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TRANSPARENCY AND TRACEABILITY IN PERFORMANCE ASSESSMENT OF HIGH-LEVEL NUCLEAR WASTE REPOSITORIES

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ABSTRACT

Both the pre- and post-closure safety cases for high-level nuclear waste repositories rely to a significant extent on analyses based on mathematical models and use a large amount of data. Such analyses called integrated safety analysis (ISA) and performance assessment (PA), respectively, are usually quite complex. An ISA and a PA contain system descriptions and supporting databases, scenario analyses, consequence analyses, performance measure calculations, sensitivity and uncertainty analyses, and a comparison of estimated performance to regulatory requirements. For a regulator to evaluate compliance with applicable regulatory criteria, the implementor is expected to provide sufficient information in a license application for the regulator to fully understand and evaluate the implementor's approach and results. Transparency and traceability in the implementor's ISA and PA are necessary for the regulator to develop confidence in whether or not the regulatory criteria will be complied with.

In this paper, we define the terms transparency and traceability as they are applicable to performance assessment of high-level nuclear waste disposal facilities and describe basic attributes (e.g., completeness, clarity, and consistency) of transparent and traceable documents supporting a license application. Although the paper focuses on the regulatory perspectives of transparency and traceability as applicable to high-level nuclear waste repositories, it presents an overview of a framework that may be useful for developing a regulatory framework for any waste disposal facility.

INTRODUCTION

High-level nuclear waste repositories are designed to protect human health and the environment during a relatively brief operational period (e.g., 50 years) and for extended time periods (e.g., 10,000 years) after closure. The safety case for these facilities rests, to a significant extent, on analyses that simulate their performance over these long periods of interest. The post-closure analysis is called performance assessment (PA) or alternatively safety or risk assessment (e.g., see

U.S. Department of Energy, 1998; Mohanty and McCartin, 1998; Wescott et al., 1995). A somewhat analogous analysis called the integrated safety analysis (ISA) is also performed for the pre-closure period (e.g., see U.S. Department of Energy, 2000). Due to the time (and space) scales involved, presence of natural geologic and engineered components, and presence of a variety of data and model uncertainties, the post-closure PA is usually quite complex. In most countries, an implementor (e.g., the Department of Energy in the U.S.) proposing to build a high-level nuclear waste repository is required by regulation [e.g., proposed 10 CFR Part 63 (U.S. Nuclear Regulatory Commission, 1998)] to conduct an ISA and a PA and submit it to the regulator (e.g., the Nuclear Regulatory Commission in the U.S.), as a part of the application for obtaining a license. The regulator reviews the ISA and the PA (and other parts of the license application) to decide whether to grant a license. Most of the discussion in the rest of this paper is with respect to PA but it is equally applicable to the ISA.

Regulators are recognizing the importance of establishing regulations and judging compliance with them based on a risk-informed performance based (RIPB) approach. In an RIPB approach, each implementor has flexibility in how it demonstrates the safety of its high-level nuclear waste facility in compliance with the applicable regulations. Compliance with the objective criteria of the applicable regulations (e.g., the expected annual dose to the average member of the critical group) is usually determined through PA. The PA should play a defining role in the establishment and demonstration of the risk-informed approach to regulatory compliance. The objective of a PA is to evaluate safetythe , expressed as the calculated exposure of the public to release of hazardous material depending on the operational and release scenarios expected at a particular containment facility and to determine likely performance while considering the risks and uncertainties associated with their evaluation. In addition, the process of conducting the PA will establish risk insights, that will allow attention to be focused on the most important attributes of the repository system. Transparency and traceability are key attributes of an RIPB PA and will enhance the ability of the implementor to make an informed case of demonstrating compliance with regulations in their PA.

Stakeholders may have different vested interests in having a transparent and traceable safety case. The implementor may wish to use the results to persuade other stakeholders about the acceptability of the project. The regulator is interested in conducting an efficient and effective review. Other stakeholders may be interested in understanding the effects of the proposed project, understanding the considerations used to develop the proposed design, or gaining confidence in the implementor's analysis.

DEFINITION OF TRANSPARENCY AND TRACEABILITY IN THE PERFORMANCE ASSESSMENT PROCESS

Transparency has been defined by the Nuclear Energy Agency (NEA) as an attribute of a PA report that is "written in such a way that its readers can gain a clear picture, to their satisfaction, of what has been done, what the results are, and why the results are as they are" (NEA, 1998). NEA amplifies this definition by noting that transparency is more subtle than traceability and that the relative

transparency is audience-dependent. That is, a document that is transparent to a regulator or practitioner of PA may not be transparent to a member of the public (NEA, 1998). The Swedish Nuclear Power Inspectorate (SKI, 1998a) recognized that it may not be possible for all stakeholders (e.g., public, environmental groups, state government, regulators) to understand all technical issues in detail nor is it possible for technical experts to understand each other's disciplines in detail. However, a PA document should provide sufficient transparency to allow the stakeholders to evaluate compliance with regulatory performance criteria.

Transparency extends to writing PA documents that address the needs of a technical or regulatory reviewer who requires an overview of the work done and its outcomes, but who will also use portions of the document to focus on very specific topics or aspects of the proposed high-level nuclear waste disposal system. A transparent PA document, thus, should be structured to provide guidance while facilitating in-depth reviews so that the technical reviewer does not have to search an entire document to compile information for specific topics of interest (NEA, 1998). Transparency exists when there are systems (e.g. procedures, protocols, and conventions) in place that ensure the reliability of data, processes, and methods and provide the reviewer or user with clear evidence of reliability (King, 1992). Any analysis should be transparent to ensure that the implementor meets the normal requirements of technical explanations, proof of authenticity, and legitimacy of actions.

Traceability as defined by NEA is an unambiguous and complete record of the decisions and assumptions made, and of the models and data used in arriving at a given set of results (NEA, 1998). To be complete, at a minimum, this record should include (i) information on when and by whom various decisions and assumptions were made, (ii) the basis for the assumptions, (iii) how these decisions and assumptions were implemented, and (iv) what versions of codes and data sets were used (NEA, 1998). In addition, model parameter values should be traceable to raw data whether measured in the laboratory or field, or obtained through expert elicitation. Key decisions should be recorded with supporting evidence. Traceability exists when there is an unbroken chain linking the result of an assessment (e.g., final dose calculation) with models, assumptions, expert opinions, and data used in the formulation of the result (National Conference of Standards Laboratories, 1994). All information may not necessarily be contained in the top level PA reports, but it should be found in supporting technical reports, documents, and catalogs that are readily available for review by interested parties. Traceability can be achieved by implementing a rigorous Quality Assurance (QA) program. A test of the adequacy of traceability in a report is that an independent PA group should be able to reproduce the entire analysis or selected parts (NEA, 1998). From the regulator's perspective, a good test whether a PA is sufficiently transparent and traceable is to determine if a competent technical expert can independently reproduce various aspects of the analysis.

The PA involves technical analyses primarily using relatively complex mathematical models embodied in computer codes to obtain quantitative estimates of performance measures (e.g., dose, health effects, annual risk, cumulative release of radionuclides). More specifically, the PA process consists of developing system descriptions and supporting databases, together with conducting scenario analyses, consequence analyses, estimating values of performance measure(s), sensitivity

and uncertainty analyses, and comparison to performance objectives. A PA will evaluate the features, events, and processes (FEPs) that may affect future evolution of a proposed high-level nuclear waste disposal facility, and will simulate the performance of such a repository taking into account the relevant FEPs. For efficient and effective regulatory decision making, the implementor's PA should be both transparent (readily understood) and traceable (easily tracked) to the maximum extent practicable. Presence of transparency and traceability in a PA makes for an efficient regulatory review and helps build confidence that the facility will perform as expected. The proposed regulations at 10 CFR Part 63 applicable to the proposed Yucca Mountain high-level nuclear waste repository specify performance objectives related to overall system performance in terms of expected annual dose, requirements on use of multiple and diverse barriers, consideration of disruptive processes, and safety under a stylized human intrusion event. Recognizing the uncertainties in data and models, the regulation requires the implementor to incorporate these uncertainties and develop a time versus mean dose curve for 10,000 years. The regulation at 10 CFR Part 63 also imposes limits on the maximum (or peak) of this curve to be below a specified value.

The time versus mean dose curve incorporates a multitude of models representing different aspects of the repository and a large amount of data. Without sufficient transparency and traceability, visibility into the PA may be limited. Information (e.g., FEPs and laboratory and field data) flows into the PA and is processed to create new information in the form of results [see Figure 1(a)]. As the degree of transparency and traceability increases, the processes within the PA become visible or understandable [see Figure 1(b)]. For a PA to be sufficiently transparent and traceable for efficient regulatory review, the assumptions, uncertainties, rationale, and data used in the PA should all be visible [see Figure 1(c)]. Decisions taken in the high-level nuclear waste facility design, decisions to exclude or include certain FEPs, demonstration that the best possible conceptual and detailed numerical approach are considered or demonstration that additional sophistication will not substantially improve the analysis, and that the model abstraction is bounding should be transparent. Approaches taken to achieve transparency should be such that one can trace the flow of information from the beginning to the end point [see Figure 2 (a) and (b)].

The following attributes of a transparent and traceable PA are discussed below: (i) PA document style, structure, and organization; (ii) FEPs identification and screening; (iii) modeling methodology; (iv) data use and validity; (v) performance assessment results; and (vi) code design, data flow, and supporting documentation.

PA DOCUMENT STYLE, STRUCTURE, AND ORGANIZATION

As noted earlier, information necessary to achieve sufficient traceability may not be found entirely in top level PA documents and reports. PA documentation may be distributed over numerous reports. To obtain a complete understanding, the regulator will need to examine information in supporting technical documents and reports. Information may also be stored electronically in word processor files and databases. To facilitate full comprehension of the information recorded in the documents and data sources, traceability and transparency require that source documents be obtainable, well-

structured and organized, and that a road map is available showing relationships between various documents.

The regulator may have guidance documents (e.g., NUREG documents issued by the NRC) that provide guidance on how to structure a license application and the safety case in it. While these documents are only a guide and an implementor need not follow them, any substantive deviation should have strong logic behind it. For the proposed high-level nuclear waste repository at the Yucca Mountain, the NRC plans to develop and publish a review plan that is expected to serve the dual purpose of (i) providing guidance to the NRC staff on how to review any license application and also (ii) provide guidance to the DOE on what is expected to be included in the license application and the structure of the document.

PA documentation should be complete in that all required sections should be present and necessary details should be included in each section. Documentation should be clear in that the content is appropriately presented (neither too much nor too little), the relationships between sections within a document are straightforward, the terminology (e.g., technical jargon) is understandable and appropriate, and the message of each section and the entire document is precise and unambiguous. Sufficient information has to be available to facilitate full understanding of the license application. The use of various terms and phrases (e.g., probability of event, igneous event, vent versus vent alignment) throughout the PA should be consistent. When terms and phrases are defined differently for various applications, that usage difference and rationale should be clearly described. Consistency should be practiced such that important terms and phrases (e.g., "fracture zone," "major features," and "minor features") are unambiguous and precise (SKI,1997a). The documentation should be consistent internally in that, (i) the content is consistent with its scope and objectives, (ii) the content is consistent with all related work products that support the document, (iii) the content is consistent with all applicable guidelines, and (iv) related components within a document are consistent (e.g., a balance in the level of detail in the descriptions is evident throughout the PA descriptions). Any known inconsistencies should be explained.

To enhance traceability, road map diagrams, traceability matrices, and other graphic means should be used to describe the relationship within and between documents, and draw attention to important assumptions. Stakeholders with differing perspectives and roles are expected to scrutinize PA documentation. Therefore, PA documentation should be structured to facilitate such disparate in-depth reviews. A reviewer should not have to search multiple documents to address a specific issue of interest, but if multiple document searches are required, adequate mapping (e.g., cross-reference matrices) to external pertinent information should be provided. Ideally, a reviewer should be able to say, "That seems obvious; how else could you do it (Brooks, 1995)?" As a general measure of transparency, the best documents are short, use appropriate terminology (e.g., toxicity versus Total Effective Dose Equivalent), and are diagram-intensive. PA documentation should have a balance in the level of detail, clearly state assumptions and simplifications made, and reference the source of basis data (e.g., dose-conversion rates) in its main volumes (SKI, 1997a, and b).

There is a government initiative in the United States to communicate with the public in "plain English," which means that PA documents should be written in a clear, concise manner with minimal technical jargon and at the level of comprehension of a member of the general public. The government's emphasis on "plain English" appears to be motivated by the recognition of a growing need for non-technical stakeholders to understand the concepts being presented, assess the proposed disposal facility in the context of other risks, and decisions made by society, and allow them to form independent, objective opinions on the issues. This is consistent with the conclusions reached by the NEA (1999). Special writing skills are required to prepare such a technical document for the general public. However, there appears to be some disagreement in the regulatory community on how PA documents should be tailored to respond to the differing needs of the general public and technical experts. Instead of requiring one document for all stakeholders, some regulatory agencies may require multiple documents because the technical reviewer needs more detail and complexity of argument and demonstration than is required by the general public. Regardless of how many stakeholder-specific documents are provided, these documents need to meet the expectation and needs of potential audiences without sacrificing the presentation of details of exhaustive technical studies, results, and conclusions in a transparent and traceable manner (Swedish Nuclear Power Inspectorate, 1998a).

PA documents are usually written for technical reviewers who are expected to be well-informed on the substantive issues and the methodologies used in the PA. Any attempt to provide exhaustive traceability may weaken key arguments and results and actually lessen transparency. Special efforts must be taken to appropriately convey the process and results of a PA to non-technical stakeholders who have different viewpoints and who have bases for judgments that are not readily addressed by purely technical explanations. It is suggested that the implementor investigate how the stakeholders receive and process PA information. Factors that influence public perception should be identified. Armed with such knowledge, the implementor should tailor the PA presentations for the widest possible audience while ensuring that the intended messages remain clear and that transparency and traceability are maintained.

FEATURES, EVENTS, AND PROCESSES (FEPS) IDENTIFICATION AND SCREENING

Identification and description of significant system features, events that may occur during the life time of the repository, and physical and chemical processes that will occur within the repository or within its environment, forms the foundation of a PA. A PA will identify, classify, and screen FEPs that are combined into scenarios. The same screening process is also followed to exclude FEPs from further consideration (i.e., FEPs not placed into scenarios).The regulator will evaluate the PA to determine if the implementor has adequately identified and addressed those FEPs that are likely to affect performance (by whatever codified criteria) within the compliance period.

Sufficient documentation that allows an adequate understanding of the methods and criteria used for the screening of FEPs, including rationale for including or excluding selected FEPs from the assessment, should be provided (Reamer, 1995). Additional documentation (e.g., an interaction

matrix, interaction diagram) may be employed to enhance understanding of the relationship between relevant FEPs and how the relationship is modeled.

Categorization of FEPs is reviewed during evaluation of the scenario analysis process. The documentation of the relationships between FEPs (e.g., leakage discharge versus erosion) is necessary to support modeling decisions. Documentation of all steps in a FEPs screening methodology is necessary to ensure that the implementor has properly considered appropriate evolution of a high-level nuclear waste disposal system and to provide the traceability needed to facilitate future revisions.

MODELING METHODOLOGY

Transparency and traceability in a PA should allow for sufficient understanding of the mathematical framework for the conceptual models, (i.e., abstraction) to assess the repository performance. Specifically, this includes the relationship of the actual repository design to the assumptions, models and parameters used in the PA calculations and the relationship of site information to the assumptions, models and parameters used in the PA.

The method(s) of deriving conceptual models should be described starting from assumptions defining the scope of the assessment to assumptions concerning specific processes and the validity of given data. Sufficient information should be available to allow an independent reviewer to trace the abstraction process from fundamental background information to the source code (forward traceability) and back (backward traceability) (Pressman, 1997). A mapping (e.g., a “road map” diagram, a traceability matrix, a cross-reference matrix) to explain exactly what conceptual features (e.g., patterns of volcanic events) and processes are represented in the PA models and their associated algorithms is expected to be present.

The implementor should assure that sufficient information is available that allows an understanding of the decisions and assumptions made during the abstraction process, when and by whom and on what basis various decisions and assumptions were made (Hooks, 1994). Documentation should also describe any inconsistency in application of assumptions among the various models, the rationale (e.g., simplification), and the effect on results.

An explicit discussion of uncertainty (e.g., high risk scenarios) to identify which issues and factors are of most concern or are key sources of disagreement is expected in the PA documentation (NRC, 1998). Information should be available that allows sufficient understanding of how problems, limitations, and uncertainties are identified and isolated in the PA including the resolution of stakeholder concern.

When there is no consensus as to the validity or meaning of data sets or models, an approach that the implementor may take is to review the literature, interact with key experts individually, and then resolve the situation. As a means to ensure authenticity, independent reviewers should be able to

verify that the expert elicitation process is formal and is clearly defined, documented, and followed. The implementor should ensure that a process is in-place that can assist in identifying and clarifying facts, expert judgment, uncertainties (e.g., model, data), value judgments, levels of significance, and open questions (HMIP, 1995). Value judgments should be clearly identified and should not be mixed or confused with objective facts (SKI, 1998a and 1998b).

Each step in development of a complex PA methodology is a refinement in the level of abstraction. During the early stages of development, a solution may be stated in terms that are familiar in the problem domain (e.g., objectives of the assessment, technical basis, computational approach, etc). As one moves through the refinement process, the level of abstraction is reduced. Finally, the highest level of abstraction is reached when a computer code is generated. To allow an independent reviewer to assess the implementor's abstraction methodology from fundamental source information (e.g., codes, FEPs, laboratory data, etc.), the entire process needs to be recorded, together with the uncertainties and biases accumulated and resolved at each stage, including evidence used (e.g., expert elicitation). It is important in the PA to "... distinguish uncertainties about facts of outcomes from uncertainties involving value judgments ..." (Smith, 1993). Value judgment has an influence on which issues ultimately are addressed in the PA. Factors that can contribute to the distortion of assessment results or introduce bias include confusing strong opinion with fact (value judgment) or seeking only information that confirms one's own views (distortion) (HMIP, 1995).

DATA USE AND VALIDITY

The validity of PA results depends not only on the validity of the model(s), but also on the validity of the data used with the model. The sufficiency of data (field, laboratory and/or natural analogs) to adequately define relevant parameters and conceptual models should be evident. More importantly, the derivation of model parameters from raw data should be clearly explained. In addition, the implementor should identify the important parameters that exist among many less important ones (NRC, 1999). An explicit discussion of these "important" parameters in the PA is critical in assessing the information gathered on those parameters. An implementor may develop data (numerical values or ranges of numerical values) used in the PA to describe different physical and chemical aspects of the high-level nuclear waste disposal facility, the geology and geometry of the surrounding area, and possible scenarios for human intrusion. Values may be well-established physical constants or may be physical, chemical or geologic characteristics that the implementor establishes by experimentation. Transparency and traceability should allow for an understanding of the source and validity of these data and their use in the PA.

The implementor should establish an "audit trail" to allow an assessment of the quality and validity of all the data used in a PA, including data developed outside of the QA program, particularly data used to guide modeling assumptions and decisions. Sufficient information should be provided regarding QA controls placed on the data used in the PA including data collection procedures, use of standards, data reduction, and data analysis (SKI, 1996).

Attributes of the repository that are important to performance may be identified through PA and may be evaluated further through a performance confirmation program. Performance confirmation is defined in NRC regulations at 10 CFR 60.2 as "the program of tests, experiments, and analysis which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." A thorough description of the performance confirmation program is critical to assessing the ability of a licensed facility to comply with requirements. A complete description of the process used to develop any performance confirmation program parameters is required. Sufficient information should be available to allow an independent reviewer to develop a good understanding of the processes used to select the parameters to be measured in the performance confirmation program. Specifically, the implementor's description of performance confirmation should include: (i) identification and selection of candidate parameters, (ii) methods used to collect information for each parameter, (iii) model and model abstraction selection and rationale for use, (iv) performance confirmation test selection and rationale, and (v) effect of repository design changes.

PERFORMANCE ASSESSMENT RESULTS

PA results [e.g., the peak expected (in the statistical sense) annual dose within the compliance period], should be traceable back to sensitivity studies and other applicable analyses that identify the critical assumptions, input parameters, and models used in the PA. Sufficient documentation should be available to trace the origin of important assumptions and decisions and verify that the results obtained can be clearly linked to those decisions and assumptions (SKI, 1997a). It should be possible, in principle, to trace back to decisions regarding, for example, various classes of uncertainty. Transparency and traceability should foster a comprehensive understanding of the results of any PA.

Documentation should be available in the PA to allow for a comprehensive understanding of the process used (e.g., QA procedures) to promote traceability and to demonstrate that the process has been consistently applied. Documentation should allow for a comprehensive understanding of the mobilization, release, and transport of hazardous high-level nuclear waste to a critical group or affected environment.

Intermediate results should be presented as they present insight into the PA results. Information should be provided to allow an evaluation of the technical basis for overall barrier capability and the parameters and assumptions that may affect the capability of individual barriers. For example, the U.S. Department of Energy (DOE) is required as per NRC proposed regulations at 10 CFR Part 63 to demonstrate, in the case of the proposed geologic repository at Yucca Mountain, that the repository comprises multiple diverse barriers. The NRC does not prescribe a specific mechanism for such demonstration (NRC, 1998). Although the proposed rule does not prescribe numerical criteria for the may not apply to performance of individual barriers, NRC believes that presentation of presenting intermediate results that depicting performance of individual barriers will help independent reviewers build an understanding of the behavior of the total system.

CODE DESIGN, DATA FLOW, CODE VALIDATION, AND SUPPORTING DOCUMENTATION

The implementor should present a convincing case that the code used for their PA produces results that can be accepted with confidence (Hill, 1990). There is always a degree of uncertainty inherent in translation of a formal model into a computer code (Smith, 1993). Therefore, it is important that a PA code be transparent because independent reviewers will inevitably need to understand the code to evaluate its use and output. Discussed below are some important aspects of a transparent/traceable PA computer code including (i) code design, (ii) data flow; (iii) code validation, and (iv) supporting documentation.

Transparency and traceability of a PA is enhanced if the design of the code (e.g., computational scheme) is explained, including the flow of information (input and output) between the various models and modules within a model and the forms of abstraction, (e.g., the use of look-up tables) [see Figure 1(e)]. Because of the overall complexity of most systems and the need to understand the total system behavior, an integral part of a PA is the abstracted models used in conducting the analyses and their representation in the form of a computer code. The assessment results are only as good as the models used in the assessment, in that error in the PA may result from an incorrect analytical solution for a model or an abstraction may not capture the actual behavior of the system. Therefore, subject matter specialists may review a code to understand the logic an implementor has used in developing a portion of a conceptual model or treatment of data in the model.

An implementor's approach to transparency and traceability for code design and data flow should assure that: (i) the structure of code is mechanically correct and (ii) the input and output (flow of information) between the various modules is clearly described. Adequate documentation should be provided (e.g., structure charts, data flow diagrams, etc.) to demonstrate that a PA code has a sufficiently high degree of modularity to facilitate an in-depth review, if required.

A fundamental principle of structured design is that a large or complex system such as a PA code should be partitioned into manageable modules to be transparent (McConnell, 1998). However, it is important that this partitioning of the system be carried out in such a way that the modules are as independent as possible. Two measures of modularity are coupling and cohesion. Coupling is the degree of interdependence between two modules. Low coupling between modules indicates a well-partitioned system. Low coupling is achieved when two modules communicate only through parameters, each parameter representing only the necessary communication of data between modules. Cohesion is the measure of the strength of functional association of instructions or group of instructions within a module. Highly cohesive modules contain elements that all contribute to execution of one and only one problem-related task. Functions are isolated into separate modules (e.g., functions, subroutines). A high degree of cohesion leads to less coupling and enhanced transparency. Additionally, detection of design functionality beyond what is required is also critical because unnecessary functionality increases complexity which can make the code inherently more error prone (Page-Jones, 1980).

Code commentary should fully describe functions, interfaces, and data used. The presentation style of the code (e.g., use of white space and comments) is expected to enhance the understandability of implementation and provide sufficient information describing the evolution of the code (e.g., a record of changes and why, with dates and names of programmers). Internal code commentary should be deliberately planned because no programming language is truly self-documenting (Glass, 1992). Consistent naming conventions, a logical structure, and the use of appropriate format enhance transparency and therefore facilitate the review and understanding of a complex code.

Code validation (or confidence building) is discussed in Eisenberg et al. (1999) as defined as "a process carried out by comparison of model predictions with field observations (including natural analogs) and experimental measurements" (NRC, 1999). The goal of validation of PA code results is to demonstrate, in a transparent fashion, a level of confidence that the code can perform all intended functions. Also, that the code does not perform any unintended functions that either by itself or in combination with other functions can degrade the integrated output of the entire system (Myers, 1979).

A computer code comprises a lower level of documentation in the hierarchy of documents included in a PA. Additional, supporting documentation (e.g., user's manuals, design documents) should clearly describe code structure and relationships between modules. The information should allow for a comprehensive understanding of the overall structure of the PA code and coupling of models. Major elements of the code as they relate to the need to consider the suites of applicable FEPs should be evident. The theoretical basis for the code should be explained. The range of applicability of the model(s) used to evaluate performance should be identified. Control flow, data flow, control logic, and data structure should be visible and effective. Domain and range of valid inputs (e.g., range and precision) and legitimate outputs as well as input-output formats should be highlighted. External interfaces, the user interface, database organization, and error handling should be obvious. The validation process should be discussed and the results should be presented in readily understood terms. Additionally, supporting documentation should describe the major design alternatives that were considered, the reasons that the selected approaches were chosen, and the reason other alternatives were not selected.

CONCLUSIONS

Considerable effort is required to produce a PA that is sufficiently transparent and traceable. For the regulator and other stakeholders, transparency and traceability are overriding attributes of an acceptable and successful PA. The ability for any independent reviewer to be able to follow, comprehend, and if desired, duplicate the analysis lends significant credence to the efforts of the implementor. An acceptably transparent and traceable PA provides an independent reviewer with a solid base on which to build judgments regarding the ability of a facility to meet the performance objectives set for it. Additionally, a well-documented and well-constructed PA provides self-proving documentation for legal challenges. A strong QA program can help assure transparency and traceability of PA documentation by providing the authors the appropriate checks to ensure that

desired goals for comprehension by independent reviewers are met. Even though all information may not be contained in a single document, the system of procedures, protocols, and conventions followed by the implementor must ensure the reliability of data, processes, and methods, providing independent reviewers with the ability to judge the adequacy of a PA.

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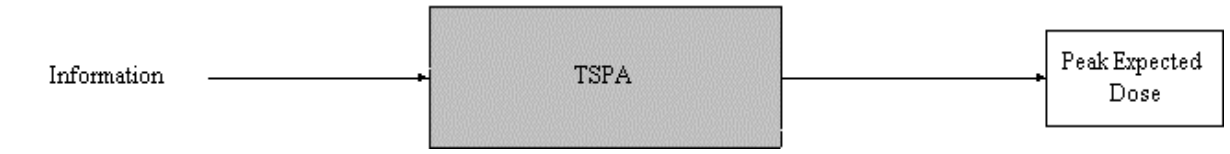

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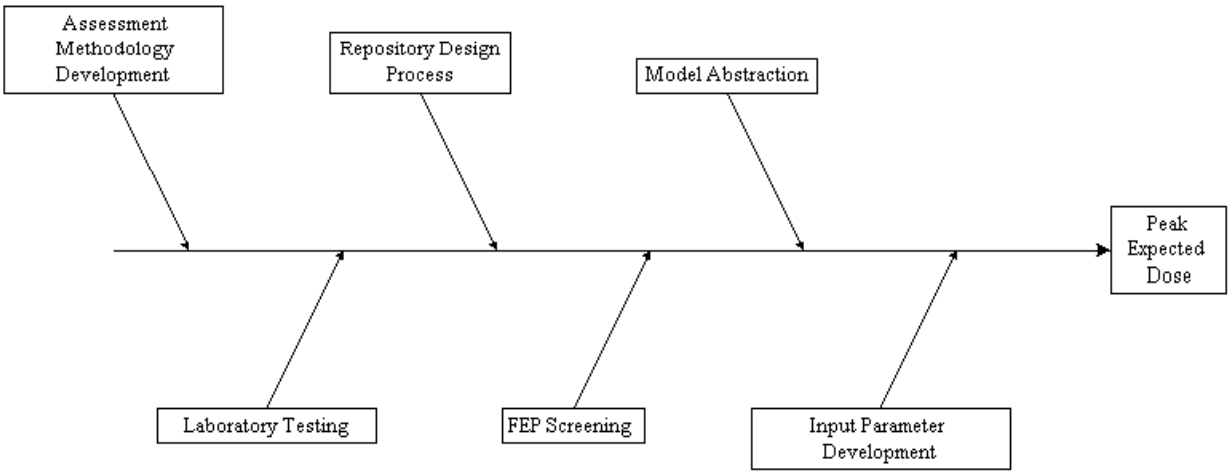

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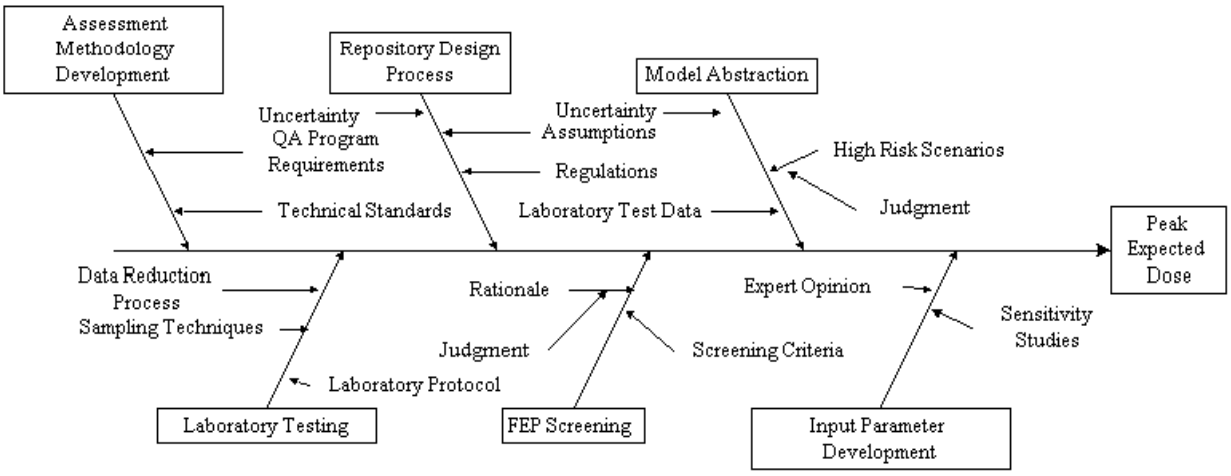
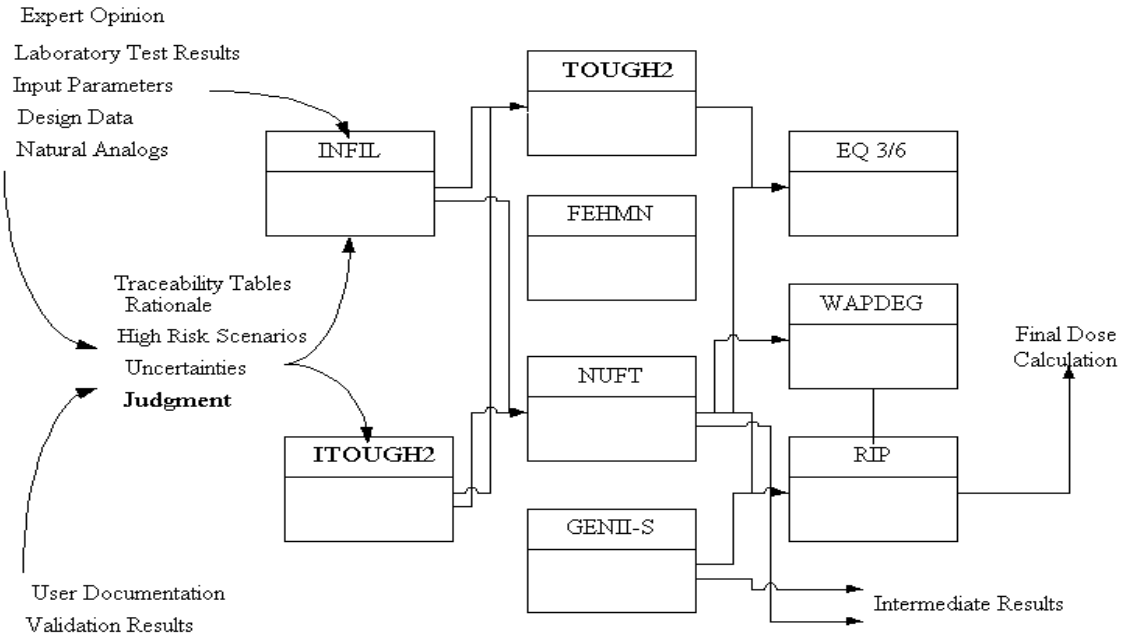


(c)

Figure 1. Examples of degree of transparency of a performance assessment for a high-level nuclear waste repository:(a) black box, (b) partially transparent, (c) fully transparent



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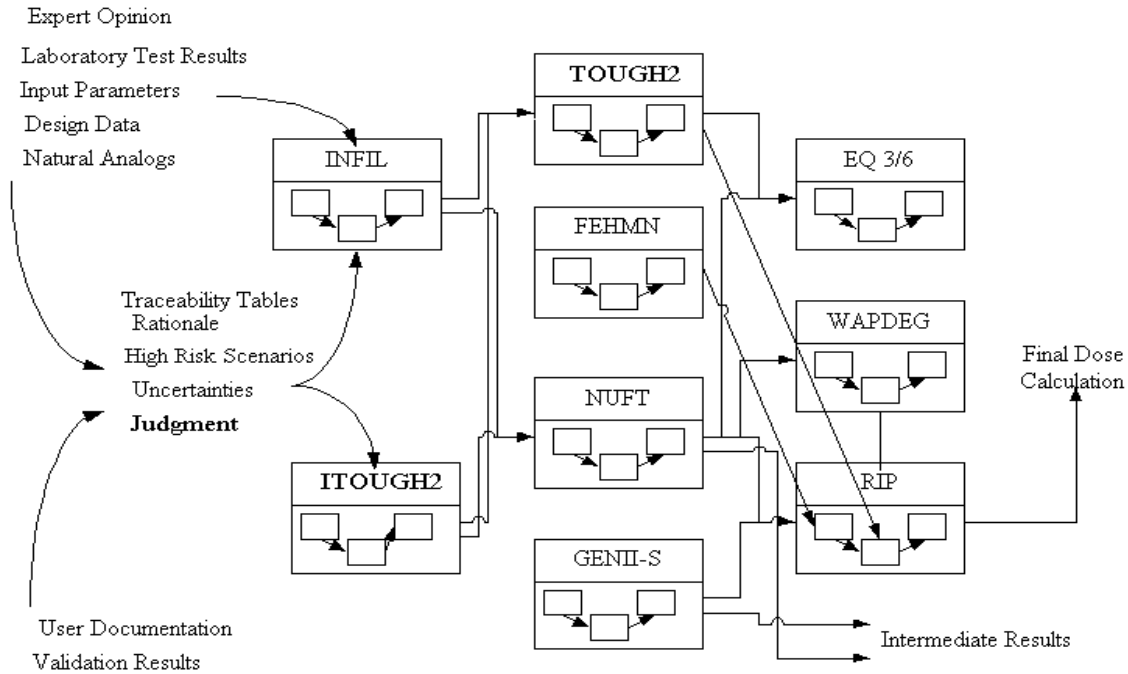

(b)

Figure 2. Examples of modularity in the performance assessment model for a high-level nuclear waste repository: (a) with partial transparency, (b) with additional transparency

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