See Pocket 6 for encl.

DEVELOPMENT OF AN INTEGRATED LICENSING ASSESSMENT METHODOLOGY

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ABSTRACT

The U. S. Nuclear Regulatory Commission (NRC) is developing a licensing assessment methodology (LAM) for independently evaluating the Department of Energy's license applications for nuclear-waste repositories. Several NRC contractors are working separately on the LAM. A task called "integration" is examining the LAM for completeness, coherency, and redundancy, in an effort to assist the NRC in meeting its objective of ensuring that all necessary parts of the LAM are available at the time of licensing. There are four goals of the integration effort: first, to determine what analyses are required by the applicable regulations; second, to determine what components and subcomponents of the LAM are necessary to assess compliance with these regulations; third, to examine current NRC-funded work to determine whether necessary components are under development; and finally, as component methodologies evolve, to examine the interfaces between them. The bulk of the work on the first two goals is complete. The necessary components are scenario development, probability assignment, data evaluation, consequence analysis, and comparison with the standard. Probability assignment has been identified as a component that is currently missing from the LAM.

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See A1165 Draft 3/8/85

CONTENTS

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Note: the following sections have not yet been written.

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INTRODUCTION

The U. S. Nuclear Regulatory Commission (NRC) is developing a set of tools and techniques, called a licensing assessment methodology (LAM), for use in independently evaluating the license applications to be submitted by the Department of Energy (DOE) for mined geologic nuclear-waste repositories. The NRC has a number of contractors working separately on various specific aspects of the LAM. Aerospace, Inc., is developing a method for assessing the compliance of the waste package. Golder Associates has worked on aspects of the problem dealing with engineered barriers. Sandia National Laboratories in Albuquerque, New Mexico, (SNLA) is developing tools and techniques for far-field performance assessment. SNLA and GA Technologies, Inc., are developing tools for preclosure performance assessment. It has become increasingly clear that an integration effort is needed to examine the LAM as a whole for completeness, compatibility of the parts, and redundancy and to suggest corrections for any flaws. The integration task is taking place at SNLA. It is examining the various component methodologies thus far developed, summarizing the existing reports, and evaluating their contribution to the overall methodology.

Integration is expected to be a long-term task, because the development of some parts of the LAM has only recently been funded. For example, the development of a set of methods to determine the probabilities of various geologic events and processes began concurrently with integration. As this and other component methodologies evolve, the integration task will examine the new components and their relationship to and interfaces with the more developed components.

Even though the integration task has only recently begun, some gaps and duplication have already been identified (Table 1). For example, there have been scenario development and far-field consequence analyses of hypothetical repositories in basalt (Golder 1984, Pepping and others 1983, Hunter 1983) and bedded salt (Cranwell and others 1982), but no comprehensive work on determining the probabilities of the scenarios has been done.

It is expected that this integration effort will systematically identify missing links and redundancies in the overall methodology. The results from this task can be used by NRC to prioritize its allocation of funding and to guide DOE in its collection of data and design of engineered barriers.

The overall objective of the integration effort is to determine whether the NRC has or is developing all the tools and techniques that will be needed to evaluate the performance assessments contained in DOE's license applications. There are

Table 1. Gaps and redundancies in a demonstration of the licensing assessment methodology for basalt

Area	Authors
Engineered Barrier Analysis	None
Far-field Description	Guzowski and others (1982)
Scenario Development	Pentz and others (1984), Hunter (1983)
Probability Determination	None
Consequence Analysis	Pentz and others (1984), Pepping and others (1983)
Comparison with Standards	Pentz and others (1984), Pepping and others (1983)

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four individual goals. First, the EPA standard and NRC regulation must be examined to determine what analyses are required. As discussed below, the regulation presents both explicit and implicit requirements, and frequently requires that some other regulation or standard be met, which may have both explicit and implicit reqirements of its own. Second, integration must determine what components and subcomponents of a LAM are necessary to assess compliance with these regulations. The integration effort to date indicates that the components of the performance assessment methodology agreed on in the past by the waste management community as a whole are indeed appropriate. These components are scenario development, data evaluation, consequence analysis, probability assignment, and comparison with the standard or regulation. Some subcomponents of the existing NRC LAM may be less appropriate. Third, integration will examine current NRC-funded work to see whether all necessary components and subcomponents exist or are under development. For example, an early conclusion of the integration effort is that no comprehensive set of techniques for determining probability of geologic processes and events exists, although such work has recently been funded. Another apparent lack, not previously identified, is the absence of a formal technique or phase for an assessment of the qualitative suitability of data for use in the performance assessment. The fourth goal of integration, not yet begun, will be to examine each subcompnent of the LAM to see whether it interfaces correctly with the next subcomponent. Large parts of performance assessment can be viewed as a string of beads: output from the inventory model becomes input for the leaching model; output from the leaching model becomes input for the transport model, and so on. Each interface between codes must be examined by the integration effort to ensure that the beads string together properly. Special attention will be given to the interfaces between codes written by separate contractors. The bulk of the work on the first two goals of integration has been completed. Work on the third has begun.

REGULATORY BASIS FOR AN OVERALL LICENSING ASSESSMENT METHODOLOGY

In response to the first goal described above, we systematically examined the NRC regulation, the EPA standard, and other relevent documents for the criteria that NRC will use to evaluate performance assessments (Table 2). These criteria range from specific quantitative requirements to qualitative quidelines. Examination of the criteria has revealed that certain components of performance assessment are necessary to demonstrate compliance with the regulation. Some of these components are explicitly required, while others are implicitly required. This section discusses each regulatory requirement and identifies its performance-assessment counterpart. The next section discusses in more detail the performance-assessment components identified.

Table 2. Performance-assessment components implicitly and explicitly required by 10CFR60

Section	Required Components				
	SD	PA	DE	CA	CS
	Explicit				
21.c.1.i			X		
21.c.1.ii.B			X	X	
21.c.1.ii.C				X	
21.c.1.ii.D	X			X	
21.c.1.ii.E				X	
21.c.1.ii.F			X		
21.c.3	X			X	
51.a.4			X		
72.b			X		
113.a.1.i				X	
113.a.1.ii				X	
113.b			X		X
122.a.2.i			X		
122.b			X	X	
131.a				X	X
	Implicit				
21.c.1.ii.B	X				
21.c.1.ii.C	X	X	X		
21.c.1.ii.D			X		
21.c.1.ii.E	X		X		
21.c.3		X	X		
111.a				X	X
112	X	X	X	X	X
113.a.1.i	X		X		
113.a.1.ii	X	X	X		X
122.b	X	X			
131.b	X	X			X
133.f	X				
134	X				
135.a	X		X		

Abreviations: SD--Scenario Development, PA--Probability Assignment, DE--Data Evaluation, CA--Consequence Analysis, CS--Comparison with Standard.

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The NRC staff has developed a set of licensing issues that they believe must be addressed in any license application that shows the suitability of a site for licensing (Table 2.5. Some of these licensing issues are directly related to specific regulatory requirements (Table 3). Others do not seem at first glance to be related to regulatory requirements. For example, the licensing issue "When does water contact the waste package?" does not address a regulatory requirement: no part of the regulation places a time limit on resaturation of the rock surrounding the waste package. However, the regulation does address the question of when the waste canister may first release waste to the facility. To model this release, some information must be available on resaturation times; therefore the time that water contacts the waste package becomes an issue. Clearly, it is not possible to determine what the components of a LAM should be by examining only the regulation. Examining the regulation shows only the minimum set of components that is needed, not the complete set.

Performance Assessment Components Explicitly Required

The performance assessment will be included in the Safety Analysis Report (SAR) to be submitted as a part of the license application. Section 60.21 of the NRC regulations (NRC 1983) describes the content of the SAR. Among other information, the SAR will include an evaluation of the performance of the repository for the period after permanent closure, assuming both anticipated and unanticipated events. "Anticipated" and "unanticipated" are qualitatively defined to mean "reasonably likely" and "not reasonably likely," respectively. The section also requires an analysis of both normal and accident conditions during operation of the repository and analysis of the extent to which favorable and potentially adverse conditions contribute to or detract from isolation. Satisfaction of these requirements clearly demands scenario development, that is, descriptions of possible sequences of events and processes leading to waste release.

Some consequence analyses are explicitly required. Section 60.111 imposes performance requirements on the repository operations before permanent closure. Section 60.111 (a) states that radiation exposures must be within the limits specified in Section 20 and any standards established by the EPA. Section 60.111 (b) states that the waste must be retrievable for 50 years following waste emplacement. Section 60.113(a.1.ii.A) requires that containment of HLW within the waste package be substantially complete for 300 to 1,000 years. Section 60.113 (a) (1) (ii) (B) requires that following this containment period, the release rate from the facility of most radionuclides must not be more than one part in 100,000 annually. Finally, Section 60.113 (a) (2) requires that a demonstration that the ground-water travel time before water emplacement along the fastest likely path of radionuclide

Table 2.5. Licensing Issues (after NRC 1984)

Preclosure Phase of Performance Assessment

1. How do the design criteria and design address releases of radioactive materials to unrestricted areas within the limits specified in 10CFR60?

2. How do the design criteria and design accommodate the retrievability option?

Postclosure Phase of Performance Assessment

Near-field Ground-water Modeling

3. When and how does water contact the underground facility?

4. When and how does water contact the waste package?

5. When and how does water contact the waste form?

Releases from the Waste Package

6. When, how, and at what rate are radionuclides released from the waste form?

7. When, how, and at what rate are radionuclides released from the waste package?

8. When, how, and at what rate are radionuclides released from the underground facility?

9. When, how, and at what rate are radionuclides released from the disturbed zone?

Releases from the Far Field

10. When, how, and at what rate are radionuclides released from the far field to the accessible environment?

Far-field Ground-water Modeling

11. What is the pre-waste emplacement ground-water travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?

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Table 3. Regulatory Performance Requirements

		Waste Package	Facility	Far-field	Total System
1	Safe Emplacement	60.111(a) 60.131	60.111(a) 60.131 60.132 60.133		
2	Retrievability	60.111(b)(1) 60.135(b)	60.111(b)(1) 60.132 60.133		
3	Water Contacts Underground Facility				
4	Water Contacts Waste Package				
5	Water Contacts Waste Form				
6	Waste Form Releases Radionuclides	60.113(a)(1)			
7	Waste Package Releases Radionuclides	60.113(a)(1)	60.113(a)(1)		
8	Engineered Barrier System Releases Radionuclides	60.113(a)(1)	60.113(a)(1)		
9	Disturbed Zone Releases Radionuclides				
10	Far Field Releases Radionuclides to Accessible Environment	60.135(a)			60.112
11	Far-field Ground-water Travel Time			60.113(a)(2)	

travel be at least 1,000 years from the disturbed zone to the accessible environment. Thus an analysis that develops scenarios and examines operational exposures, retrievability, degradation of the waste package, rates of release from the facility, and pre-emplacement ground-water flow is explicitly required.

Performance Assessment Components Implicity Required

Other aspects of performance assessment are not explicitly required, but must be carried out in order to comply with some section of the regulation. Section 60.112 is particularly important because it requires a demonstration of compliance with any established EPA standard for both anticipated and unanticipated processes and events. The proposed EPA standard (EPA 1982) defines performance assessments to include not only consequence analysis but also estimates of the probabilities of events and processes that might affect the disposal system. Section 191.15 requires that a performance assessment be conducted. A determination of the probabilities of various geologic and other events and processes is clearly required. Although Section 60.113 refers only to releases that might occur if the system works as designed, assuming anticipated processes and events, Section 60.21 and the EPA standards specifically requires the examination of releases following unanticipated processes and events. For these reasons, techniques for scenario screening and probability assignment must be part of the LAM.

Although sensitivity and uncertainty analysis are not explicity required by either the final NRC or proposed EPA regulations, it is generally believed that phrases like "reasonable assurance" and "reasonable expectation" mean that they should be an integral part of the LAM. Draft 4 of the Final 40 CFR 191 (EPA 1984) is more explicit: Section 191.16 (b) refers to "the full range of uncertainties considered in the performance assesment" and how they should be presented.

Section 60.122 sets a number of siting criteria that superficially do not seem to require performance assessment techniques in the demonstration of compliance. Closer examination of the siting criteria, however, reveals that many can only be demonstrated with a performance assessment. For example, two favorable conditions, pre-waste emplacement ground-water travel times of substantially more than 1,000 years and mineral assemblages whose capacity to inhibit the transport of radionuclides under expected thermal loads, probably cannot be directly measured. Numerical modeling of far-field ground-water travel times, temperature rises away from the canisters, and radionuclide transport would probably be required to demonstrate that these favorable conditions exist. Furthermore, demonstration that a number of the potentially adverse conditions (Section 60.122 (c) (1) through

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(6)) do not exist would require scenario development and screening, probability determination, and far-field consequence modeling. Section 60.21 (c) (1) (ii) (B) requires that these analyses of the favorable and potentially adverse conditions be included in the Safety Analysis Report.

COMPONENTS OF AN OVERALL LICENSING ASSESSMENT METHODOLOGY

An overall licensing assessment methodology includes techniques for the analysis of the quantity and quality of data, scenario and probability analysis techniques, and techniques for consequence assessment, that is, codes that produce an end product that can be compared to the applicable rules and standards. Figure 1, a preliminary sketch of the overall postclosure methodology, shows these five components. Preclosure and postclosure methodologies are being developed independently, but the LAM components are undoubtedly the same. Although many of the subcomponents and techniques may be similar, others will differ because the preclosure and postclosure environments are so dissimilar. Because so much more work has been completed on the postclosure performance-assessment methodology than on the preclosure methodology, the postclosure methodology will be discussed first.

Postclosure Methodology

An example of a preliminary methodology is presented in Figure 2. Data requirements include site characteristics and design and degradation characteristics of the waste package and underground facility. Scenario and probability analysis techniques must include methods for developing and screening scenarios for waste release based on both probability and consequence. Most analyses of transport and release of waste require complex codes. Code output must be in a form that can be easily compared with criteria and requirements in NRC's 10CFR60 and Environmental Protection Agency's 40CFR191.

As discussed above, only an assessment of selected consequences is explicitly required by 10 CFR 60. The NRC regulation does not explicitly call for scenario analysis, probability estimates, or data evaluation. The regulation makes these three components essential to any demonstration that a proposed repository will meet the requirements, however, by requiring compliance with the EPA standard, which in turn explicitly requires scenario analysis, probability estimates, and uncertainty analysis.

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COMPONENTS	SUBCOMPONENTS				
SCENARIO DEVELOPMENT	Waste Package Scenarios: Base Case Common Cause Failures Design Failures Construction Failures	Facility Scenarios: Base Case Long-term Failures Far-field Effects	Far-Field Scenarios: Geologic Hydrologic Human Intrusion Repository Induced		
DATA EVALUATION	Judgement of Suitability of Data	Sampling Techniques	Sensitivity Analysis	Uncertainty Analysis	
CONSEQUENCE ANALYSIS	SOURCE TERM Inventory Heat Generation	WATER INFLOW Into the Facility Contact the Waste Package	Water contacts the Waste Form	RADIONUCLIDES RELEASED From the Waste Form From the Waste Package	From the Underground Facility From the Disturbed Zone From the Far Field to the Accessible Environment
PROBABILITY ASSIGNMENT	Quality Control Failures	Geologic Events and Processes			
COMPARISON WITH STANDARD	Determine Preemplacement Ground-water Travel Time Must be >1000 years--60.113/a/2	Determine Waste Package Lifetime Must be 300-1000 years--60.113/a/1/ii	Determine Release Rate from Facility Must be $<10^{-5}$ Annually--60.113/a/1/ii	Determine Contribution of Favorable Conditions to and Detraction of Potentially Adverse Conditions from Waste Isolation 60.21/c/1/ii/B	Determine Releases Assuming Anticipated and Unanticipated Processes and Events 60.21/c/1/ii/C and 191

Abbreviation:
60 10CFR60

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Figure 1. Major components and selected subcomponents of the preliminary postclosure LAM.

nario Development

The waste package and underground facility will be designed the geologic setting will be chosen to contain and isolate wastes given anticipated conditions, that is, given the rent geologic conditions, proper installation of the llity, and the predicted heat and radiation from the waste. repository must also be designed to provide adequate lation in the event of unanticipated conditions. To assist the design of the repository, selection of the geologic ting, and development of appropriate computer codes, narios describing both anticipated and unanticipated litions must be developed. A comprehensive suite of sically possible scenarios can be used to guide code elopment and data collection, ensuring that all necessary es will be available and verified at the time of licensing. narios that could occur at one site might be impossible at a ond site; therefore they can be useful in site selection and eening. Waste package and facility design must, by ulation, be site-specific; again, scenarios are necessary to de the designer. Finally, the NRC regulation requires that EPA standard be met, and the EPA standard will probably uire that a suite of scenarios be developed.[4] Methods for development of far-field scenarios for the release of oactive waste have been discussed previously.[5]

The required functional lifetime of the repository is cted to exceed 10,000 years (EPA 1982). The waste package underground facility will be designed and the geologic ing will be chosen to contain and isolate the wastes given conditions which are expected, that is, given the current ogic conditions, near-perfect installation of the facility, the predicted heat and radiation from the waste. The sitory must also be designed to provide isolation and ainment in the event of various physically possible but pected conditions. To assist in the design of the sitory, the selection of the geologic setting, and the lopment of appropriate codes, scenarios describing both the cted and unexpected conditions must be developed. A rehensive suite of physically possible scenarios can be to guide code development and data collection, ensuring all necessary codes will be available and validated at the of licensing. Scenarios that might disqualify one site t be impossible at a second site, thereby assisting in site ction and screening. Waste package and facility design , by regulation, be site-specific, and here again, arios are necessary to guide the designer. Finally, the regulation requires that the EPA standard be met, and the standard requires that a suite of scenarios be developed.

Methods for the development of far-field scenarios for the ase of radioactive waste have been discussed by Cranwell, wski, Campbell, and Ortiz (1982). The method has been

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nstrated in an application for a hypothetical repository in lt (Hunter 1983). The method is very similar to those used OE for the WIPP site (Bingham and Barr 1979) and for the I site in tuff (Hunter and others 1982). It appears that le or no research remains to be done in the area of field scenario development. The existing techniques can be ied to any geologic setting, because they are independent ock type and of the processes that might be found at a n repository site. The method can be used where large ers of data are already available or can be used in an ative fashion to guide data collection. It has been luded (Cranwell, Guzowski, Campbell, and Ortiz 1982; Hunter) that it is reasonable to screen scenarios for modeling on basis of physical reasonableness, probability, and a iminary estimate of consequences.

It seems likely that the techniques used in developing field scenarios could also be used in developing facility- ackage-scale scenarios as well, although no demonstration ich an application has been carried out for the postclosure e. No Golder documents describing this or other techniques the development of facility-scale scenarios is available. space (198) investigated the use of fault trees and event s in describing waste-package failure and concluded that techniques as described were inappropriate to the needs of LAM. The techniques used by Aerospace to develop event s appear to differ substantially from those used for the field work.

Scenario-development techniques for aspects of the ormance assessment dealing with the far field are complete ave been demonstrated. No techniques have been discussed monstrated for the development of facility- or ge-scale scenarios for the postclosure phase.

bility Assignment

There is consensus in the waste-management community that ll scenarios are equally probable or important. Generally ting, scenarios that are highly probable, like ground-water through the repository, are considered to be most tant, and scenarios that are highly improbable, like rite impact, least important. Most scenarios are neither y probable or highly improbable, and satisfactory iques for determining their probabilities have not been lished. A variety of techniques have been used in the but no consensus seems to exist about the best way to mine probabilities of the scenarios of interest. In fact, rly result of the integration task has been to identify ack of accepted techniques for determining probabilities weakness in the current LAM.

For example, if two scenarios demand differing design changes, then some means of choosing which scenario, and therefore which design changesshould be considered more important must be available. One such means of choosing is probability. Given equivalent consequences, highly probable scenarios should be given more weight than highly improbable scenarios. In order to use the criterion of probability in screening scenarios, some technique must be available for determining probabilities.

Techniques for the determination of probabilities of scenarios and of the occurrence of the events and processes included in the scenarios are necessary because the EPA standard is probabilistic. The draft of the final standard requires probabilities to be assigned to all important scenarios so that a complementary cumulative distribution function can be developed and compliance with the standard can be assessed.[4]

There is general agreement that the number of scenarios that can be developed is much greater than the number that can be reasonably expected to be modeled. Modeling is time-consuming and expensive, and modeling of highly improbable scenarios would detract from the study of more likely and important scenarios. Data also might not be available for the adequate modeling of these scenarios, but if they are improbable, data collection may be a waste of time and money.

Sandia is currently under contract to the NRC to examine techniques for determining probabilities of far-field scenarios (FIN A-1165, Task 3). Apparently no similar effort for facility- or package-scale scenarios currently exists for the postclosure phase.

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Data Evaluation

Assuming that a comprehensive suite of scenarios has been developed and their probabilities have been determined, it becomes necessary to analyze some of the scenarios for consequences. Data requirements for consequence analysis include site characteristics and design and degradation characteristics of the waste package and underground facility. Some types of data may be easy and inexpensive to collect, and presumably data sets will be adequate in those cases. In other cases, however, data will be very difficult to collect or very expensive, and two questions arise: "are a few data enough to show the range of variability in consequences that arise due to this parameter?" and "how certain is the answer that we get?" Three data-evaluation techniques are essential. In the case of voluminous data, some sampling techniques that fairly represents the full range of the data must be available, because most codes are only able to deal with point values, not

ranges. Sensitivity analysis is especially helpful if the data are few, because it allows the investigator to determine the relative importance of various parameters, so that only important data need be collected. Uncertainty analysis allows the investigator to bound the behavior of the system based on available data.

Sampling techniques that can be used for all types of data of interest to the performance assessment have been discussed in connection with the far-field performances assessment methodology (Iman and Conover 1980; Iman, Davenport, and Zeigler 1980). Latin Hypercube Sampling is a highly efficient sampling technique that allows voluminous data or systems with several parameters to be modeled easily while maintaining an adequate description of all possible outcomes using available data.

Sensitivity analysis techniques have been discussed (Iman and Conover 1983; Iman, Conover, and Campbell 1980; Iman, Helton, and Campbell 1978) and demonstrated (Helton and Iman 1980; Campbell, Iman, and Reeves 1980) in connection with the far-field performance assessment methodology. It seems likely that the same or similar techniques could be used in package- or facility-scale performance assessment; however, no sensitivity analysis techniques have been discussed or demonstrated for these parts of the problem.

Uncertainty analysis techniques have also been discussed (Ortiz and Cranwell 1982) in connection with the far-field performance assessment methodology. Several uncertainty techniques have been compared for similar applications (Iman and Helton 1985--get ref from Bob or Nestor).

Sensitivity and uncertainty analysis and sampling techniques are all quantitative tools for data manipulation. Sensitivity and uncertainty analysis are performed on the results of consequence analysis to determine the impact of the data per se and the impact of uncertainties in the data on consequences. The use of the three techniques implicitly assumes that data have been collected on qualitatively appropriate parameters. This assumption may not be correct. Code development, repository design, and so on, are still in the early stages. Today, it is fairly common practice to use any data that happen to be available and superficially similar to those expected to be gathered during site characterization for model development, code verification, and scoping calculations. Use of these data is entirely acceptable, indeed necessary, for now. It does point out the fact that the data are transparent to the codes, however, and that inappropriate data could inadvertantly be used during performance assessment without giving rise to easily discovered errors. For this reason, the LAM must include at some point a qualitative judgement as to whether the data are indeed appropriate.

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›priateness includes both accuracy or precision of the data ›pplicability of the collected data to the assumptions in :s in which the data will be used.

›quence Analysis

Iost consequence analyses uses large and sophisticated ıter codes. Code development is therefore a major part of levelopment of an overall LAM. Although DOE is developing verifying numerous codes for use in consequence assessment, ıas in some cases funded the independent development of : codes for evaluating the results to be presented by DOE licensing documents. Code output must be in a form that can ısily compared with criteria and requirements in NRC's 360 and EPA's 40CFR191.

far-field Performance-assessment codes. NRC's far-field ormance-assessment methodology is being developed by Sandia onal Laboratories Waste Management Systems Division. ral far-field codes have been developed and demonstrated as rt of the performance assessment methodology. Some of e are Network Flow and Transport, Distributed Velocity od (NWFT/DVM) (Campbell, Kaestner, Langkopf, and Lantz ; Campbell, Longsine, and Cranwell 1981; Campbell, sine, and Reeves 1980; Duda 1983; Finley and others 1981); (Cranwell, Campbell, and Stuckwisch 1982; Cranwell, bell, Stuckwisch, Longsine, and Finley 1983); Sandia e-Isolation Flow and Transport (SWIFT and SWIFT II) (Dillon others 1978; Finley and Reeves 1982; Reeves and Cranwell ; Reeves, Johns, and Cranwell 1983, 1984; Ward and others); the Environmental Transport Model (Brown and Helton ; Helton, Brown, and Iman 1981; Helton and Iman 1980); sport Model (Campbell, Iman, and Reeves 1980); ways-to-Man (Helton and Finley 1982; Helton and Kaestner); and Dosimetry and Health Effects (Runkle and others ; Runkle and Finley 1983).

DNET simulates salt dissolution in bedded salt formations nwell, Campbell, and Stuckwisch 1982). It includes salt p, subsidence, and thermomechanical effects.

SWIFT and SWIFT II are three-dimensional, transient, finite erence models that solve coupled equations for the ısport of radionuclides in saturated geologic media (Finley Reeves 1982). The codes consider fluid flow, heat ısport, and the migration of both dominant and trace ies. SWIFT considers porous media only, while SWIFT II is ıal porosity code, that is, it can be used to represent ıtured media.

NWFT/DVM is a computationally efficient code that simulates ınd-water flow and contaminant transport in a saturated ›us medium. It is a semi-analytic, quasi-two-dimensional

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code that is especially useful when large numbers of calculations are required (Duda 1984).

Pathways-to-Man includes the Environmental Transport Model and the Transport-to-Man Model (Helton and Kaestner 1981). Environmental Transport represents the long-term accumulation and movement of radionuclides at the Earth's surface. Transport-to-Man represents the movement or radionuclides from the environment to man and is based on concentration ratios. Dosimetry and Health Effects estimates long-term risks from releases of radioactive waste (Runkle and others 1981). It includes doses from exposure to contaminated soil, sediment, air, and water. Neither the NRC or EPA regulations currently require the types of calculations carried out by these four codes in the postclosure performance assessment. The EPA standard sets limits on releases of radioactive waste to the accessible environment only, not on doses to man or on health effects. Instead, calculations of doses to man and health effects were used originally in developing the technical rationale for the standard. Recent drafts of the EPA standard include limits based on dose to an individual; the above codes can be used to estimate dose to an individual. They are also useful in assessing compliance with the preclosure standards.

Facility-scale Performance-assessment codes. Previous NRC-funded work in performance-assessment- methodology development at the facility scale has been carried out by Golder Associates. This work (Pentz and others 1985) has depended on DOE and other pre-existing codes. For example, the analytic models used to evaluate engineered-barrier performance in a basalt repository were ORIGEN, BARIER, and NUTRAN, the NRC far-field code SWIFT, and Latin Hypercube sampling and uncertainty analysis techniques. ORIGEN (Bell 1973) was used to calculate radionuclide inventories as a function of time. SWIFT provided regional and local ground-water-flow and temperature history and solute transport. BARIER (Stula and others 1980) calculated waste package containment time for specified site conditions and canister corrosion. NUTRAN (TASC 1982) estimated peak, integrated, and cumulative releases of radionuclides at selected points in the engineered and geologic systems, by calculating radionuclide movement along predicted flow paths. Data uncertainties and their effects on the estimated barrier performance were evaluated using the LHS uncertainty analysis model (Iman, Davenport, and Zeigler 1980). The numerical models were used to analyze barrier performance both for expected and credible but unexpected repository conditions (Pentz and others 1985).

There are apparently no current contracts to develop NRC-funded facility-scale codes for use in independent evaluations of the DOE license applications.

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Package Scale Performance-assessment Codes. NRC's contractor for waste-package performance-assessment methodology is Aerospace Corporation, Eastern Technical Division. Aerospace (1985) has found that some existing codes, ORIGEN, HEATING 5, ADINAT, and ANISN-W, are acceptable for direct use by the NRC in evaluating DOE's performance assessment of some waste package degradation processes. Other codes that may be acceptable are PHREEQE, EQ3/EQ6, RADIOL, CHAINT, MAXIMA-CHEMIST, MAGNUM-2D, and PORFLO. ADINA and NIKE are acceptable mechanical process models. Aerospace concluded, however, that models for canister corrosion and degradation of glass waste forms or spent fuel rods and cladding are either unavailable or not obviously acceptable. Aerospace plans to use a modular approach that allows each barrier to be analyzed separately.

HEATING 5 (Turner and others 1977) models heat conduction. ADINA (Bathe 1975) is a general purpose structural and rock mechanics stress analysis code. ADINAT (Bathe 1977) is a thermal analysis code that interfaces with ADINA. NIKE (Hallquist 1979) models static and dynamic responses of two-dimensional solids to deformation. ANISN-W (Oak Ridge and Westinghouse 1973 is a transport code. PHREEQE (Parkhurst and others 1980) models a variety of geochemical reactions depending upon the extent of the data base. EQ3/EQ6 (Wolery 1979) computes equilibrium models of aqueous geochemical systems. RADIOL (Simonson and Kuhn 1983) predicts the amounts of radiolytically produced species in brine solutions. PORFLO (Sagar and Clifton 1983) models flow through porous media. MAGNUM 2D (Baca 1984b) simulates transient ground-water flow and heat transfer in fractured porous rocks. CHAINT (Baca 1984a) simulates multicomponent radionuclide transport in a fractured porous medium. MAKSIMA-CHEMIST (Carver and others 1984) simulates mass action kinetics.

Preclosure Methodology

Preclosure components of the LAM are being developed by SNLA and GA Technologies. Harris, Ligon, Stamatelatos, Ortiz, and Chu (1985) have recently described a systematic methodology to assess the safety of high-level waste repositories before closure (Figure 1). The methodology can be used to identify and quantitatively rank structures, components, systems, and operations that are important to safety. The methodology will also help to assess compliance with the operational phase standards (10CFR60, 10CFR20, and 40CFR190) by estimating potential releases of radionuclides and dose to the public.

A tool of this nature could incorporate techniques from existing probabilistic risk and safety assessments. Several previous analyses addressing these areas for the preclosure phase have been reviewed (Ligon and others 1984). SNLA and GA

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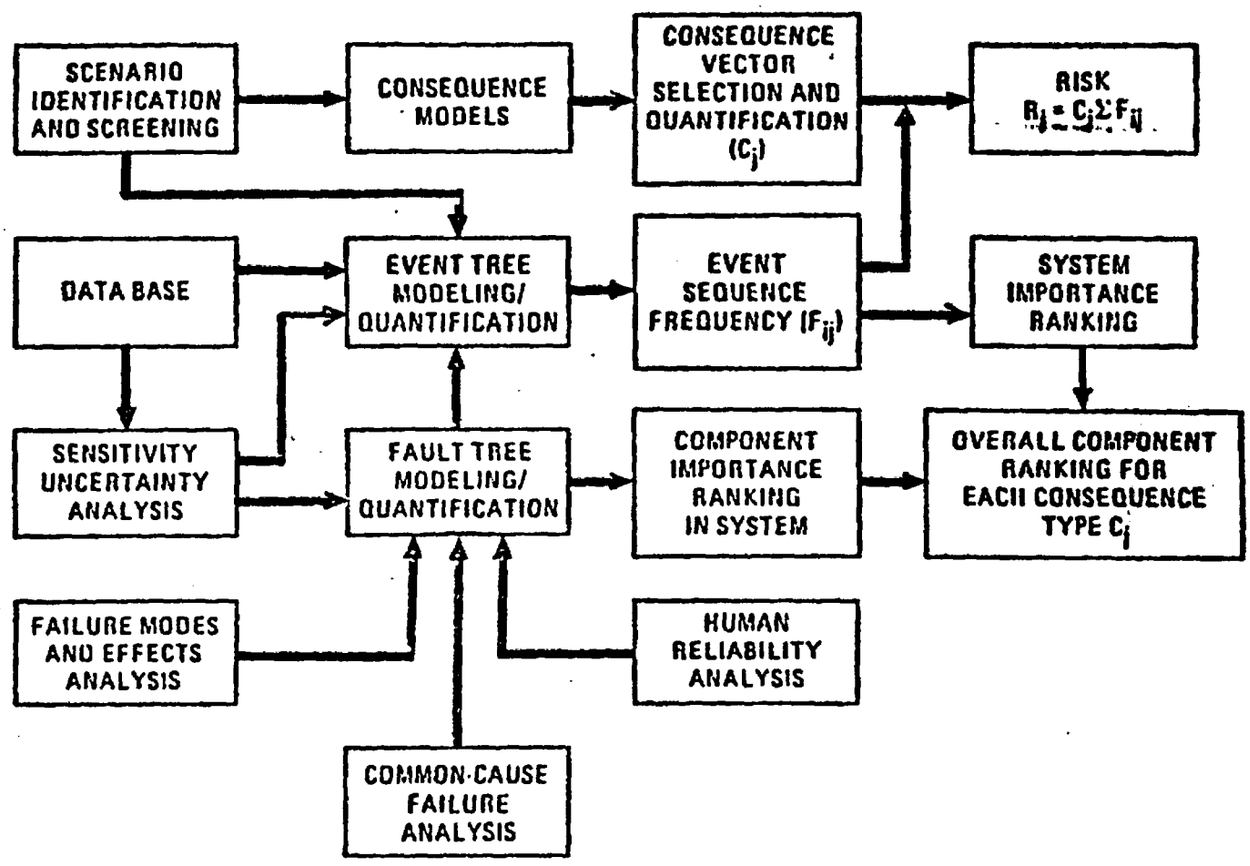

Fig. 1. Methodology for high-level preclosure safety systems analysis (Harris, Ligon, Stamatelatos, Ortiz, and Chu 1985).

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Technologies will build on currently available, accepted techniques wherever possible.

The preclosure phase of the LAM concentrates on operations involving the receipt, examination, preparation, and emplacement of commercial high-level waste. Retrieval is also included, with the goal of characterizing the incremental risk. The option for retrieval of emplaced waste is currently required by NRC regulation (10CFR60). Retrieval must remain a valid option until such time as the NRC is satisfied as to the likely success of the isolation process. Both immediate and delayed retrieval are being considered.

Scenario Development

The first step in determining the risk from facility operation is identification of potential accidents and their consequences. An accident scenario contains three components: the initiating event, the interaction with additional facility systems that could influence the course of that event, and the consequences that could be expected if the accident were to progress unchecked. The spectrum of all plausible accident scenarios with consequences detrimental to public health and safety define the contribution of the facility to overall societal risk. Determination of this body of accident scenarios, representation of the scenarios as a quantifiable set of logic models, and acquisition of the data base necessary for quantification are the major tasks of scenario development.

All initiating events (accidents) potentially capable of causing consequences of concern to public health and safety must be identified for a given a conceptual repository design. They must be screened on a preliminary basis to remove obviously insignificant contributors. Remaining initiating events are developed into accident scenarios by coupling the interaction of all plant systems potentially capable of influencing the outcome of each initiating event.

A detailed examination of material flow through a facility described in the basalt repository conceptual design (REF??) has been performed to determine the plausible accidents that could occur for all expected facility operations (Harris, Ligon, and Stamatelatos 1985). Process flow diagrams specifying all individual operations required in every major facility area were developed. Accidents were subjected to an initial screening process used in a previous NRC study (Pepping and others 1981) for early elimination of insignificant contributors. An additional screening criterion from the draft EPA standard (EPA 1982), suggesting a lower credible occurrence frequency of 1.0E-08/year, was also used . Initiating events surviving this screening process were developed into accident scenarios.

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Logic models (e.g., event trees, fault trees) must be selected to suitably represent accident scenarios in a numerically quantifiable form. The combination of event and fault tree methodology was selected for construction of logic models to represent the spectrum of potential accidents (Harris, Ligon, and Stamatelatos 1985). Event trees were used to simulate the interaction of various systems that could influence the outcome of an accident. Fault trees were used to model individual systems for which sufficient information was available. Portions of fault trees from previous analyses (Pepping and others 1981; Stearns-Roger Engineering Co. 1978; Bechtel Group 1981) were incorporated where system and function were similar. Additional detail identifying the contribution of human error was added to the trees.

The potential for disruption of and possible radiological release from several systems in the facility by natural and induced external events (e.g., earthquake, fire) was also considered (Harris, Ligon, and Stamatelatos 1985). The vulnerability of each system to disruption or damage by the external event was examined. Where this possibility existed, another accident sequence was created, specifying the external event as the accident initiator and identifying potentially degraded intermediate events.

The computer code SETS (Worrell, 1978) is used to quantify fault trees. It is capable of reducing large fault trees to minimal cut set expressions. VALUE (Harris, 1982), a computer code for importance ranking, is used to estimate the probability of failure for complex mechanical systems from the failure probabilities of all critical components. VALUE is a companion code to SETS.

Probability Assignment

Each system identified in an accident scenario as capable of influencing consequences must then be assigned a failure probability based on the expected behavior of that system. Systems described in sufficient detail from the conceptual design can be modeled explicitly by several different techniques. Other systems (such as support systems) that are identified but not described in detail must be assigned a failure probability based on the performance of similar systems.

After completion of the logic models and preliminary numerical evaluation, common cause failures are considered. Examination of common cause failures can alter both system-failure probabilities and accident-sequence frequencies, because failures in some systems can cause failures in other systems previously assumed to be independent. A complete logic model of system interaction is required to identify subtle system interdependencies.

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STADIC-2 (Koch 1983) is a Monte Carlo simulation code used to combine probability distributions of the input variables in accordance with the mathematical operations specified by that function.

Data Evaluation

The data needed to quantify logic models can be divided into initiating event frequencies, component and system failure rates, and human error rates for tasks of varying complexity and stress level. Sources of initiating- and external-event frequency data include previous repository studies for waste-process specific events; accident statistics for switchyard, transporter, and other transportation-related events; warehousing and shipping accident statistics for events addressing lifting and movement of heavy objects; and siting studies conducted for intended repository site.

Primary component-data sources will be the Nuclear Plant Reliability Data System (Southwest Research Institute 1981) and the Government Industry Data Exchange Program (GIDEP 1984). These two sources contain accumulated data histories, including sample size and variance for uncertainty calculations, for almost any conceivable component.

Human error rates can be estimated using the approach of Swain and Guttman (1983). These error-rate calculations will suffice for operations identified at both the individual system and system interaction levels.

With data from the above sources, uncertainty analysis can be performed using direct distribution sampling to provide a true estimate of top event (e.g., release of radioactive material to the public) uncertainty. A simple perturbation method was selected (Harris, Ligon, and Stamatelatos 1985) for performing sensitivity analysis given the complete logic models.

Consequence Analysis

The consequences of the accident sequences must be linked together into categories of similar risk level. Accident sequences containing similar consequences can be grouped together into categories. The sequences in each category can then be treated as the contributors to that level of risk.

Initially, several types of consequences were considered, including public radiological exposure, personnel radiological exposure, personnel nonradiological injury, loss of repository availability, financial impact, and compromise of long term repository performance (Harris, Ligon, and Stamatelatos 1985). After identification of accident sequences contributing to each category, only public and personnel radiological exposure categories were pursued. Several consequence models for the

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itial release, transport, and movement into the open vironment were identified. An existing method was modified quantify the probable source term given the drop of a spent el handling cask. Coupling of accident sequences to nsequence types was performed by examining the immediate nsequence (i.e., cask drop) to determine whether the bsequent release and transport path posed a hazard to the blic or to the operating personnel.

The tasks outlined above are a fairly straight-forward plication of existing risk assessment techniques. Several litional requirements for this analysis are not amenable to a ndard approach. Ranking the contributions of systems, nponents, and operations to each category of risk requires e measure of importance for each component in each system subsequently each system in each accident scenario. It has n shown that human error is a major concern in activities operations that require human handling (Swain and Guttman 3); therefore, human interaction at both the component and tem levels must be included. Finally, uncertainty in the a must be reflected in the overall estimate of risk in each egory, and the sensitivity of the overall risk to different ponent or system values must be examined. Techniques for aining these results must be integrated into the structure the performance assessment.

Several importance measures (Lambert 1975) were evaluated use in ranking risk contributors. The Fussel-Vesely sure seems to be the best technique for consideration of h dominant single contributors and also lower probability tributors that occur more than once (Harris, Ligon, and natelatos 1985).

Mining activities were examined to provide an estimate of ciating events that could be expected in the repository ronment and to better characterize equipment reliability. ning consultant (Engineers International) provided tional expertise and located the required data more rapidly.

Two consequence codes being considered for incorporation the preclosure LAM are PADLOC and CRAC2. PADLOC is a dimensional mass-transfer code used to analyze steady-state time-dependent plateout of fission products in an arbitrary ork of pipes. CRAC2 (Ritchie 1983) is a Gaussian plume ersion model that can be used to determine aerosol release he environment.

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EXAMINATION OF INTERFACES

Movement of radionuclides from the waste form to the phere entails many different physical processes, which are led by many different computer codes. Codes have been

written or funded by NRC, DOE, EPA, national laboratories, and private industry. It is likely that many codes will provide output that is incompatible with the input requirement of the next code. It is essential to identify gaps and weaknesses that might exist in linking the output or response of one model to the next within a given performance assessment methodology. For example, in the calculation of thermomechanical response, it is common to first solve the transient thermal response, which can then be used as input to a mechanical-response code. However, numerical mesh sizes may differ in the two codes, making it necessary to interpolate or extrapolate the nodal temperatures from the first mesh to the next.

In some cases output of existing codes cannot be directly compared to the applicable regulations. For example, in evaluating the license application it will be necessary to determine whether the release rate criterion has been met. To the best of our knowledge, no existing codes present the output in the form of a fractional release rate of radionuclides, although one of the performance criteria in the NRC regulation is a fractional release rate of 10^{-5} parts per year. Instead, release is commonly described as a concentration or flux. A tool that will permit conversion of the output (e.g. flux) to a fractional release rate is necessary. In this project, a major effort willl be to ascertain compatibility between consecutive models.

RELATIONSHIP OF OVERALL LAM TO REGULATORY REQUIREMENTS

Determination of Preemplacement Ground-water Travel Time

Section 60.113 (a) (2) requires that the time of travel of ground water along the quickest path from the repository location to the accessible environment be more than 1,000 years before emplacement of the repository. Issue 11 (Table 2, p. 4) corresponds to this requirement in the regulation. The determination of travel time requires neither scenario development nor probability assignment: ground-water flow from the repository location to the accessible environment is presumed to be in steady state and to be occurring now at some rate, however small. Although there may be uncertainty in the data and in the conceptual model derived from the data, the existing flow, whatever it is, is not ambiguous. No data on waste characteristics or transport enter into the calculation of travel time.

Data evaluation is essential to a credible determination of ground-water flow time. First, the data must be examined for suitability. Some of the questions that might be asked about the data are these:

Are any data gathered from laboratory measurements genuinely indicative of field conditions?

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Are the data that have been collected applicable to the
est path of ground-water travel?

Are the data accurate and precise?

Have all parameters that are modeled in the flow codes been
ured?

e questions reflect on the suitability of the data for use
he determination of ground-water travel time.

Determination of Waste Package Lifetime

Determination of Release Rate from Facility

amination of Favorable and Potentially Adverse Conditions

Determination of Releases Assuming Anticipated and
Unanticipated Processes and Events

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SUMMARY

The regulations and standards against which DOE's performance assessments will be judged are being examined to see what results are explicitly and implicitly required, and hence what the components of performance assessments and the LAM should be. A performance assessment that meets the requirements of the NRC regulation must include scenario analysis, probability assignment, data evaluation, consequence assessment, and comparison with the standard. The LAM must include techniques for assessing results generated by these components. Probability assignment has been identified as a component that is currently missing from the LAM. Qualitative judgement of data is a missing subcomponent.

Much work remains on the LAM. Subcomponents of each of the five components discussed here must be identified. Codes and other tools to implement each subcomponent must be identified and evaluated. Interfaces between codes must be carefully examined. NRC can use the results of this task to prioritize its allocation of funds and to guide DOE in its collection of data and design of engineered barriers.

As discussed above, only an assessment of selected consequences is explicitly required by 10CFR60. The NRC regulation does not explicitly call for scenario analysis, probability assignment, or data evaluation. Two sections of the regulation make these three components essential to any demonstration that a proposed repository will meet the requirements, however. The first is straightforward: The NRC regulation requires compliance with the EPA standard, which in turn explicitly requires scenario analysis, probability assignment, and uncertainty analysis.

Future work on the LAM will include identification of the subcomponents of each of the five components discussed here, identification of existing physical examples of each component and subcomponent (e.g., existing codes), and investigation of the physical examples to insure that they are compatible.

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