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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Workshop on Performance Assessment Techniques for High-Level Waste (Probabilistic Risk Assessment Technology Training Program) (20-3702-065-206-010)

DATE/PLACE: September 10-13, 1991 at the NRC Training Center, Bethesda, MD

AUTHORS: D. Turner and M. Ahola

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PERSONS PRESENT: D. Turner and M. Ahola

BACKGROUND:

The purpose of this workshop was to introduce the concept, methods, and role of performance assessment in high-level waste management with emphasis on probabilistic risk assessment techniques. The instructors for the course were Drs. Jonathon Young and David Lester of SAIC. A notebook containing all instructional materials used in the presentation was distributed to course participants. This notebook can be obtained from the authors of this trip report.

SHORT COURSE ACTIVITIES:

The short course was divided into 12 parts. A flow chart of the subjects covered, and summaries relevant to the different sections covered are included in this trip report for reference. Dr. Young began with an introduction to the history of performance assessment as applied to problems in industry, engineering, and radioactive waste disposal, and presented the regulatory issues (in 10 CFR Part 60 and 40 CFR Part 191) relevant to the post closure performance of a geologic HLW repository. Dr. Young also introduced the three concerns that must be addressed by any performance assessment: (1) "What Can Happen?"; (2) "How Likely is it to Occur?", and; (3) "What Are the Consequences?".

Dr. Lester presented the next two sections. The main focus of Section 2 was to introduce the four basic scales of a hypothetical disposal system. These include the regional scale (tens to hundreds of kilometers), the repository scale (about 1 km or less), the mined facility scale (tens to hundreds of meters), and the waste package scale (on the order of 1-5 m). Barriers for waste isolation will differ in importance at the four scales, ranging from geologic barriers at the regional scale to engineered barriers at the scale of the waste package. The concept of a base case for performance assessment was introduced. Physicochemical processes are allowed to operate in the base case, but it is assumed that no

natural or human events external to the system occur to change the basic properties of the system. Event trees are also introduced (see enclosure) for the different scales of the geologic repository.

Section 3 addressed the regulatory framework that establishes the different performance requirements for a geologic HLW repository. The performance objectives in 10 CFR Part 60 are principally deterministic in nature, while the dose/health requirements established by the EPA in 40 CFR Part 191 are designed around probabilistic considerations. The last part of Section 3 covers the tools of performance assessment (scenario development, probabilistic modeling, consequence modeling), and discusses the importance of uncertainty/sensitivity analysis. Performance assessment results will always be probabilistic due to the uncertainties and stochastic nature of the problem. Complementary Cumulative Distribution Functions (CCDF) are introduced as a means of displaying the results of the performance assessment modeling and evaluating compliance with regulatory limits.

Dr. Young provided an overview of probabilistic modeling in Section 4. In performance assessment, the calculation of risk involves four steps: determination of scenarios, determination of scenario frequency or probability, determination of scenario consequences, and the uncertainty/sensitivity analysis of the results. Scenario development consists of three components: definition of the sample space (**S**) of concern, a collection of possible events from **S**, and determination of the probability of the various events occurring. Sample space can be finite or infinite. In the instance of infinite sample space, probability density functions (e.g., Gaussian and log-normal distributions) can be used to represent the probability of an event occurring. Frequency, the rate of occurrence of an event, is distinct from probability, which measures the likelihood of a given event occurring at a particular point in time. To demonstrate these components, an exercise in probability was conducted by tossing coins and pairing like events (combinations). Developed to address risk analysis, CCDFs are a plot of the probability that a given consequence will exceed some given value versus the consequences of all events (commonly expressed in EPA normalized release for HLW).

Section 5, presented by Dr. Young addressed the questions "What Can Happen?", and "How Likely is it to Happen?". Identification and selection of significant scenarios were discussed, particularly as a combination of events, conditions, and processes leading to the release of radionuclides from a geologic repository to the accessible environment. Scenario identification is basically a five-step process that involves the identification of potentially disruptive events and processes, screening and classification of these events and processes, the construction of all the scenarios, and the evaluation (at least in a qualitative sense) of these scenarios. Additional considerations in scenario selection are the capabilities of the modeling tools available for performance assessment, data compatibility, and the completeness of the data.

Three types of approaches to scenario identification were discussed: judgmental methods, simulation methods, and event tree analysis. Based on considerations of completeness (i.e., all possible outcomes identified) and current feasibility, judgmental and simulation methods were downgraded by Dr. Young, and event trees were identified as a currently effective and practical method for scenario identification and selection. Simple examples were introduced for illustration, and screening of scenarios using physical reasonableness, probability, and consequence criteria was investigated using the IAEA list of potentially relevant scenarios for radioactive waste repositories. The difficulties of addressing human intrusion in scenario development was discussed, and the iterative nature of the identification process was emphasized. It was also stressed that site characterization and scenario identification should be interactive in order to better guide both activities.

Dr. Lester addressed the question "What Will Be the Outcome?" in Section 6. This section was basically concerned with the release and transport of radionuclides from the repository to the accessible environment. The first step in modeling must be the determination of the type of model appropriate to the problem at hand. While a complex model should not be used for a simple problem due to the added uncertainty introduced by poorly constrained parameters, a simple model may be inadequate to address a complex problem. The verification and validation of computer codes and system models were discussed. Verification techniques include benchmarking, peer review, comparison against analytical solutions, extensive history of use, and verification by parts. Validation is much more difficult, and the options for meaningful results at the time scales of interest are more limited. Natural and anthropogenic analogs offer one option for validation. Definition of initial and boundary conditions in these instances is problematic. Short term and accelerated testing offer more well-defined problems, but the extrapolation of the results to times on the order of thousands of years is uncertain. Release and transport are discussed from the small scale of the waste package outwards to the large regional scale of transport to the accessible environment. The mathematics of the convection-dispersion/diffusion equation for reactive solute transport were presented, and in the case of the waste package (near-field), heat transfer generated by radioactive decay was also discussed. Some of the complicating factors such as kinetics, diffusion, temperature, etc. were discussed. Specific examples of computer codes used to model contaminant transport at the different scales were presented, and the assumptions, characteristics, and limitations of many of them are presented in the short course notes.

Section 7 was an overview of the dose/health considerations in consequence modeling. While 10 CFR Part 60 is predominantly associated with containment release rates during the post-closure period, the EPA uses dose and health effects analysis to establish the limits in 40 CFR Part 191. Dose/health consequence modeling

can provide input into risk calculations associated with radionuclide release. A dose/health consequence model basically consists of three components: exposure pathways, a dosimetry model, and a health effects model. Direct exposure pathways can include air and water. Exposure to radionuclides can also occur through the more indirect route of contamination of the food chain. Dosimetry and health effects models are generally developed using the guidelines of various federal and international agencies such as the International Commission on Radiological Protection (ICRP). Dosimetry models are concerned with converting the quantity of radioactive material ingested to a radiation dose to various organs. Health effects models involve the prediction of adverse health effects resulting from exposure. These include both acute early health effects based on threshold values and latent effects such as cancer fatalities resulting from prolonged exposure.

In Section 8, Dr. Lester discussed the evaluation and application of data in performance assessment. This includes the sources and form of data for input into performance assessment models. Sources of data include field and laboratory investigations, the body of scientific literature, expert opinion, and the regulations themselves. Data can be empirical in nature and derived from curve-fitting for input, or can represent fundamental physical and chemical properties for input into more mechanistic performance assessment models. Two kinds of uncertainty are associated with input data. The first is the stochastic variation that can be expected for any body of experimental data. The second source is in the inadequacy of the data either through a poor understanding of the processes involved or a limited ability to completely describe the system of interest.

In Section 9, Dr. Young examined the issue of uncertainty and sensitivity analysis in performance assessment. He identified five basic sources of uncertainty: completeness of the selected scenarios, adequacy of the level of detail, model selection, uncertainty in the data, and the stochastic variation inherent in all natural systems. Uncertainty and sensitivity analysis differ in that model uncertainty originates from the uncertainty of the various inputs, while the goal of sensitivity analysis is to determine the contribution of the various inputs to the model results. Informal approaches to uncertainty/sensitivity analysis include parametric and importance analysis. Parametric analysis calculates the effects of modeling alternatives or ranges in parameters on performance assessment results. Importance analysis determines the impact of changes in event probabilities (or frequencies) on modeling results. Uncertainty analysis usually includes a combination of these two methods. Formal uncertainty/sensitivity analysis relies on mathematical or statistical treatments of the data. These approaches can include differential and response surface analyses, Fourier Amplitude Sensitivity Tests, and Monte Carlo techniques. While the other formal methods are discussed briefly at the end of the section, Dr. Young considered Monte Carlo approaches the most suitable for radioactive waste disposal, and the bulk of the remainder of

Section 9 dealt with description and application of the method. The approach is conceptually simple, widely used, and efficient sampling techniques such as importance and Latin Hypercube sampling can reduce computational costs. Drawbacks of these techniques include the expense of multiple runs to generate sufficient population statistics, and interpretation of the results is less straightforward than other methods. The basic steps of the approach are selecting ranges and distribution for the parameters of interest, generate samples (realizations of the model), evaluate the model for each sample, and through statistical treatments, perform uncertainty (expected value, variance, distribution function) and sensitivity (scatterplots, regression/correlation analysis) analysis of the results.

Section 10, presented by both Dr. Young and Dr. Lester, consisted of a performance assessment model considered from beginning to end using a simplified hypothetical system at the WIPP site in New Mexico, which is discussed in more detail in Sandia Report SAND90-7103 which has been used as a reference in the presentation notebook. Three events were considered, and an event tree was constructed for scenario development and evaluation. Scenarios were grouped based on outcome and probability. Examples of the types of radionuclides considered, and the ranges in input parameters available for the site were also presented. Based on the proposed codes and models, a family of CCDF curves was generated to determine compliance. Uncertainty/sensitivity analyses were performed using Monte Carlo techniques, and scatterplot graphs of regression analysis are included for several parameters related to the groundwater travel time and release of plutonium and uranium to the accessible environment.

Dr. Lester presented Section 11, which dealt with performance assessment results and the uses and applications of performance assessment, respectively. Performance assessment, designed to address the three questions defined in the introduction (see above), results in the generation of families of CCDFs, each of which addresses a set of scenarios. Multiple CCDFs reflect the uncertainty in both the input parameters and in scenario frequency. Dr. Lester emphasized that the focus of performance assessment is dependent on the regulatory framework. Numerical criteria and specific guidelines are presented in the regulations concerning what constitutes regulatory compliance.

In Section 12, Dr. Young emphasized that performance assessment is appropriately applied to many aspects of high level waste disposal, including: site evaluation, providing guidance for site characterization activities, aids in repository engineered barrier design, and perhaps most importantly, the qualification and licensing of the waste management system. Dr. Young suggested that the NRC can use PA results in four essential areas: site characterization review - is the right data being collected?; regulatory compliance assessment; evaluation of the regulatory basis - are the regulations adequate?, and the development of regulatory guidance for the license applicant. Dr. Young stressed

the iterative nature of model development and data improvement. Beyond the licensing process, performance assessment should be an ongoing activity during the construction and operation of the repository, as more data becomes available, and uncertainty is reduced. The credibility of performance assessment depends upon the confidence which can be placed on the adequacy of the tools available, and the appropriateness and integrity of the data used in the models. The section closes with a list emphasizing the limitations and strengths of performance assessment (see attached).

CONCLUSIONS AND COURSE EVALUATION:

The way it is currently structured, the course is a good introduction into the concepts and philosophy of performance assessment for HLW disposal. Mathematical concepts and currently available computer codes are introduced, but the course is largely non-technical in its approach. In most cases, sufficient additional information is presented to provide a starting point should a more technical follow up be required. The regulatory framework behind the repository is discussed thoroughly, and its importance as a driving force behind performance assessment is emphasized by the course instructors. The steps for a performance assessment model are outlined and described in logical order. Exercises to illustrate the approach are used, but perhaps more examples would help to clarify the modeling process and illustrate its strengths and limitations.

The course is geared towards a general discussion of performance assessment, and is perhaps more appropriate for either regulators seeking a better understanding of the methods employed in performance assessment, or technical staff trying to gain an overall view of probabilistic risk assessment. Those already familiar with the methods and techniques of performance assessment would probably benefit less from this type of workshop.

PROBLEMS ENCOUNTERED: NONE.

PENDING ACTIONS: NONE.

SIGNATURE

Mikko Ahola — Date: 9/25/91

Dave Turner — Date: 9/25/91

CONCURRENCE

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Manager, RDCO

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John L. Russell
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09/26/91
Date

Wesley C. Patrick
Technical Director

9/26/91
Date

Probabilistic Risk Assessment Technology Training Program

Performance Assessment Techniques for High Level Waste

U.S. Nuclear Regulatory Commission
Washington, D.C.

Idaho National Engineering Laboratory

A91 0576
Sept. 1991

Jonathon Young, Senior Program Manager, SAIC

Program Manager with over 20 years experience in safety, reliability, and probabilistic risk assessment (PRA) activities. Internationally recognized expert in PRA and has taught courses in the techniques and application of PRA to both domestic and international clients.
Career span incorporates the aerospace and utility industries starting with the Apollo project and involving weapons systems, energy facilities, and varied nuclear reactors.
Key actor in the development and application of PRA techniques since he directed the Pressurized Water Reactor (PWR) Fault Tree Analysis activities on the USNRC's Reactor Safety Study (WASH-1400).

David H. Lester, Senior Scientist, SAIC

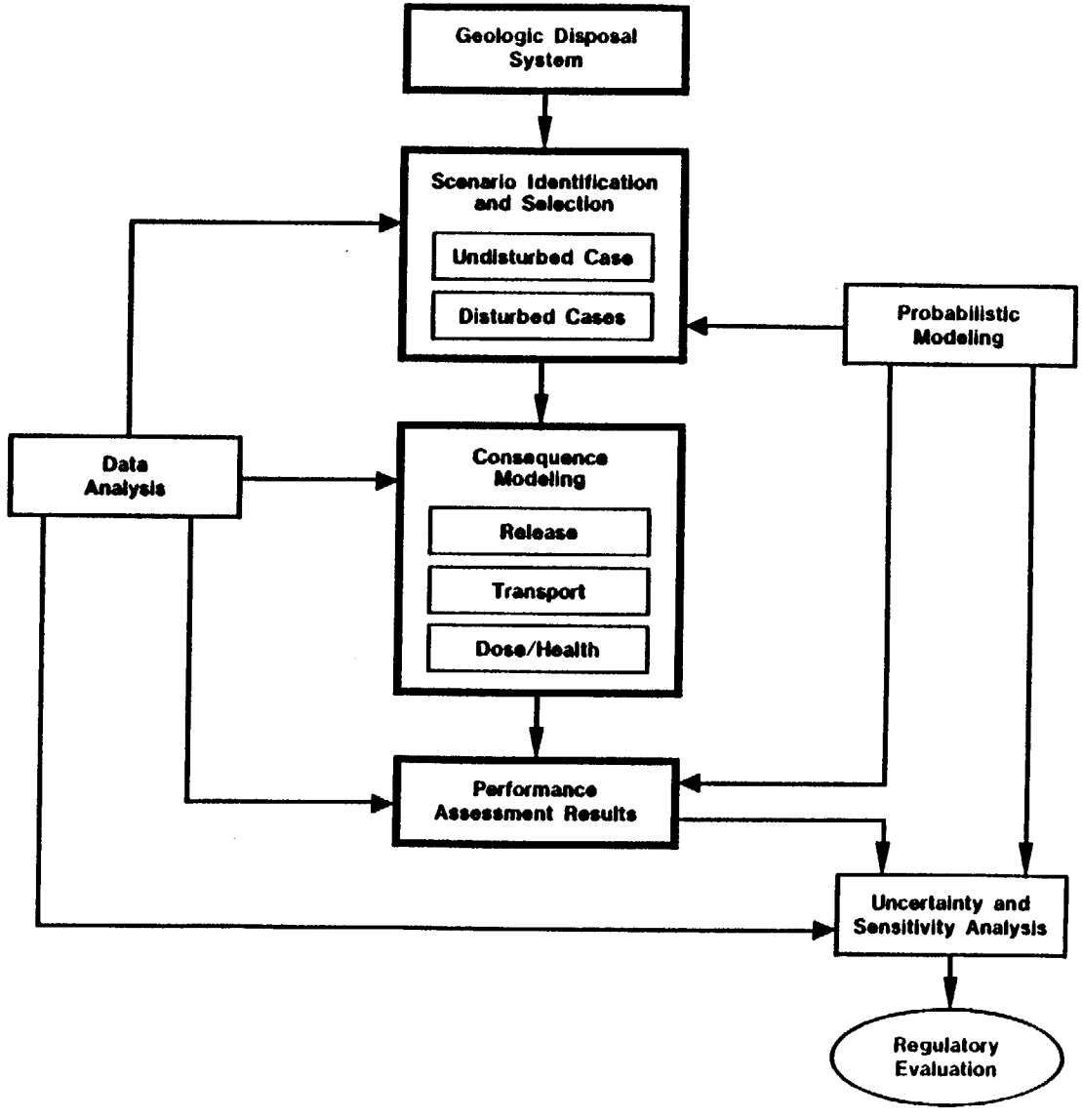
David H. Lester is a Senior Scientist at SAIC. He has over 21 years experience in chemical and nuclear engineering, including 17 years specializing in hazardous and nuclear waste management.
Mr. Lester is currently contributing to the Hanford Remedial Investigation/Feasibility Study program for Hanford waste management and cleanup, contributing to a technical assistance project for the Japanese (PNG) High Level Waste program, and contributing to various Hanford facilities safety analyses.
His experience on waste projects includes risk assessment of low-level nuclear waste burial operations, ground water contamination transport modeling, risk assessment of high-level nuclear waste systems, emergency action alterative studies, conceptual design of treatment systems, design and analysis of high level waste packages, and studies of soil remediation alternatives. He was an Adjunct Professor, University of Washington Chemical Engineering Department. During this time he taught graduate level engineering courses at the Graduate Center in Richland, Washington.
Courses taught included (1) Chemical Kinetics and Reactor Design, and (2) Advanced Unit Operations (chemical process equipment design).

Section 1 Introduction

Study Guide

- Topic
  - Introduction
- Purpose
  - Basic orientation of students to the subject of Performance Assessment
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Define High Level Waste Performance Assessment
    - Explain the purpose of Performance Assessment
    - Relate High Level Waste Performance Assessment to related technologies
    - Describe the future of Performance Assessment
- References
  - 10 CFR 60, 40 CFR 191, 10 CFR 960
  - US NRC, Draft Generic Technical Position on Licensing Assessment Methodology for High-Level Waste Geologic Repositories, 1984
  - US DOE, Environmental Assessment, Deaf Smith County Site, DOE/RW-0069, 1986
  - IAEA, Safety Assessment for the Underground Disposal of Radioactive Wastes, Safety Series No. 56, 1981

A91 0577


Geologic Disposal System
Scenario Identification and Selection
Undisturbed Case
Disturbed Cases
Probabilistic Modeling
Data Analysis
Consequence Modeling
Release
Transport
Dose/Health
Performance Assessment Results
Uncertainty and Sensitivity Analysis
Regulatory Evaluation

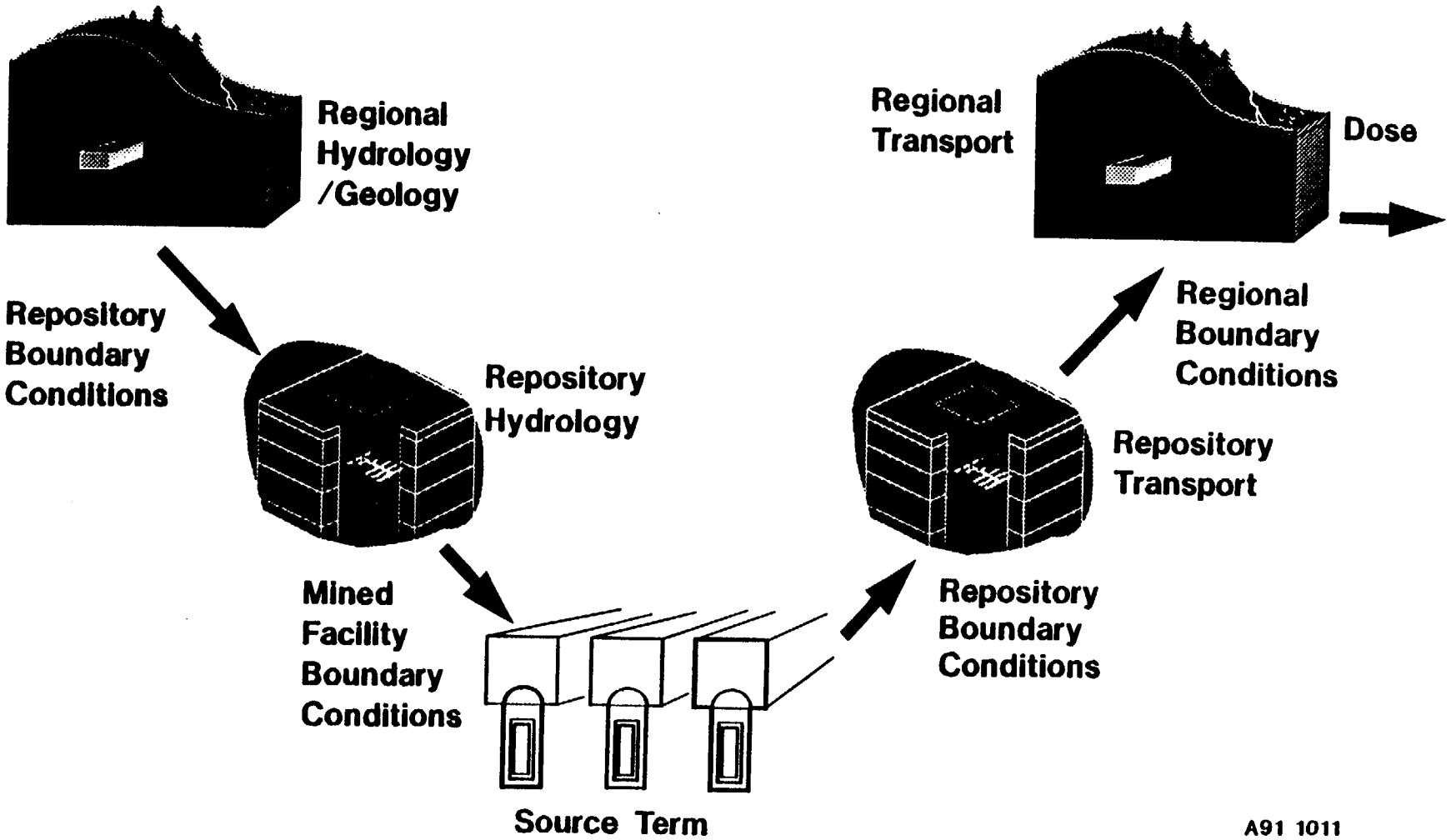
A91 0582

Study Guide

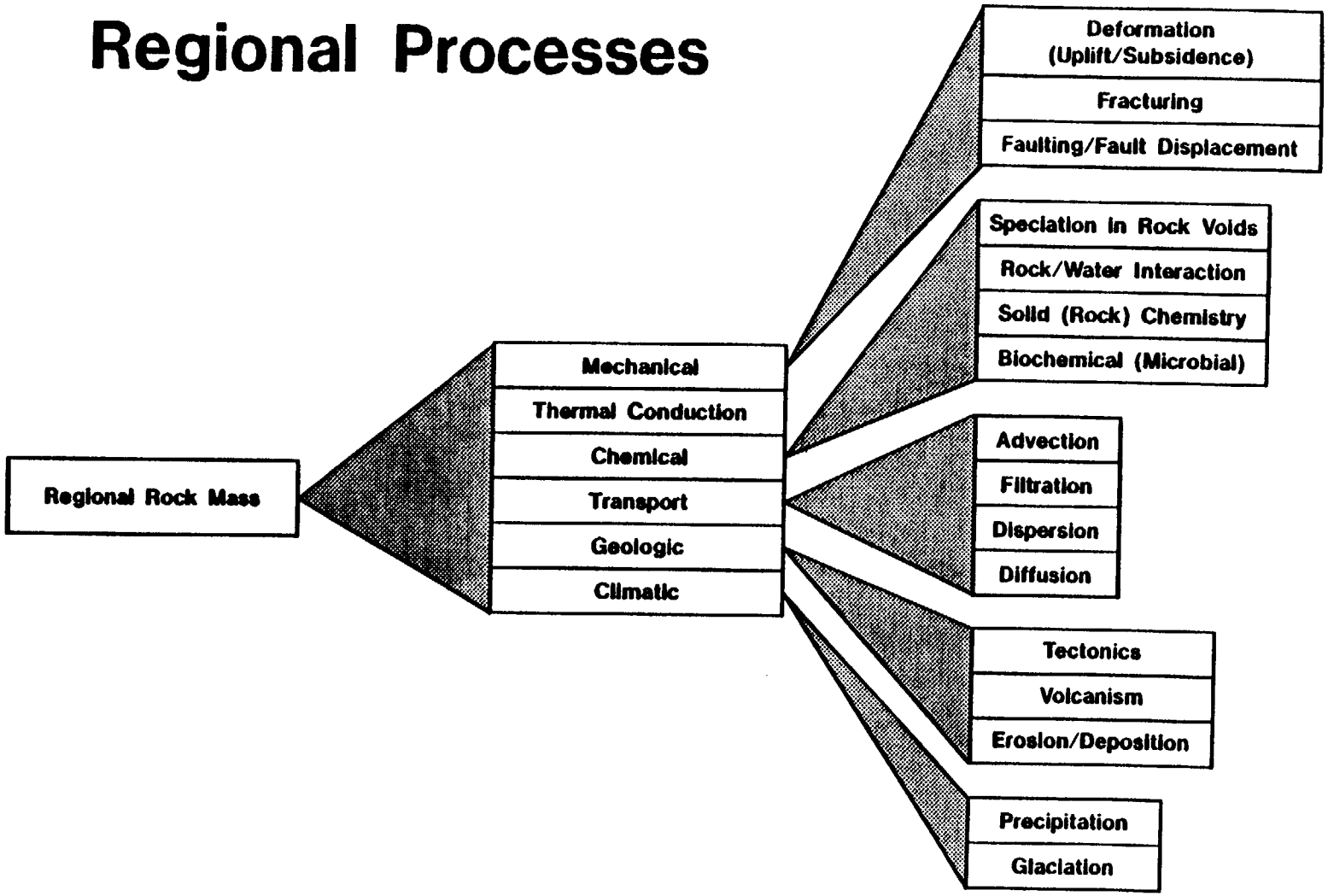
- Topic
  - Geologic Disposal System
- Purpose
  - Orientation to the components of the underground system and the scales into which it is divided. The definition of these scales provides the framework for discussion of techniques for performance assessment of the post-closure, underground system
  - This material is a template for the rest of the instruction
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Define the four repository system scales
    - Describe the relationship of types of waste barriers to the four scales and their relative importance to waste isolation
    - List the principal processes which affect the subsystems in each of the scales
    - Discuss the problems of interfacing models of the principal processes on these four scales including parameter and boundary condition coupling
    - Describe the relationship of the four scales to the general calculational procedure for performance assessment

A91 0592

Base Case Regional/Repository/Mined Facility/Waste Package Integration



Regional Processes



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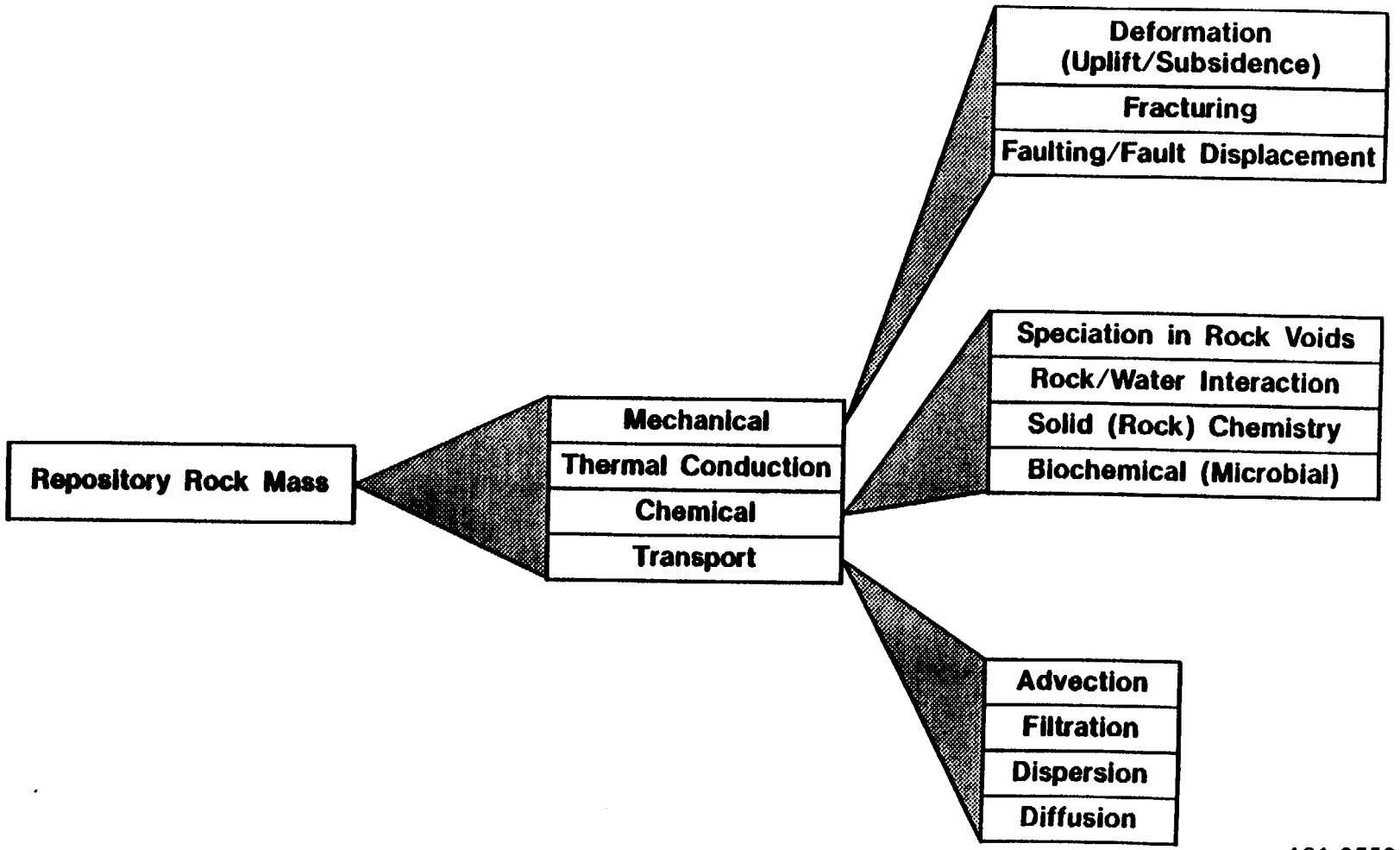
Repository Processes



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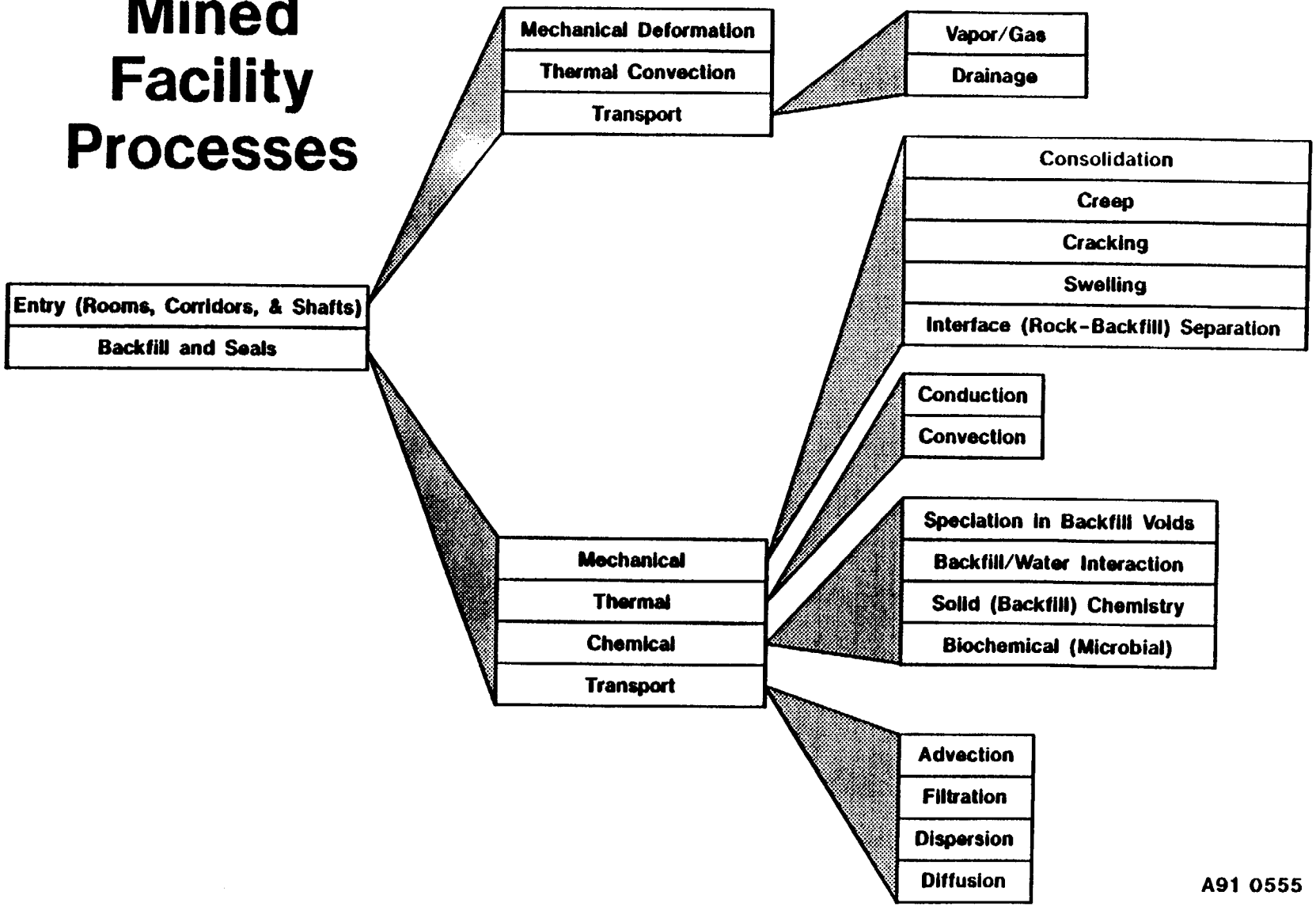
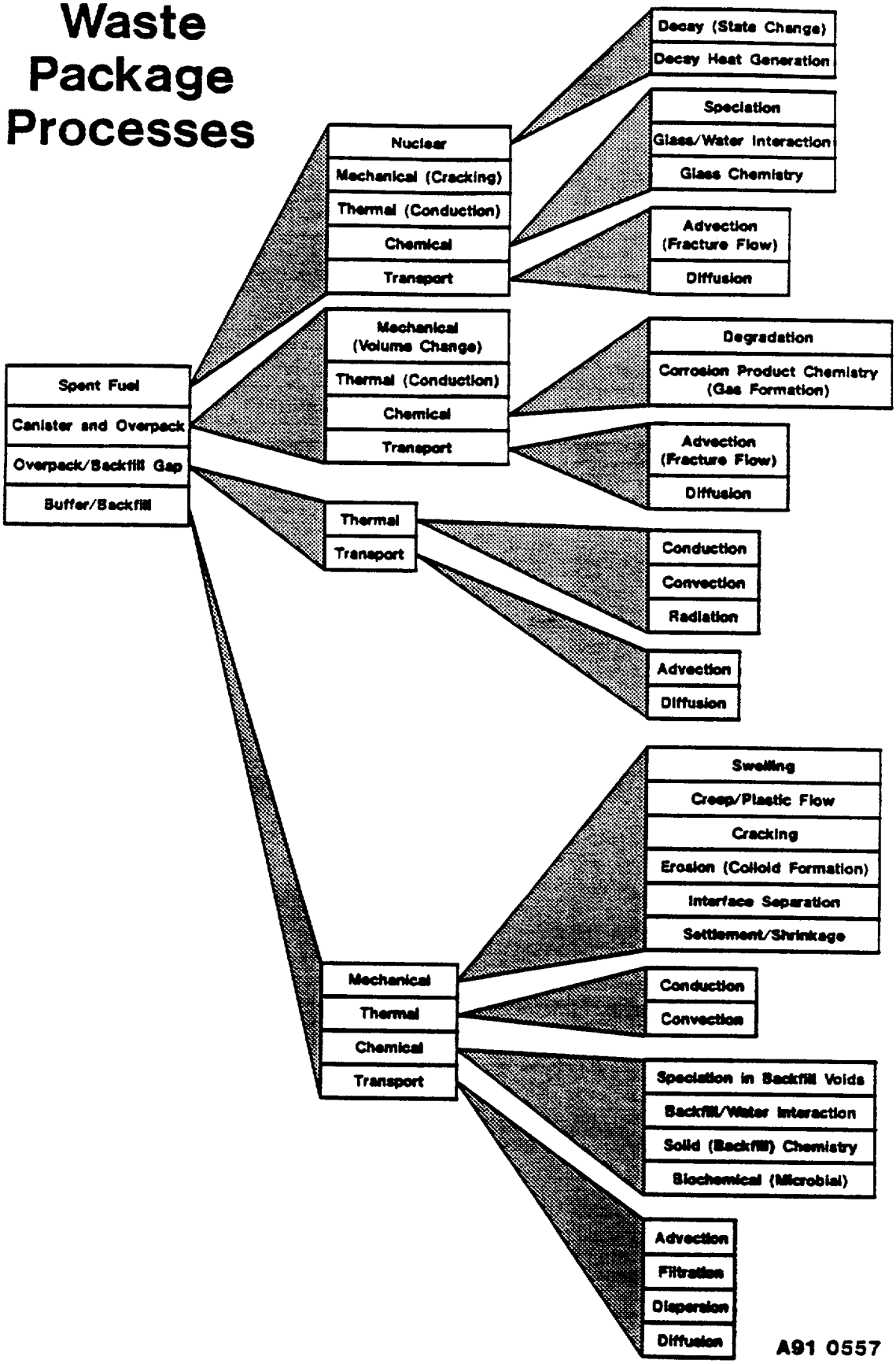
Mined Facility Processes



A91 0555

Waste Package Processes



Study Guide

- **Topic**
  - Fundamental Concepts of Performance Assessment
- **Purpose**
  - Review of pertinent regulatory requirements and the fundamental elements of the performance assessment. This section provides an overview of performance assessment which will help the student see how all the parts discussed during the course fit together and relate to the regulatory requirements.
- **Objectives**
  - At the conclusion of this topic, students will be able to:
    - Describe the key regulatory requirements that pertain to post-closure performance assessment of the geologic disposal system
    - Identify the essential elements of performance assessment and describe how they support each other and contribute to regulatory evaluation
    - Define key concepts related to performance assessment and understand their role in performance assessment
    - Describe performance assessment risk profiles and their relationship to the regulations

A91 0729

Study Guide

- Topic
  - Probabilistic Modeling
- Purpose
  - This topic will provide an overview of the basic concepts associated with probabilistic modeling. The concepts of probability and risk will be explained along with their role in performance assessment, and a comparison will be made of the probabilistic results of performance assessment to EPA release limits (40 CFR 191).
- Objectives
  - At the conclusion of this topic the students will be able to:
    - Define probability and its role in performance assessment
    - List the three components of probability in performance assessment (sample space, events, probability function)
    - Define the parts of a risk measure and its role in performance assessment
    - Explain the subjective and frequentist interpretations of probability
    - Explain the relationship between the EPA release limits and risk
- Reference
  - 40 CFR 191

A91 0613

Section 4 - Probabilistic Modeling

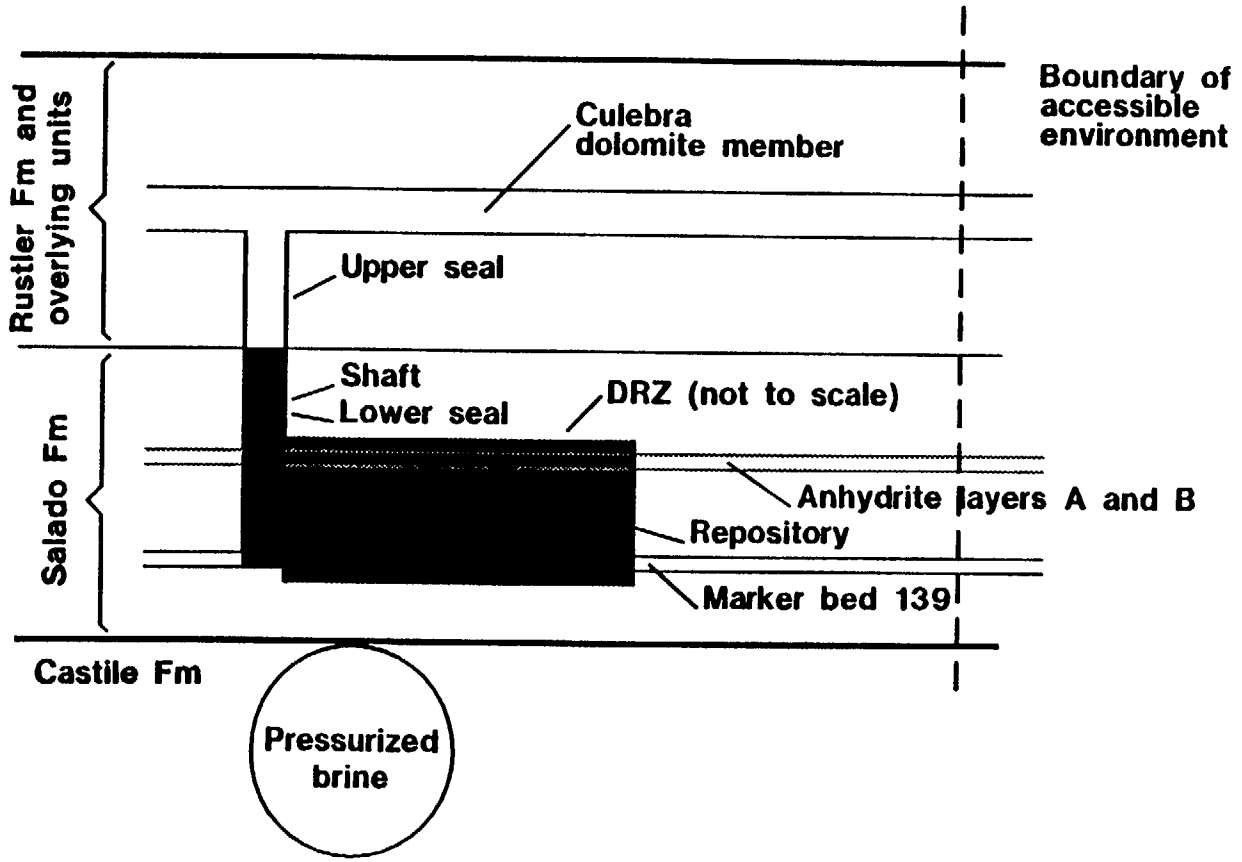
Sec 5 - Scenario Identification and Selection

Study Guide

- Topic
  - Scenario identification and selection
- Purpose
  - This topic will provide the students with an understanding of the role of scenario identification in a performance assessment. The approaches to scenario identification will be discussed and the process of evaluating and screening events, processes, and scenarios will be described.
- Objectives
  - At the conclusion of this topic the students will be able to:
    - Describe the role of scenarios in performance assessment
    - Identify the elements of a scenario
    - Identify the approaches used to define scenarios and an approach considered to be effective and practical
    - List the five steps in scenario selection
    - Identify the three event, process screening factors
    - Screen a list of natural events, processes based on physical reasonableness
    - List the three roles human intrusion events can play in scenarios
    - Explain the process of evaluating and screening scenarios
- References
  - NUREG/CR-1667
  - NUREG/CR-2452
  - SAND89-7149
  - Engineering Geology, 26 (1989) "Scenarios for Repository Safety Analysis"

A91 0670

Conceptual Geologic Disposal System



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Study Guide

- Topic
  - Release and Transport Consequence Modeling
- Purpose
  - Review concepts of modeling as they apply to performance assessment and review the application of models to predict release and transport of radionuclides from the waste disposal system
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Describe the process of developing simpler models from general concepts
    - Relate objectives of models to their features and appreciate the interdisciplinary features of performance assessment modeling
    - Discuss the basic approaches to modeling processes and events which are relevant to radionuclide release and transport
    - Cite some typical computer codes used to calculate release and transport
    - Discuss key issues related to modeling processes and handling coupling between processes
- References
  - Greenkorn, Robert, Flow Phenomena in Porous Media, Marcel Dekker, Inc., New York, New York, 1983
  - Bird, R.B., Stewart, W.E., and Lightfoot, E.N., Transport Phenomena, John Wiley & Sons, Inc., New York, New York, 1962
  - Tsang, C.F., Coupled Processes Associated with Nuclear Waste Repositories, Academic Press, Orlando, Florida, 1987

A91 1023

Section 7 - Dose/Health Consequence Modeling

Study Guide

- Topic
  - Dose/Health Consequence Modeling
- Purpose
  - This topic will provide students with an understanding of the role of dose/health consequence analysis in a performance assessment, emphasizing post-closure performance assessment issues. The purpose of dose/health consequence modeling will be explained and the components of a dose/health consequence model will be described.
- Overall objectives
  - At the conclusion of this topic, the students will be able to:
    - Identify the principal concern of post-closure performance assessment in relation to dose/health consequence analysis
    - Describe the purpose of dose/health consequence modeling
    - Discuss the basic components of a dose/health consequence model
    - Explain the role of exposure pathways in the dose/health consequence model
    - Identify the key step towards the calculation of doses
    - Identify the important parameter in estimating the probability of early health effects
    - Identify the important parameters in estimating the probability of latent cancers
    - Describe the purpose of health effects modeling in estimating risk
- References
  - Risk Methodology for Geologic Disposal of Radioactive Waste: Final Report (NUREG/CR-2452)
  - NUREG-1150, Vols. 1 and 2

A91 0776

Study Guide

- Topic
  - Data Analysis
- Purpose
  - Review the use of data in performance assessment: how data is evaluated and applied, where it comes from, and what types of data are used. This section provides a background for Section 9 (Uncertainty and Sensitivity)
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Evaluate how data is applied in a performance assessment
    - List sources of data and describe the relationship of sources to the use of data in performance assessment
    - Describe the types of data used in performance assessment of high level waste disposal systems

A91 0926

Section 9 Uncertainty and Sensitivity Analysis

Study Guide

- Topic
  - Uncertainty and Sensitivity Analysis
- Purpose
  - This topic will provide students with an understanding of the role of uncertainty and sensitivity analysis in a performance assessment. Sources of uncertainty will be discussed and a survey of techniques used for uncertainty and sensitivity analyses will be given.
- Overall objectives
  - At the conclusion of this topic, the students will be able to:
    - Describe the purpose of uncertainty and sensitivity analyses
    - Explain what uncertainty and sensitivity analyses contribute to a performance assessment

A91 0794

Study Guide

- Topic
  - A Performance Assessment Example
- Purpose
  - Exercise the students knowledge of the issues involved in executing a post-closure performance assessment on a conceptual geologic disposal system and illustrate the objectives of this course
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Identify the issues addressed by a performance assessment
    - Understand the methods and analytical techniques used during a performance assessment
    - Describe the required input data for the methods used, the expected output of each analytical activity, and the interfaces between the analytical activities
    - List the expected performance assessment results related to the three risk questions
    - Understand the strengths and limitations of performance assessment results
- References
  - SAND90-7103, Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant

A91 0943

Section 11 - Performance Assessment Results

Study Guide

- Topic
  - Performance Assessment Results
- Purpose
  - Describe the results of performance assessment and discuss how the results are used to establish regulatory compliance
- Objectives
  - At the conclusion of this topic, students will be able to:
    - Describe the nature of performance assessment results
    - Describe how performance assessment results are applied in establishing regulatory compliance
- References
  - 10 CFR 60
  - 40 CFR 191

A91 0958

Section 12 - HLW Performance Assessment Uses and Applications

Study Guide

- Topic
  - HLW Performance Assessment Uses and Applications
- Purpose
  - Discussion of the uses of performance assessment and how NRC staff can judge the application to the HLW disposal system
- Objectives
  - At the conclusion of this topic, students will be able to:
    - List several uses of performance assessments
    - Explain the relationship between performance assessment and site characterization
    - Explain the relationship between design and performance assessment
    - Describe the relationship between performance assessment and the licensing process

A91 0600

Performance Assessment (PA) has Limitations

- Even the simplest consequence models and implementing codes become very complex. There is a significant problem in establishing confidence in the verification of the methods
- PA is based heavily on modeling and is only as good as the models themselves
- There will always be a significant lack of data
- There will be at best very limited validation

A91 2340

Performance Assessment (PA) has Strengths

- It is a framework which allows an organized definition of our uncertainties
- It is better that we know what we don't know rather than that we don't know what we don't know
- Provides a framework to guide data and research in general
- A disciplined framework for regulatory compliance review

A91 2341