow is generally not considered to be significant to the performance of below-ground disposal facilities (i.e., BGVs) constructed according to Part 61 requirements.

In surface water, radionuclides can occur in either the water column itself or in association with sediment. Partitioning among forms that remain in solution, suspension, or settle to the bottom, is controlled by the surface-water body's geochemical environment. Radionuclide

concentrations in water normally will be reduced by continued dilution with non-contaminated water or by adsorption onto bottom sediment.

When a stream is joined by a tributary, complete mixing usually is not instantaneous. Often, the water from the influent stream flows unmixed for a distance alongside water in the major stream until dispersion, diffusion, and turbulence cause the waters to mix. When the influent stream is contaminated with radioactivity, the specific activity level is not fully diluted until mixing is complete. Therefore, in assessing doses from drinking water withdrawn from a stream, it may not be conservative to assume that complete mixing has occurred. Instantaneous complete mixing is also unlikely when stream flow enters a retardant body of water such as a lake, reservoir, wetland, or tidal body. Turbulence can contribute to mixing, but thermal or density stratification may instead serve to impede such mixing if the influent stream flows as a tongue along the bottom or at some elevation in the water column. Slow flushing in a wetland or a tidal water body may also serve to concentrate radionuclides; moreover, precipitation of radionuclides may occur if entry into a brackish or saline environment affects solubility. In any of these water bodies, there is likelihood that aquatic plants and animals will concentrate whatever radionuclides are made available to them.

The point of exposure for the surface-water pathway will normally be at the nearest downstream location from the site where surface-water contact or withdrawal is feasible. Potential dose pathways for surface-water analysis may include domestic use and irrigation; livestock ranching, with or without bioaccumulation; water-contact activities such as recreation, when there may be direct gamma radiation from exposure to contaminated sediments; and consumption of fish taken from contaminated surface-water bodies (see Technical Position 3.3.7.2.1). It is unlikely that any surface-water pathway analysis would need to include all these water uses. For example, gamma-emitting radionuclides in bottom sediments are generally incapable of producing significant external doses, except possibly in low-velocity areas where sediments may accumulate. In addition, the DCFs for eating fish implicitly account for bioaccumulation in bottom-feeding aquatic organisms. Therefore, a simple screening-level analysis may permit the exclusion of radionuclides in bottom sediments from further analyses.

The nature and extent of surface-water transport analyses will depend on whether the facility is constructed above or below the ground surface. For below-ground disposal facilities (i.e., BGVs and EMCBs), eventual disposal unit degradation will result in radionuclide releases to ground water, but would not necessarily result in direct exposure of waste at the surface. Because radionuclide concentrations in contaminated ground water would be diluted by surface water, surface-water transport is not considered to be significant at below-ground disposal facilities (BGVs). Above-ground disposal facilities (i.e., AGVs), however, rely entirely on engineered barriers to isolate waste from the surface environment. Eventual disposal unit degradation and erosion will expose the waste and subject it to redistribution by surface processes. Therefore, surface-release pathways, including surface water, are more significant to the performance of above-ground disposal facilities and are potentially more difficult to analyze as well. In assessing the performance of a degraded AGV, it may be

necessary to estimate the proportion of radionuclides released that directly enter surface water from overland flow and transport and the proportion that enters surface water via ground water through seeps or springs. Depending on the particular times of travel and dilution en route, the two transfer mechanisms to surface water may each have significance for human exposure, over entirely different timeframes.

3.3.6.2.2 Recommended Approach

As noted above, the significance of the surface-water pathway will depend on the extent that erosion and overland transport of waste are relevant to the particular site under consideration. Although actual site conditions and disposal cell design should be evaluated (e.g., erosion resistance of EMCB design), generally, site selection and cover design for below-ground disposal will minimize the likelihood of erosion and overland transport of radionuclides being a problem. Since there currently are no plans for an above-ground disposal facility in the United States, the staff's recommended approach is to evaluate radionuclide concentrations in surface water resulting from the discharge of contaminated ground water.

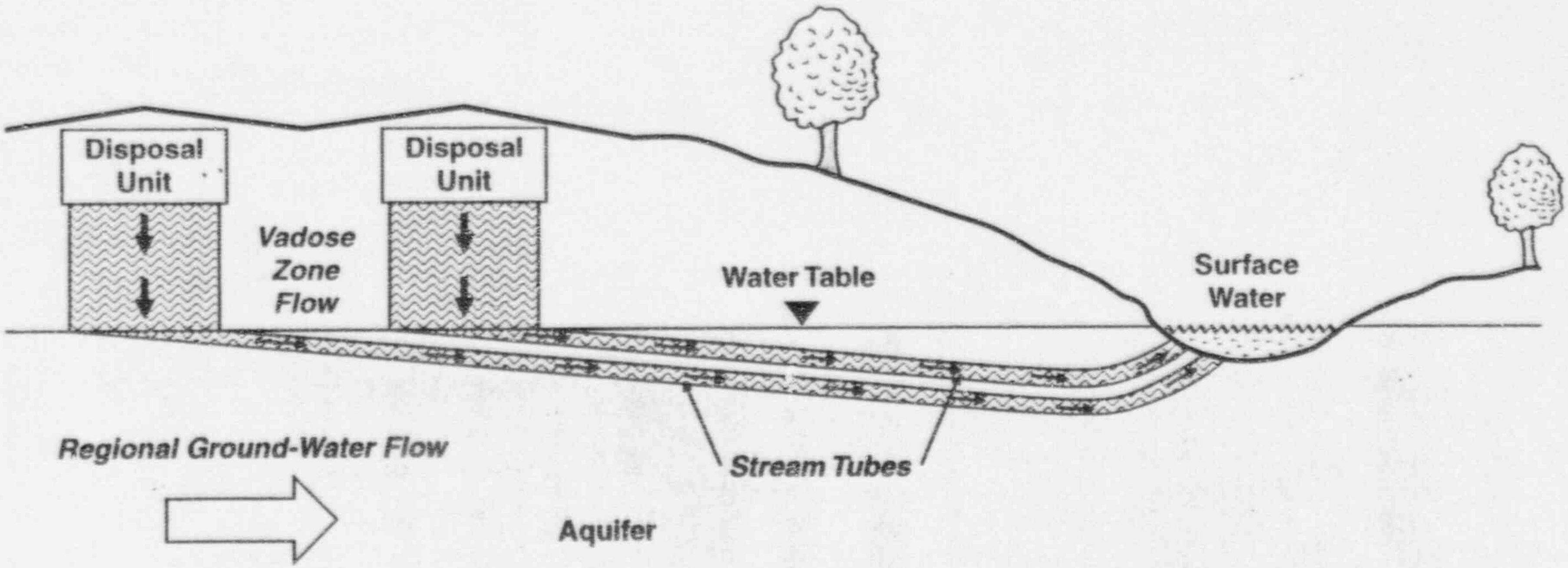
3.3.6.2.2.1 Below-Ground Disposal Facilities

As the most important transfer mechanism of radionuclides from a BGV to surface water, the interaction between ground-water and nearby surface-water bodies should be assessed. The surface-water model should be based on the assumption that all radionuclides distributed in the aquifer in the vicinity of the nearby surface-water body are discharged into it. The discharge should be assumed to occur as a point (seep or spring) at the shore; assuming a diffuse laterally distributed ground-water plume entering the surface water would be less conservative.

The staff recommends that an initial approach to calculating surface-water concentrations involves diluting the ground-water concentration at the point of release (i.e., spring) by the ratio of the surface-water discharge to the volumetric ground-water flux associated with the contaminant plume (i.e., the volumetric flux that infiltrates the disposal site). For example, if the volumetric infiltration at the site is greater than the surface-water discharge (i.e., stream flow) then there is no dilution of the concentration in the surface water. However, if the volumetric infiltration at the site is half the surface-water discharge, then the concentration in the surface water is reduced by a factor of 2. To calculate the radionuclide concentration and ground-water discharge rate at the spring, a 1-D streamtube analysis, as described in Technical Position 3.3.6.1.2 (calculating ground-water concentrations at the site boundary), is recommended. It should be noted that the determined coincident stream flow and volumetric ground-water flux of the plume should be based on a common meteorological database and analysis.

If radionuclide transport away from the initial point of surface-water contamination is an important site-specific consideration in the performance assessment, the staff recommends that the next step should be use of a site-specific surface-water transport model. For example, where appropriate, the *GENII* model can be used for a river or lake (Napier *et al.*, 1988). The surface-water model within *GENII* assumes that the flow depth, convective

Figure 12. Conceptualization showing potential surface-water contamination pathways. All radionuclides distributed in the aquifer, in the vicinity of the surface-water body, are discharged into it.


Disposal Unit
Disposal Unit
Vadose Zone Flow
Water Table
Surface Water
Regional Ground-Water Flow
Stream Tubes
Aquifer

velocity, river width, and lateral dispersion coefficient are constant; the river channel is straight and the point discharge of contaminants is continuous (Kozak *et al.*, 1990a). Other examples of analytical models used to calculate surface-water concentrations in streams subject to mixing and dispersion are provided in Regulatory Guide 1.113 (NRC, 1977c) and these models are contained in the *GENII* computer code. However, these example models are for short-term transient releases and may need to be modified to consider chronic long-term contaminant releases.

The important water pathways in LLW performance assessment usually are evaluated for only dissolved radionuclides; consequently, radionuclide interactions with sediments frequently are neglected. The usual effect of neglecting sediment sorption is to produce conservative estimates of exposure via the food chain (National Council on Radiation Protection and Measurement, 1984). A simple approach to sorption of radionuclides onto sediments is included in *GENII* and can be used if needed.

3.3.6.2.2.2 Above-Ground Disposal Facilities
In conducting a LLW performance assessment for an AGV, an applicant will be expected to address the technical concerns about above-ground disposal raised above, to the extent that those surface-water issues apply.

3.3.6.3 Air Transport
The objective of the air transport analysis is to assess the contribution of gaseous radionuclides released to the atmosphere to the TEDE to the average member of the critical group.

Several radionuclides present in LLW could be released from the LLW disposal facility in the gas phase and transported in the atmosphere by dilution and advective dispersion mechanisms to locations downwind from the disposal facility where they would be inhaled and conceivably contribute a non-trivial fraction of the dose to the average member of the critical group. In addition, radionuclides released to the atmosphere could contribute to the ingestion dose to the average member of the critical group through the ingestion of radionuclides that become incorporated in plants and animals and through radionuclides that accumulate in the soil by either dry or wet deposition and are subsequently taken up by plants and animals to become part of the food-chain pathway.

3.3.6.3.1 Considerations
Generally, the important radionuclides that must be considered as gaseous source terms and evaluated in air transport modeling for LLW performance assessments are ^{14}C, ^{129}I, ^{85}Kr, ^{222}Rn, and ^{3}H. Further details on source term releases of gaseous radionuclides can be found in Technical Position 3.3.3.7 ("Gaseous Releases").

Important atmospheric transport considerations for determining the impacts of gaseous radionuclides downwind from their release include: (a) atmospheric plume model parameters such as gaseous release source height (ground level or elevated) from the surface, wind

speed, wind direction, atmospheric stability class, and annual rainfall rate; (b) radionuclide removal mechanisms such as rainfall, dry deposition, and radioactive decay that reduce the activity levels in the atmosphere; and (c) general topography of the land near the disposal facility.

As the radionuclides travel from their release point, several processes could reduce their concentrations below those predicted by atmospheric transport and diffusion alone. These removal mechanisms include radioactive decay, dry particulate deposition, and rainfall scavenging removal. At most LLW disposal facilities, rainfall is expected to occur during a small percentage of the hours in a year, so that the dose calculation to the individual who could be affected by wet deposition may not be significantly changed by consideration of wet deposition. At best, it is estimated that as little as 2 percent of the radionuclides released to the atmosphere would be deposited on the surrounding soil from rainfall at an LLW disposal facility.

Radionuclide transport in the atmosphere is generally modeled using Gaussian plume transport equations (Slade, 1968; and Randerson, 1984) and Pasquill-Gifford atmospheric stability parameterization (Pasquill, 1974; and Culkowski and Patterson, 1976) to determine the dispersion and diffusion factors for estimating the concentrations of radionuclides at distances downwind from the disposal facility. Regulatory Guides 1.111 (NRC, 1977b) and 1.145 (NRC, 1983) as well as NUREG/CR-3332 (Brenk *et al.*, 1983) recommend approaches for estimating radionuclide concentrations in the atmosphere using dispersion and diffusion factors.

Determining atmospheric transport, dispersion, and inhalation and ingestion doses to the average member of the critical group, from gaseous radionuclides, can be performed by hand calculations or with an assortment of computer codes that can either compute dose in single directions from point source releases, or, for more sophisticated computer models, obtain doses from area releases and from multi-directions from the disposal facility. A summary of atmospheric transport and diffusion models, for monitoring or predicting the transport of gaseous materials that have been developed by Federal agencies, has been prepared by the National Oceanic and Atmospheric Administration (NOAA) (Department of Commerce/NOAA, 1993). Oak Ridge National Laboratory has evaluated the performance of several computer codes to determine atmospheric transport and human exposure from an atmospheric release of radionuclides (Fields and Melescue, 1994). Models for calculating ingestion doses from radionuclides released to the atmosphere may be found in Regulatory Guide 1.109 (NRC, 1977a)

3.3.6.3.2 Recommended Approach

A simple bounding screening approach that uses conservative radionuclide releases, local meteorological conditions, conventional atmospheric transport models, and standard dose calculations is recommended to determine if releases of the gaseous radionuclides to the atmosphere would significantly contribute to the CEDE or TEDE. If the results of the screening analysis turn out to be significant, more detailed analysis would be required to

demonstrate that the radionuclide releases to the atmosphere would not be of regulatory concern.

3.3.6.3.2.1 Screening Approach

The recommended approach for screening would include: (a) release of the entire inventory of ^{14}C, ^{129}I, ^{85}Kr, ^{222}Rn, and ^{3}H in the disposal facility to the surface over a 1-year period; (b) atmospheric plume dispersion to estimate radionuclide concentrations downwind; and (c) inhalation and ingestion pathways to calculate dose. If other radionuclides are considered by the applicant in the air pathway analysis, sufficient justification should be provided.

The decay of short-lived radionuclide (e.g., ^{85}Kr, ^{3}H) inventory activities to much lower activity levels over the 300-year lifetime of the BGVs and EMCBs is also acceptable for screening. Radon-222 activity levels can be obtained from the ^{238}U decay series at the year the performance assessment is maximized (e.g., 10,000 years). The chemical form of the radionuclide should be the most conservative, volatile species. Consideration of the food-chain pathway would be necessary where radionuclides could be taken up by plants grown and animals grazed near the disposal facility. The dose to the average member of the critical group may be estimated, using a total gaseous radionuclide release over 1 year and conservative meteorological conditions for wind speed, atmospheric stability class, and atmospheric diffusion. The applicant will need to provide justification for the conservatism of meteorological assumptions and parameters used. Because the screening analysis does not account for partitioning of radionuclides between gas and liquid phases, the entire inventory of radionuclides released to the atmosphere would still have to be considered available for ground-water transport.

For screening purposes, the gaseous radionuclides can be released as either a point source or an area source. Because an LLW disposal facility would typically occupy a large area, a more realistic determination of dose to the average member of the critical group from radionuclides released to the atmosphere may be obtained by using an area or virtual point source release model instead of point source release models. Wind directions can be either single-directional downwind from the center of the disposal facility, or multi-directional radiating outward from the center of the disposal facility. Ground-level release of the radionuclides should be assumed and Gaussian plume models with Pasquill-Gifford dispersion parameters can be used to provide the ground-level atmospheric diffusion factor X/Q for radionuclide concentrations. Doses can be calculated for the inhalation and ingestion pathways, except for ^{85}Kr, where external exposure is the dominant pathway.

An atmospheric stability Class B or C and wind velocity of three meters/second can be used for the initial screening calculations. These atmospheric stability classes and surface wind speed meteorological data reflect conventional practice for assessing impacts from radionuclides released to the atmosphere in the absence of site specific data. Except in those cases in which applicants or licensees provide acceptable alternative conditions based on regional or site specific meteorological data, they will be used by the staff in evaluating submittals for an operating license.

Air pathway CEDE or TEDE may be calculated from standard methods involving atmospheric diffusion, breathing rates, and DCFs. Single-directional ground-level releases from a point source along the plume centerline or across a 22.5° wind-sector average are acceptable for determining doses at downwind distances from the disposal facility. For single-direction air pathway calculations, the atmospheric diffusion factor, *X/Q* (seconds/cubic meter), for ground-level releases, may be calculated from standard equations involving wind speed, atmospheric stability conditions, lateral plume speed, and vertical plume speed (NRC, 1977a; NRC, 1982; Brenk *et al.*, 1983; and Turner, 1970), or from atmospheric transport computer codes such as *DWNWKE-PC* (Fields and Howe, 1993). A chronic breathing rate, inhalation DCFs for ^{14}C, ^{129}I, ^{3}H, and ^{222}Rn, and an external DCF for ^{85}Kr can be used to estimate the dose commitment to the average member of the critical group down-wind from the disposal facility. Computer models, such as *PRESTO-II* (Fields *et al.*, 1986) or *PRESTO-EPA-POP* (Fields *et al.*, 1987), that contain Gaussian plume dispersion and dose determination subroutines may be used to calculate dose directly to the average member of the critical group. Uniform area source releases to the atmosphere can be modeled with *CAP88-PC* (Parks, 1992), a computer code that uses a Gaussian plume model to calculate inhalation dose and incorporates Regulatory Guide 1.109 (NRC, 1977a) to estimate ingestion doses through the terrestrial food chain.

The applicant should use local or site-specific data, such as wind rose, and local geography, for the initial screening. Assumptions concerning exposure time and inhalation rate should be based on Appendix B to 10 CFR Part 20[17] for the initial screening analysis. Dose conversion factors should follow the recommendations made in Technical Position 3.3.7 ("Dose") of this NUREG. For ^{222}Rn, a conservative estimate of 100 percent equilibrium with daughter products is appropriate for the initial screening. The applicant may propose alternate equilibrium levels with proper justification.

3.3.6.3.2.2 Detailed Approaches

If the overall performance assessment indicates that the dose to the average member of the critical group exceeds the dose standard, and results of the air pathway screening analysis turn out to be significant, the analyst may need to consider a more detailed air pathway analysis to demonstrate compliance. The analyst may wish to consider longer periods for gaseous radionuclide inventory to be released (e.g., entire inventory released over 100 years); other smaller annual gaseous release rates; or more complicated analyses involving the waste streams and waste forms in the disposal facility. For example, the fraction of the total inventory of each gas-phase radionuclide released to the atmosphere could be estimated by examining each waste stream or waste form and determining the most likely ones that would release radionuclides in the gas phase. Detailed studies involving the LLW inventory disposal practices and facility designs, or references to published literature may provide adequate justification for alternative gaseous release rates or partitioning. Such studies or

[17] "Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage."

references to published data and information should examine: (a) LLW streams and forms most likely to undergo physical or chemical changes that would release gaseous radionuclides at some smaller fraction or rate; and (b) consideration of the transport of gases through the soils overlying the LLW disposal facility. Recent studies (Yim *et al.*, 1993a; Yim, 1994; and Yim *et al.*, 1996b) of the releases of gaseous radionuclides to the atmosphere from LLW disposal facilities provide methods for determining mechanisms of the formation of gas-phase radionuclides from LLW radionuclide inventories, estimating radionuclide gaseous generation and production rates in LLW disposal facilities, modeling gas phase radionuclides release from LLW disposal facilities, and calculating dose. More realistic gas generation rates and partitioning between gaseous and aqueous radionuclide species may be considered as a means of avoiding having to double-count the inventory of radionuclides transported in both ground water and air. Additional information on that analysis of gaseous releases may be found in Technical Position 3.3.5 ("Source Term").

More complex analysis involving the transport of gaseous radionuclides through soils overlying the LLW disposal facility may also be needed to demonstrate compliance. Movement of gaseous contaminants through air-filled pores in unsaturated materials overlying LLW disposal cells would depend on the pneumatic properties of the overlying materials. Coincident infiltration and air movement, as a function of transient soil moisture contents and pressure gradients, needs to be determined for gas ventilation models. However, ventilation models are complex, and the effects of infiltration and transient soil moisture contents on ventilation create large uncertainties (Binning *et al.*, 1995). Ideally, simultaneous vapor and solute transport modeling could be conducted using numerical simulators such as those described by Binning *et al.* (1995) and Celia and Binning (1992). Establishing boundary conditions for air-phase transport is important because they control the direction of air flow and velocity field variations (Celia and Binning, 1992).

Detailed atmospheric transport modeling may also include reliance on better defining site-specific meteorological conditions and a more thorough assessment of dose from the food-chain. For example, radionuclides removed from the plume by precipitation scavenging and dry particulate deposition may be directly taken up into the food chain. Further guidance on a recommended pathway analysis can be found in Technical Position 3.3.7 ("Dose"). Also, additional information on modeling deposition can be found in Till and Meyer (1983).

3.3.7 Dose

The objective of dose modeling in an LLW performance assessment is to provide estimates of potential doses to humans, in terms of the average member of the critical group, from radioactive releases from an LLW disposal facility, after closure. In this role, dose modeling integrates the information from the various modeling areas.

3.3.7.1 Considerations

Dose modeling for performance assessment includes the transfer of radionuclides through the human food chain and human dosimetry. The goal of this guidance is to aid in

understanding important issues related to human impacts from potential releases of contaminants from an LLW disposal facility. In addition, the guidance will provide some discussion of the calculations necessary to assess these potential doses.

The guidance in this NUREG supplements the pathway and dosimetry guidance provided in Section 6.1.6 ("Safety Assessment: Assessment of Impacts and Regulatory Compliance") of NUREG-1200 (NRC, 1991b). That guidance, along with other generally applicable pathway identification and dose calculation recommendations (referenced below), provides the foundation for the staff's technical positions described below.

There are two specific areas to consider in the assessment of doses to humans. First, the mechanisms of radionuclide transfer through the biosphere, to humans, needs to be identified and modeled. This is termed the *pathway analysis*. Second, the dosimetry of the exposed individual must be modeled (e.g., a *dose assessment*). Dose models and analytical solutions for both types of calculations are discussed below. However, this technical position does not endorse any specific computer code nor computational solution to be used in an LLW performance assessment. The applicant is responsible for providing sufficient support and documentation for any codes and/or mathematical solutions used in its compliance demonstrations. The applicant should, therefore, be familiar with the models and methodologies and provide sufficient information to allow an independent determination as to the adequacy of any codes and models used.

Pathway and dose assessment, in the context of an LLW performance assessment, is a process that consists of more than just calculating potential dose values from environmental concentrations. These processes integrate information from other sub-modeling areas and feed information back to this and other sub-modeling areas. This process is consistent with the iterative nature of performance assessment. In addition, the simplified models and analysis suggested in this technical position support an iterative modeling approach.

Pathway analysis consists of pathway identification and pathway modeling, both of which are discussed further in this section. Pathway identification, at an early stage of the performance assessment process, is very important. As per Section 61.13(a), pathways that must be considered include air, soil, ground water, surface water, plant uptake, and exhumation by burrowing animals. Results of the pathway analysis should show the contribution from each major pathway to the total dose estimate.

Pathway analysis should result in the determination of the total intake of radionuclides by the average member of the critical group. The critical group is defined as the *group of individuals reasonably expected to receive the greatest exposure to radioactive releases from the disposal facility over time, given the circumstances under which the analysis would be carried out*. For example, in a rural environment, a family farm adjacent to an LLW disposal facility may be the targeted critical group. The average member of the critical group is that individual who is assumed to represent the most likely exposure situation, based on cautious but reasonable exposure assumptions and parameter values.

Use of the critical group concept can be compared and contrasted with 10 CFR 20.1302, under which the licensee is required to assess the dose to "...the individual likely to receive the highest dose...." However, in contrast to the situation during operations, where public doses normally result from activities that are carefully prescribed and controlled, and it is possible to update, or keep track of, who might likely receive the highest exposure, the public doses, from releases in the future from the disposal facility, may result from a variety of activities for which the maximally exposed individual is much more difficult to precisely define. Therefore, the staff believes it is more prudent to use the average member of the critical group for assessing TEDE from releases post-closure because this provides a reasonably conservative estimate of public risk without attempting to speculate on which specific individual may be expected to receive the highest dose.

The practice of defining and using the critical group concept when assessing individual public dose from low levels of radioactivity is proposed in Section 3.3.6.1 of the 1990 recommendations of the ICRP (ICRP, 1990), and has been tentatively adopted by both EPA (1994) and NRC (1994).

Pathway analysis results in a calculation of the total exposure of the individual to radionuclides. The *dose assessment* converts both the internal exposure, through ingestion and inhalation, and the external exposure to a single TEDE for the individual's annual exposure. For radionuclides that are ingested or inhaled, calculations of the dose to organ, systems, and tissues of the body, and an effective dose equivalent are accomplished through the use of biokinetic models of the transfer of elements in the body and radionuclide-specific information. For external exposures, calculations of the effective dose equivalent from the time-weighted external exposure to contaminated materials include geometry assumptions, and radionuclide-specific information (such as radiation type, half-life, and energy of particle or gamma ray).

3.3.7.1.1 Pathway Identification and Modeling

Various considerations should be taken into account when analyzing the transport of radionuclides through the biosphere (to humans). These considerations should include:

(a) Modeling the movement of radionuclides through the food chain, adequately reflecting complex symbiotic systems and relationships;

(b) Treating certain isotopes individually (e.g., ^{3}H) as their uptake behavior is different from other radionuclides; and

(c) Identifying usage, production, and consumption parameters, for various food products and related systems, that may vary widely, depending on regional climate conditions, local or ethnic diet, and habits.

In addition to the above concerns, one must be concerned with both the complexity and conservatism of a model. Also, unique issues may emerge, based on site-specific conditions,

that the applicant needs to consider in the analysis. Technical Position 3.3.7.1.1 provides guidance on a recommended general approach to pathway modeling.

3.3.7.1.2 Internal Dosimetry

It is recommended that the applicant use ICRP 30 (ICRP, 1979) dose methodology for an LLW performance assessment. The NRC performance objective set forth in Section 61.41, is based on the ICRP 2 dose methodology (ICRP, 1959), but current health physics practices follow the dose methodology used in Part 20, which is based on ICRP 30 methodology. Because of fundamental differences between the methodologies, direct comparison between dose equivalent calculated using ICRP 30 methodology and the dose limits in the current LLW performance objective is not possible for most radionuclides. The license application will contain many other assessments of potential exposures (e.g., worker exposure, accident exposures, and operational releases) that will need to use ICRP 30 dose methodology. For internal consistency in the application, it is recommended that the performance assessment be consistent with the ICRP 30 methodology used in Part 20 for comparison with the performance objective. Therefore, calculation of a TEDE for the LLW performance assessment — a summation of the annual external dose and the CEDE — is acceptable for comparison with the performance objective.

3.3.7.1.3 External Dosimetry

The impact of external gamma dose from potential releases from an LLW facility depends on the facility design and the exposure pathways of concern. There are three general external exposure pathways related to an LLW facility: (a) exposure to soils contaminated by air or water deposition; (b) submersion exposure from air releases; and (c) direct exposure from the facility. Doses from the external exposure pathways would be added to the CEDE calculated by the ingestion and inhalation exposure pathways, resulting in the TEDE to the individual of interest. In general, pathway analysis should indicate the possibility of buildup of radionuclides in sediment via water-borne pathways, including via irrigation, and assess the buildup, if appropriate. If releases from the facility to the atmosphere are significant (as discussed in Technical Position 3.3.6.3, "Air Transport"), air concentrations from releases can cause external exposure by two pathways: ground shine from deposition on soil, and exposure by submersion in the plume. These air pathways need to be explored and assessed, if appropriate. In addition, direct external exposure from the LLW facility may need to be assessed depending on the design of the facility and assumed future events.

3.3.7.2 Recommended Approach

The recommended approach is to use pathway dose conversion factors (PDCFs) for calculating doses via the potential exposure pathways. The PDCFs should convert radionuclide concentrations in an environmental locale (i.e., ground-water concentration at the pumping well, or air concentration over the crops) to a TEDE dose to the average member of the critical group. The PDCF combines both the pathway analysis and the dosimetry methodology in multiplication factors (e.g., multiplying the concentration at the

pumping well by the appropriate pathway analysis conversion factor to calculate the total intake from that pathway, and then, multiplying an appropriate DCF to give the CEDE from that pathway). This approach is described in greater detail in the DEIS for Part 61. An applicant should document and justify, on a site-specific basis, the use of its PDCFs.

The approach outlined in Figure 13 is a generalization of an is a generalization of an acceptable approach to modeling the potential pathways and doses to humans. This approach is consistent with the iterative approach identified in Section 1.2 of this NUREG. The figure reveals that many of the considerations concerning pathways and parameter values need to be integrated with other modeling areas for overall consistency of the performance assessment. The approach is explained in greater detail below.

3.3.7.2.1 Pathway Identification

The applicant should apply a "current conditions" philosophy to determine which pathways are to be evaluated. That is to say that current regional land use and other local conditions in place at the time of the analysis will strongly influence pathways that are considered to be significant. The applicant should explicitly identify and document the pathways considered in its LLW performance assessment, at an early stage in the performance assessment process. The identification of pathways should be consistent with the types of transport in the conceptual model. Figure 14 shows generalized pathways to consider for releases from an LLW facility. Pathway identification is discussed in various literature sources, such as Volume 1 of NUREG/CR-5453 (Shipers, 1989) and NUREG-1200 (NRC, 1991b). An applicant must consider each of the general pathways discussed in Section 61.13 of the regulation. Consistent with the guidance found in Section 6.1 of NUREG-1200 ("Safety Assessment: Release of Radioactivity"), if any of the pathways studied are found to contribute less than 5 percent of the total dose, that pathway need not be evaluated in detail. When the pathways discussed in Section 61.13 are not evaluated in detail, the applicant should provide some justification for the basis not to consider them (e.g., design considerations, 5 percent screening models, etc.).

3.3.7.2.2 Model Identification and Identification of Parameter Values

Pathway modeling for dose assessment is discussed in a wide array of literature sources (Till and Meyer, 1983). The models suggested for pathway analyses, in this technical position, are simple mathematical formulations to reflect transfer compartments in the environment. These formulations are documented in various places and are based on models described in Regulatory Guide 1.109 (NRC, 1977a), and NUREG/CR-5512 (Kennedy and Strenge, 1992). Figure 14 shows the overall approach that is suggested for developing PDCFs and the interactions with other submodeling areas.

The following items should be considered in developing a pathway modeling approach and selection of parameter values.

(a) One acceptable approach for modeling the transport of radionuclides through the

Figure 13. Technical Position 3.3.7: Recommended approach for modeling potential exposure pathways and dose to humans.

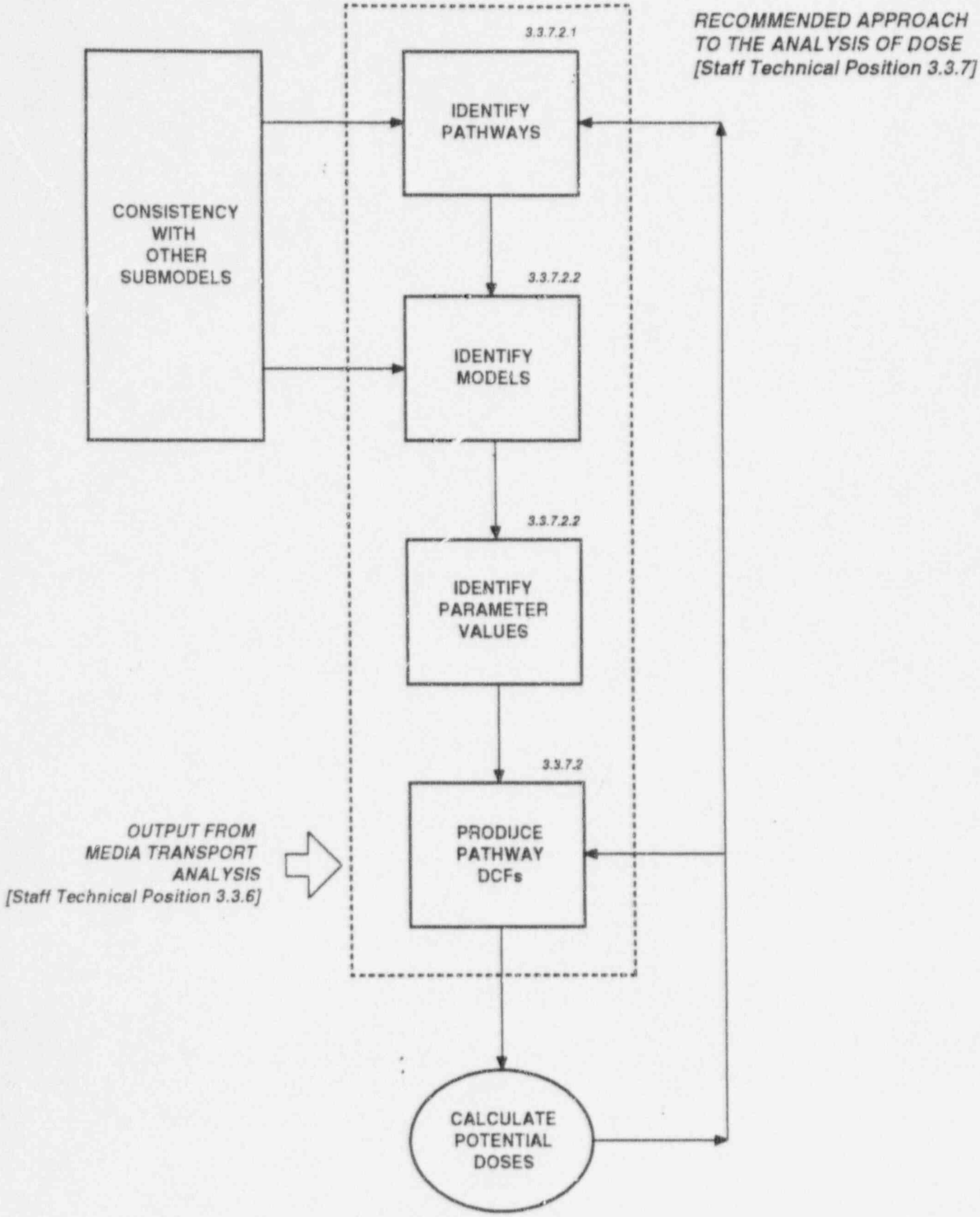
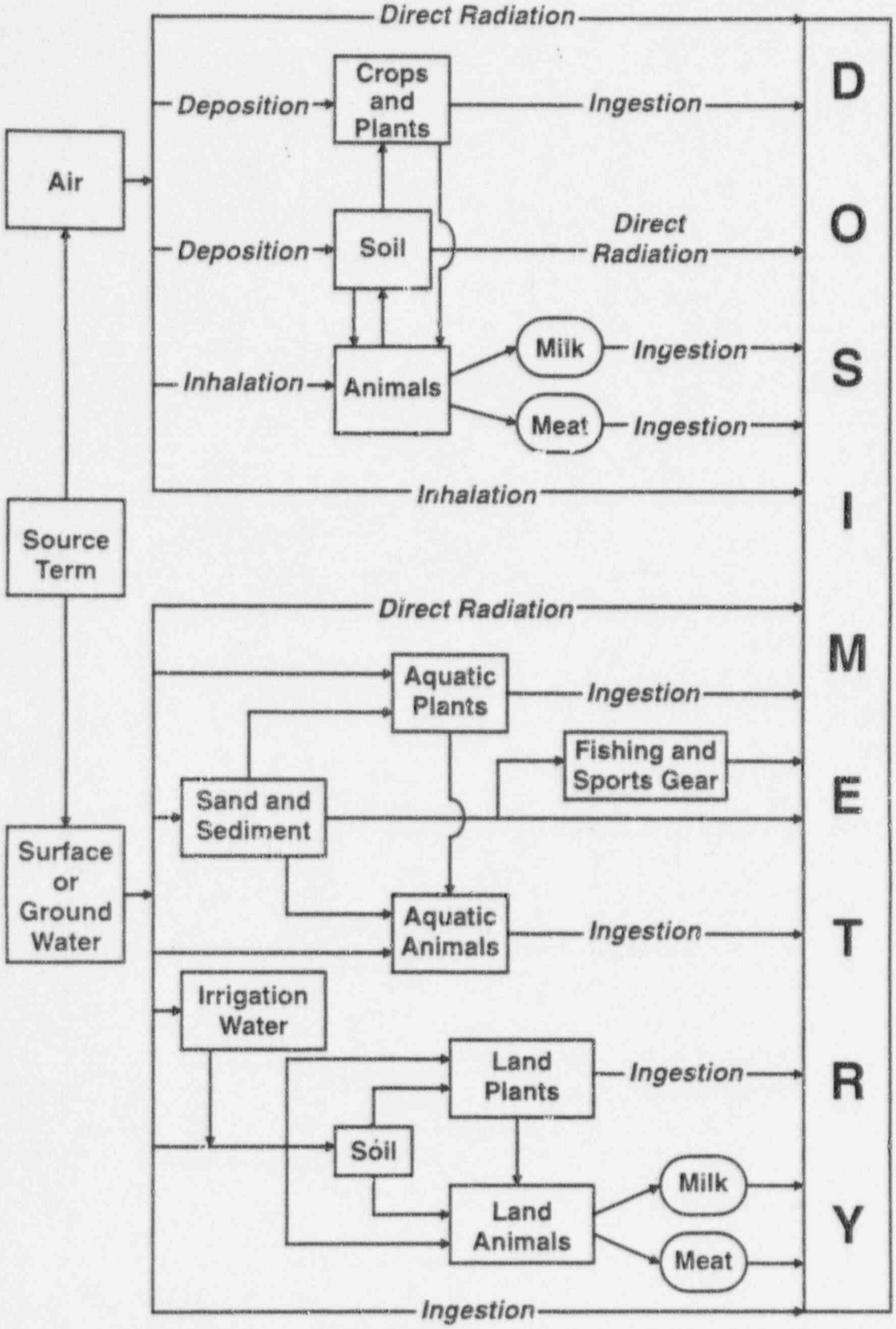

RECOMMENDED APPROACH
TO THE ANALYSIS OF DOSE
[Staff Technical Position 3.3.7]
CONSISTENCY
WITH
OTHER
SUBMODELS
3.3.7.2.1
IDENTIFY
PATHWAYS
3.3.7.2.2
IDENTIFY
MODELS
3.3.7.2.2
IDENTIFY
PARAMETER
VALUES
3.3.7.2
PRODUCE
PATHWAY
DCFs
OUTPUT FROM
MEDIA TRANSPORT
ANALYSIS
[Staff Technical Position 3.3.6]
CALCULATE
POTENTIAL
DOSES

Figure 14. Example of potential dose pathways to be considered in an LLW performance assessment. Determination of appropriate pathways depends on site-specific information (i.e., habits of the critical group). Adapted from EPA (1972).



Direct Radiation
Deposition
Crops and Plants
Ingestion
Air
Deposition
Soil
Direct Radiation
Inhalation
Animals
Milk
Ingestion
Meat
Ingestion
Inhalation
Source Term
Direct Radiation
Aquatic Plants
Ingestion
Fishing and Sports Gear
Sand and Sediment
Surface or Ground Water
Aquatic Animals
Ingestion
Irrigation Water
Land Plants
Ingestion
Soil
Land Animals
Milk
Meat
Ingestion
DOSIMETRY

biosphere employs steady-state transfer factors and bioaccumulation factors. An applicant should document the sources of soil-to-plant, plant-to-animal, and other transfer factors used. Regulatory Guide 1.109 (NRC, 1977a) provides conservative values for a variety of these factors. Regional or local parameters (ranges of parameters) should be used if these data are available, as discussed below. Generic parameter values found in the literature need to be documented as to their applicability to the expected site conditions and the applicant should attempt to represent a best estimate of the actual values at the site. A minimum number of sources of generic data should be used to maintain internal consistency.

(b) For facilities with potentially significant releases of ^{3}H and ^{14}C, specific-activity models may be useful. Both isotopes appear to be widely distributed in the environment, and if released, rapidly mix with their stable element counterparts in nature. Thus, specific-activity models are generally used to describe their movement through the terrestrial biosphere, and may be acceptable for dose assessment. The specific-activity methodology assumes that an equilibrium state exists between their concentrations in the atmosphere (for ^{14}C) or water (for ^{3}H), food products, and body tissues, for the specified location. Specific-activity models should not be used for pulse releases or for ^{14}C in water. More information on specific-activity models can be found in Till and Meyer (1983).

(c) Because of the site-specific nature of performance assessment for LLW facilities, the applicant should obtain the best available data for regional food generation and consumption rates, irrigation rates and durations, and other significant parameters used in pathway analysis. Regional food production and consumption rates are generally available through a variety of sources, including U.S. census information and other site-specific studies (e.g., Baes *et al.*, 1984). Typical regional values of consumption rates and exposure durations should be used, rather than maximum regional rates. Regulatory Guide 1.109 (NRC, 1977a) values may be acceptable, but may be highly conservative for certain food pathways, because of changes in dietary habits since its compilation. Use of generic data, such as those in Regulatory Guide 1.109, needs to be justified in the application.

The staff recognizes the conservatism in these models; however, in the absence of more sophisticated modeling, which may be justified on a case-by-case basis, this approach is suggested. The applicant should perform a sensitivity analysis on the pathways and parameters used in the performance assessment. The sensitivity analysis may indicate that more complex modeling may be appropriate for certain pathways. If more complex models are used, they should be developed to allow the sensitivities and uncertainties associated with the models to be evaluated.

An acceptable general approach to resolving unique issues discussed above is a tiered approach, consistent with the overall iterative approach of the performance assessment. First, simple models and single parameter values are to be used for modeling the potentially

complex systems (e.g., Kennedy and Strenge, 1992). If this approach is not sufficient to demonstrate compliance, next, simple models and parameter ranges should be considered, which encompass all realistic parameter values and quantify the range of consequences associated with the parameters. This approach should also identify the sensitivity of the model to significant parameters.

3.3.7.3 Dosimetry

The applicant should document the dosimetry methodology used in the application. Considerations that should be addressed by an applicant include: (a) internal dosimetry methodology and calculation; and (b) external dosimetry methodology and calculations. Other considerations that influence model or parameter choice should be documented, as appropriate.

The applicant should show the contribution from each major pathway to the total dose to the average member of the critical group. Generally, these pathways can include the drinking water, food crops, meat products, external dose, aquatic foods, and inhalation.

3.3.7.3.1 Internal Dosimetry

The simplified approach of calculating doses using DCFs will assist in conducting a performance assessment. EPA has published DCFs for inhaled and ingested intakes of radionuclides for most isotopes in Eckerman *et al.* (1988). This publication, designated as *Federal Guidance Report 11*, provides a simple intake to dose ratio for most isotopes considered in an LLW performance assessment. Internal doses should be calculated with the internal DCFs provided by EPA (in *Federal Guidance Report 11*) to give the CEDE to the average member of the critical group. These DCFs represent the dose per unit intake values calculated using the ICRP 30 methodology discussed above. Assumptions regarding human activity and uptake rates and human organ weighting factors are also identified in *Federal Guidance Report 11* and in Part 20. In general, an applicant should use the most conservative of the internal DCFs for TEDE calculations for radionuclides with multiple DCFs based on chemical form, unless the applicant can justify a particular chemical form for the element (e.g., analog studies).

3.3.7.3.2 External Dosimetry

The staff recommends the use of dose rate conversion factors for evaluating external doses. Potential doses can be calculated using tabulated dose rate conversion factors (e.g., Eckerman and Ryman, 1993). Shielding from potential over-burden and/or buildings should be considered. The use of dose rate conversion factors can be easily incorporated in the development of pathway DCFs. The external pathway DCFs should calculate the external dose to the whole body based on the assumptions for the critical group. The TEDE is the summation of the CEDE from all the other pathways and the external dose to the whole body from the external pathway.

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APPENDIX A
GLOSSARY

As used in this guidance:

"Area source" means the release of gaseous radioactive material over the uniform area of the disposal facility.

"Atmospheric diffusion factor" (*X/Q*) is the relative concentration of gaseous radioactive materials normalized for wind speed, atmospheric stability, and distance from the source. The diffusion factor is used to compute normalized estimates of time-integrated air concentrations of radioactive gases at a given distance from their release.

"Atmospheric dispersion" is the combined influences of diffusion and transport affecting the behavior of an airborne plume of radioactive gases.

"Auxiliary analyses" are analyses performed to provide the bases for model simplifications, or to support or provide data for input to models.

"Committed dose equivalent" is the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

"Committed effective dose equivalent" (CEDE) is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

"Conceptual design" refers to those descriptions, sketches or initial plans describing the disposal facility (e.g., physical layout, vault disposal, multi-layered cover, and subsurface drainage system) to provide a preliminary overall definition of a facility. The conceptual design would not typically include detailed design features based on complex engineering analyses.

"Conceptual model" is a qualitative description of the processes, geometry, and boundary conditions associated with a disposal site or site sub-system component (i.e., ground-water system, flow-through covers, source term, etc.). Conceptual model development includes abstracting system, or sub-system, descriptions into more simplified forms that can be mathematically modeled.

"Critical group" is a group of individuals reasonably expected to receive the greatest exposure to releases over time, given the circumstances under which the analysis would be carried out.

"Deep-dose equivalent" (applies to external whole-body exposure) is the dose equivalent at a

tissue depth of 1 centimeter (1000 milligrams/square centimeter).

"Degradation" is a process of gradual reduction in the physical capability of materials used in the construction of low-level waste disposal facilities to limit water infiltration and the release of radionuclides; the physical decline of an engineered barrier following the service life, when important physical characteristics of an engineered barrier progress from an expected design value to the degraded condition.

"Degraded barrier" is an engineered barrier that has fully undergone the process of degradation resulting in reduced material and performance characteristics: a degraded barrier could still perform a function limited by the properties of the remaining durable constituent materials.

"Diffusion release" is a release mechanism that is characterized by the movement of radionuclides in the direction of their concentration gradient (e.g., diffusion of radionuclides out of a cementitious waste form).

"Dissolution release" is a release mechanism that is characterized by the break down of a solid in a liquid or the corrosion rate of the waste type (e.g., the corrosion rate for activated metals).

"Dose" (or radiation dose) generically refers to absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent.

"Dry deposition" is the process of removal of airborne radioactive materials from gravitational setting or through contact with surfaces, ground, vegetation, or other ground cover.

"Durability" is the ability to retain important physical characteristics over a long span of time.

"Engineered barrier" is a man-made structure or device designed to improve the land disposal facility's ability to meet the performance objectives of 10 CFR Part 61 described in Subpart C, meaning the ability to isolate and contain waste, to retard and minimize possible release of radionuclides to the environment.

"Flux" is the specific discharge of a fluid equal to the volumetric flow rate per unit cross-sectional area through which the flow occurs.

"Gaussian plume" is a mathematical model commonly used to predict atmospheric diffusion of gases and particulates. The model is based on assumptions of statistically normal or Gaussian plume dispersion, modified by empirical dispersion coefficients.

"High-integrity container" is a container that provides the structural stability required by 10 CFR 61.56(b) for Classes B and C waste. Guidance on demonstrating this structural stability is given in NRC (1991).

"Infiltration" is the net water intake into the native soils at the site or into a disposal unit(s) through the land or cover surface(s).

"Liner" is a vessel used in a transportation package or disposal container to facilitate transportation and/or disposal operations. Sometimes a liner is also used as the disposal container.

"Member of the public" refers to an individual in a controlled or unrestricted area. However, an individual is not a member of the public during any period in which the individual receives an occupational dose.

"Natural recharge" is the entry of water into the saturated zone.

"Nonstochastic effect" is a health effect, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect).

"Pathway analysis" refers to an analysis of radionuclide transport in the biosphere, along pathways that result in a receptor's internal or external exposure (i.e., ground water-forage-cow-milk-man).

"Pathway dose conversion factor" is a conversion factor that translates a radionuclide concentration at a potential receptor location in the environment (i.e., a well) and the resultant total effective dose equivalent to an individual, considering the various potential modes of ingestion, inhalation, and exposure to the radionuclide (i.e., drinking the water, irrigating crops, contaminated dust in the air, direct exposure to contaminated soils).

"Rad" is a special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joules/kilogram.

"Radionuclide inventory" is the isotopic distribution of radioactive materials by waste class, waste form, and waste container disposed of in the facility and potentially available for release to the environment.

"Radionuclide removal mechanisms" refer to wet and dry deposition processes, and radioactive decay that deplete the atmosphere of gases and particulates.

"Reference natural setting" is in reference to a set of natural conditions, processes and events, based on geologic, hydrologic, and other knowledge about the site, that is used in conceptual models to represent the site for quantitative predictions of performance. The

reference natural setting includes a range of features and events, and associated parameters, that bound both current conditions at the site and those likely to occur over the period of performance. The reference natural setting does not account for highly uncertain natural phenomena or human behavior based on unreasonable speculation.

"Rem" is a special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor.

"Rinse release" is a release of radionuclides from a waste form the instant water contacts the waste form or waste type (i.e., a "wash-off" of radionuclides). (Although release from a waste form is considered instantaneous, the dissolution of radionuclides in ground water will be moderated by solubility limits and retardation for the particular geochemical conditions appropriate for the disposal unit being analyzed.)

"Screening process" is the process of performing a simple, overly-conservative calculation for the expressed purpose of eliminating certain radionuclides from consideration in a performance assessment or eliminating the need for further more complicated analysis (e.g., the screening calculation results meet the regulatory requirements).

"Service life" is a reasonably obtainable and expected length of time over which an engineered barrier performs as designed.

"Solidified waste form" refers to liquid or wet-solid wastes, or encapsulated solid wastes (e.g., filter cartridges) that have been mixed with cement, bitumen, or vinyl-ester styrene to meet the requirements of the disposal facility and 10 CFR Part 61. A solidified waste form that meets the requirements of 10 CFR 61.56(b) and the associated guidance in NRC (1991), is a **stabilized** waste form.

"Solubility limit is the maximum amount of a radionuclide (solute) that can be dissolved per unit of liquid (solvent) under specified conditions (e.g., temperature, pH).

"Sorption coefficient" (K_d) is the ratio of the mass of solute on the solid phase per unit mass of solid phase to the concentration of solute in solution. The validity of this ratio requires that the reactions that cause the partitioning are fast and reversible (e.g., chemical equilibrium is achieved) and the sorption isotherm is linear.

"Source term" is the quantity of radionuclides expected to be released over time out of a clearly identified boundary (such as the waste form, container, disposal unit, or facility).

"Stability" is a structural stability term and refers to the physical stability of the waste and the disposal site so that once waste is emplaced, backfilled, and covered, water access to the waste over time is minimized to achieve long-term stability.

"Stability class" (diffusion category) is a classification scheme that describes an atmospheric

turbulence condition in terms of boundary layer atmospheric stability. Diffusion categories are generally grouped in six classes, ranging from Class A, very unstable, to Class F, very stable.

"Stochastic effects" are health effects that occur randomly and for which the probabilities of the effects occurring, rather than their severity, are assumed to be linear functions of doses without thresholds. Hereditary effects and cancer incidences are examples of stochastic effects.

"Streamline" is a line whose tangent at any point in a fluid is parallel to the instantaneous velocity of the fluid at that point.

"Streamtube" is an analytical model of ground-water flow; a streamtube may be used to represent the set of streamlines that originate from a distinct source (i.e., a specific waste vault) and end at a particular discharge point (i.e., a well or surface-water body).

"Total effective dose equivalent" is the sum of the deep-dose equivalent (for external exposures) and the CEDE (for internal exposures).

"Waste form" refers to the physical and chemical properties of the radioactive waste (e.g., liquid, cement, metal) without its container or packaging.

"Waste stream" is the origin of a low-level waste type or combination of waste types with a particular radionuclide content and distribution independent of its physical characteristics.

"Waste type" refers to those radioactive materials such as cloth, wood, plastic, glass, or metal, or other substances obtained from radioactive waste treatment systems, industrial processes, or research experiments. Some examples of waste types are dry solids, dry active waste, ion-exchange resins, sorbed liquids, filter cartridges, and activated metals.

"Weighting factor" (organ or tissue) is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly.

"Wet deposition" is a type of deposition resulting from the scavenging of particles and gases by falling precipitation.

Reference

U.S. Nuclear Regulatory Commission, "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility (Rev. 2)," Office of Nuclear Material Safety and Safeguards/Division of Low-Level Waste Management and Decommissioning, NUREG-1199, January 1991.

EXECUTIVE TASK MANAGEMENT SYSTEM

<<< PRINT SCREEN UPDATE FORM >>>

TASK # - 7S135 DATE- 05/28/97 MAIL CTRL. - 1997

TASK STARTED - 05/28/97 TASK DUE - 06/06/97 TASK COMPLETED - / /

TASK DESCRIPTION - BTP ON PERFORMANCE ASSESSMENT METHODOLOGY FOR LLRW
SEND TO A/S & COMPACTS

REQUESTING OFF. - NMSS REQUESTER - WITS - 0 FYP - N

PROG.- SNS PERSON - STAFF LEAD - SNS PROG. AREA -

PROJECT STATUS - OSP DUE DATE: 6/6/97

PLANNED ACC. - N
LEVEL CODE - 1

~~Paul~~ [initials] 5/28/97

5/28/97

I'm starting on this today. Do you have any suggestions?

Steve

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

MEMORANDUM TO: David L. Meyer, Chief
Rules Review and Directives Branch
Division of Freedom of Information
and Publications Services
Office of Administration

FROM: Michael J. Bell, Acting Chief
Performance Assessment and High-Level Waste
Integration Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

SUBJECT: FEDERAL REGISTER NOTICE ANNOUNCING THE AVAILABILITY OF DRAFT BRANCH TECHNICAL POSITION ON A PERFORMANCE ASSESSMENT METHODOLOGY FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES - NUREG-1573

Attached is a Federal Register notice which announces the availability of the subject guidance document for public comment. In accordance with SECY procedures, the original and five additional conformed copies of the notice are also attacheo as well as an electronic version cn disk.

Attachments: As stated

CONTACT: Michael P. Lee, NMSS
415-6677

[7590-01]

NUCLEAR REGULATORY COMMISSION

Availability of Draft Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities

SUMMARY: The U.S. Nuclear Regulatory Commission is announcing the availability of the "Draft Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities."

DATE: The comment period expires [insert date 90 days from publication date].

ADDRESSES: Send comments to Chief, Rules Review and Directives Branch, Division of Freedom of Information and Publications Services, U.S. Nuclear Regulatory Commission, 11545 Rockville Pike, Mail Stop T-6-D59, Rockville, Maryland 20852-2738. Comments may be delivered to the same address between 7:45 a.m. and 4:15 p.m., on Federal workdays.

A copy of the draft Branch Technical Position (BTP) is available for public inspection and/or copying at the NRC Public Document Room, 2120 L Street (Lower Level), NW, Washington, DC 20555-0001. Copies of the draft BTP may also be obtained by contacting Karen S. Vandervort, Division of Waste Management, Office of Nuclear Material Safety and Safeguards. Telephone: (301) 415-7252.

FOR FURTHER INFORMATION CONTACT: Anne E. Garcia, Division of Waste Management, Office of Nuclear Material Safety and Safeguards. Telephone:

Attachment

(301) 415-6631.

SUPPLEMENTARY INFORMATION: The U.S. Nuclear Regulatory Commission's (NRC's) regulation regarding the licensing requirements for the land disposal of low-level radioactive waste (LLW) can be found at 10 CFR Part 61. Part 61 requires that technical analyses be performed to demonstrate protection of the general population from releases of radioactivity to the general environment in certain environmental pathways such as ground water, surface water, air, soil, and biota (plants). A LLW performance assessment is a technical analysis that can be used to demonstrate compliance with NRC's performance objective for radiological protection of the general public - 10 CFR 61.41. NRC's Performance Assessment Working Group has prepared a draft BTP, designated NUREG-1573, as a step toward providing detailed LLW performance assessment guidance to potential applicants for a NRC license. When finalized, the BTP may contain information that may be useful to Agreement States and disposal site developers on LLW performance assessment. In this regard, the draft BTP includes the staff's technical positions on: (a) an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (b) five principal regulatory issues regarding interpreting and implementing Part 61 performance objectives and technical requirements governing LLW site post-closure performance; and (c) implementation of NRC's LLW performance assessment methodology. In arriving at the proposed positions taken on these issues in the draft BTP, the staff has considered a number of alternatives. Nevertheless, the staff is interested in the public's views on both the suitability of approaches presented in the draft BTP for measuring

the performance of LLW disposal facilities, as well as the staff's proposed positions on certain LLW regulatory issues: (a) consideration of future site conditions, processes, and events; (b) performance of engineered barriers; (c) timeframe for an LLW performance assessment; (d) treatment of sensitivity and uncertainty; and (e) the role of performance assessment during the operational and closure periods.

To obtain early feedback on the guidance for LLW performance assessment under development by the staff, a preliminary draft of the BTP was distributed for comment to LLW-sited and host Agreement State regulatory entities; the Advisory Committee on Nuclear Waste (ACNW); the U.S. Department of Energy (DOE); the U.S. Environmental Protection Agency; and the U.S. Geological Survey in January 1994. The staff briefed the ACNW and the Commission on the scope and content of the BTP in March and April 1994, respectively. The staff subsequently held two workshops on the BTP and LLW performance assessment. The first was a 2-day workshop held at NRC Headquarters on November 16-17, 1994. The second was a half-day workshop, limited to certain technical issues in LLW performance assessment, held at the 16th Annual DOE/LLW Management Conference on December 13-15, 1994. Finally, the staff briefed the ACNW on key regulatory issues and its evaluation of the workshop comments on March 16, 1995. This draft BTP reflects the staff's consideration of feedback received during those interactions. However, the staff did not formally respond to these comments in preparing this version.

In a related matter, the staff would be interested in the views of the public concerning whether it would be appropriate to discount potential doses, from a

hypothetical LLW disposal site, to future generations. In the context of LLW disposal, it does not appear that the use of the "time-value of money" approach to discounting is implementable considering the long time frames of performance considered. In the context of LLW disposal, application of discounting, either qualitative or quantitative, might more appropriately weigh present-day economic cost of design and performance features associated with LLW disposal against expectations about future health risks. This approach would not allow the standard to be exceeded, but would address the level of assurance necessary to demonstrate that the LLW performance objectives will be met. Although the draft BTP does not address this issue, the staff has been asked by the Commission to request comment on this concept as part of the public comment process.

Finally, the staff is aware that several entities have commented on aspects of the BTP, as presented in the January 1994, preliminary draft, through the Commission's November 1995 Strategic Assessment and Rebaselining Initiative. The staff was directed by the Commission to inform it on how it plans to resolve those comments prior to a decision to finalize the BTP. As part of the public comment process, the staff will provide the Commission with a summary of all public comments, including those made during the Strategic Assessment and Rebaselining Initiative, and proposed resolutions to those comments prior to finalizing the BTP.

Dated at Rockville, Maryland, this 22nd day of May 1997.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION.

/S/

Michael J. Bell, Acting Chief,
Performance Assessment and High-Level Waste
Integration Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards.