REPOSITORY PERFORMANCE - UNCERTAINTY AND
REASONABLE ASSURANCE

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ABSTRACT

This paper addresses some of the fundamental questions of successfully licensing a geologic repository. This unique process has begun in the U.S.A. and a formal procedure of staged licensing has been put into place. The question of defining both the components of uncertainty and reasonable assurance must be addressed if DOE is to successfully deploy a repository on any agreed schedule.

A method of optimizing the deployment of a repository is presented provided that EPA define the required level of confidence in the overall system at decommissioning of the repository.

INTRODUCTION

A nuclear waste repository has as its principal design goal the long-term containment and isolation of radionuclides. Demonstrating that this performance goal is fulfilled will, in part, be accomplished by mathematically simulating repository performance. The U.S. Nuclear Regulatory Commission (NRC) in 10CFR60 provides a standard by which a prediction of repository performance is judged. The NRC terms this standard as "reasonable assurance", requiring that performance be demonstrated with reasonable assurance.

"Reasonable assurance" is not defined by NRC but is based upon a well-recognized principle, the doctrine of the "reasonable man". In a non-numerical sense, it implies that a comprehensive and defensible analysis supports any finding. The term "reasonable assurance" implies a subjective and a quantitative approach to determining acceptable performance, with the subjective portion addressing the defensibility of performance analysis.

This paper explores these issues of performance, uncertainty and reasonable assurance. The focus of the discussion is prediction of long-term radiologic performance of nuclear waste repositories. Within the paper is discussed the elements of repository performance, sources of uncertainty in performance and alternative approaches to demonstrating performance with reasonable assurance. Since the NRC has dictated a staged licensing approach this paper has also addressed the problem of how "reasonable assurance" must change through the licensing process. This concept of changing the definition of reasonable assurance is fundamental to an orderly, defensible licensing process and also would allow for a repository deployment program which had tangible goals and, thus, allow for a defensible schedule to be established.

REPOSITORY PERFORMANCE

A repository is subdivided into three main dependent components, these include: the geologic setting limited by the accessible environment and including shafts and boreholes; the engineered system which is limited by the disturbed zone within the geologic setting and the limits of the waste package; and the waste package which is that portion of a container which can be transported and retrieved if necessary. Repository performance may be placed into two categories: namely short and long-term performance. Short-term performance predictions of the operational phase of a repository including handling, packaging of nuclear waste are not perceived to present new and unique licensing difficulties. This is not discussed further in this paper.

Simulating the long-term radiologic performance of a repository requires mathematical simulations of and defensible data for:

- Waste Package Breach
- Nuclide Release from Waste Form
- Nuclide Transport in Engineered System
- Nuclide Transport in Geologic Setting to Accessible Environment

The two sequences of this process are shown for both saturated and unsaturated conditions in Fig. 1. Many predictive models support these calculations including hydrologic models, thermal models and chemistry simulations. These simulations provide the information which is necessary to determine compliance with the NRC and draft EPA radiologic criteria which apply to the waste package lifetime, the nuclide flux out of the engineered system and the nuclide flux into the accessible environment.

The defensible mathematical basis for and use of these simulation models requires a comprehensive and defensible understanding of the physical and chemical processes acting on a site, the repository site's geochemistry, hydrochemistry and geohydrology,

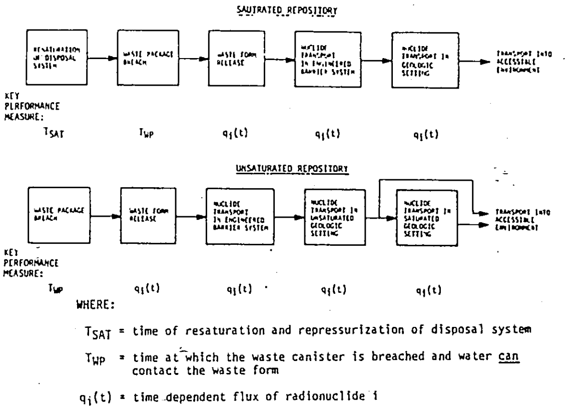

Fig. 1. Performance Methodology for Saturated and Unsaturated Repositories.

as well as the effects of heat, radiation, engineered system materials and repository construction upon each. This information provides a definition of the time-varying repository and geologic setting environment. With this information, relevant predictions on waste package, waste form and nuclide behavior may be made. Only with this information can repository performance be defensibly predicted.

UNCERTAINTY

Prediction of repository performance involves a myriad of independent and dependent variables and processes, which may introduce a great deal of uncertainty into performance analyses and hence, predictions. Major sources of uncertainty are discussed below.

The first major source of uncertainty is the complexity and natural variability of the geologic setting, including hydrology, geochemistry, and geohydrological framework, into which a repository is placed. Simplistically, for a repository which is 1000 meters deep and which has an accessible environment which extends 10 km in all lateral directions from the extent of the excavations, a geologic setting of the repository may have a volume of 5×10^{11} cubic meters. The excavated volume of a complete repository and associated shafts and exploratory or monitoring boreholes, is only a small fraction of the geologic setting. The volume of the exploratory shaft and in situ test facility required prior to License Application for Construction Authorization is even smaller. Even the most regular rock mass can be expected to have significant natural variability within this volume, which can only be inferred from limited data sets, resulting in a possibility that significant features which affect performance may be missed during site characterization. The result of this variability and the inability to definitively quantify the geologic setting, provides for potentially large uncertainty in the predicted geochemistry, hydrochemistry and geohydrology of the site. Whilst careful site characterization can provide bounds on this variability, prediction of repository performance will nonetheless depend on extrapolation of data between the limited excavations and relatively few boreholes.

The second major source of uncertainty results from the data measured to support performance calculations. This uncertainty, which is probably currently the best understood, results from the ability to directly rather than indirectly measure a parameter, variability of potential test methods and accuracy of test results. This source of uncertainty is best quantified by making multiple measurements and carefully performing associated data reduction. This uncertainty may be reduced throughout the repository development and operation, so long as acquired data provides a converging model of the site, and not a diverging model.

The third major uncertainty source is in the models used to predict performance. Two elements are included here. The first is the simple accurancy of sophisticated computer models. This is presently quantifiable. The second is the degree to which the models reflect the actual behavior of a system. This is a potentially more significant source of uncertainty. A model may omit certain phenomena or interactions because the designer believes the phenomena neglected are not significant to the process. Alternately, a model may omit complex phenomena which are not clearly understood, or for which the acquisition of supporting data would be prohibitive. In addition, there may be phenomena which are not known or recognized to apply to the situation being modelled. However, even through a model designer or user will attempt to quantify these uncertainties, this can never be (by definition) absolutely successful. A good example of this uncertainty is the coupled thermomechanical and hydrological in situ tests which are currently the subject of some considerable technical debate.

Thus, in summary, these model uncertainties may be derived from uncertainties in geology and data, as well as poorly understood processes and interactions. This possibility raises the question of relevancy of the data measured either in the field or laboratory since data selected for measurement may be appropriate only for models which do not adequately represent reality. Because field and laboratory data acquisition programs should be designed with specific performance models in mind, a continual evaluation of uncertainties in models must be made, and data acquisition programs checked to ensure consistency. The consequence of not doing this may be a self-consistent but inaccurate model of repository performance.

For example, if a model of hydrogeology predicts repository resaturation after many thousands of years, then a package performance model would be produced in which corrosion and leach are dominated by near ambient temperature groundwater with a hydrochemistry close to the natural condition. The resulting data program would focus on the temperature and hydrochemical conditions predicted to most influence the waste package. However if there is a large uncertainty in the resaturation, resulting in possible onset of corrosion within a few years after repository closure, then the corrosion environment will be very different than under the former condition. Unless explicitly addressed in the data acquisition program, then this uncertainty can pervade the entire test program, and lead to incomplete performance assessments, jeopardizing the licensability of a site.

REASONABLE ASSURANCE

The nature of the licensing process which NRC has put in place (10CFR60) together with the final EPA regulation 40CFR91 are the basis for defining the requirements, which the applicant must meet during the licensing process. NRC's rule and the EPA draft 40CFR91 are also intended to be basis for defining acceptable compliance. The authors believe that there are currently deficiencies in these documents which make it difficult to adequately define the requirements at the different stages of the licensing process. Thus, in our opinion, it is currently impossible to adequately define what is compliance with these requirements for each stage in the licensing process.

EPA will shortly set a limit on the release of radionuclides at the accessible environment. Since this release or flux rate is to apply to a geological repository which is required to operate for tens or hundreds of thousands of years, it is reasonable that EPA may also set a limit to the level of confidence at the time of the last phase of the licensing process (i.e., decommissioning). EPA may also set required numerical levels of confidence in meeting the EPA criterion at each stage of the licensing process (i.e., License Application for Construction Authorization License to Operate-Emplace Waste, etc.). However, it may be that these levels of confidence should be set by negotiation between DOE and NRC because they are a function of national strategy of how to meet a standard within a prescribed licensing process. The diagram shown on Fig. 2 (Golder

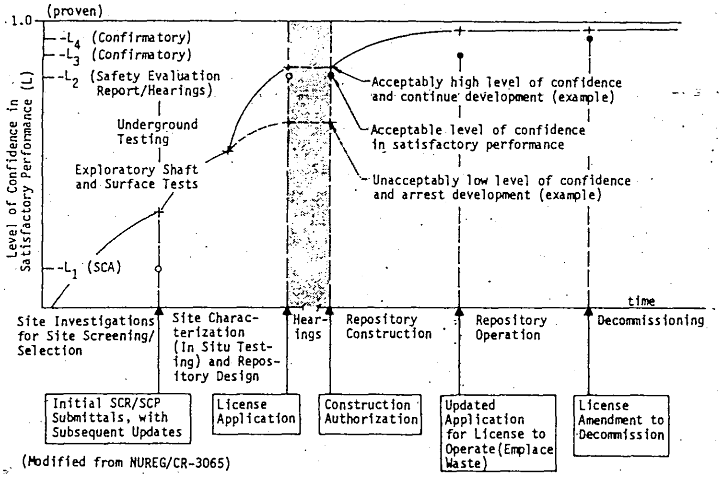

Fig. 2. Level of Confidence in a Repository at Each Licensing Stage

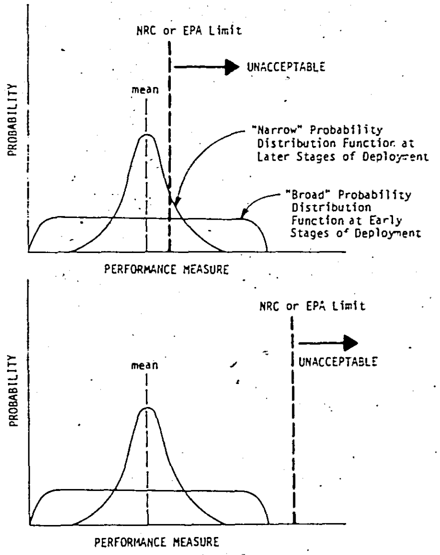

Fig. 3. Alternate Distributions of Performance.

Associates, 1982) demonstrates how conceptually the required level of confidence must progressively improve through the licensing process. It is important to point out that NRC's procedural rule was put into place so that there would be progressively increased confidence in the repository system. The option of retrievability has always been emphasized in NRC's ongoing evaluation of the current projects. This is, in part, as a protection to finding conditions later in the operational life of a repository which prevents a decommissioning license to be given. There is, thus, a strong implication that the level of confidence at the License Application should be lower at the time of the License Application for Construction Authorization than the level which would be required at Decommissioning. The question of level of confidence at each stage of the Licensing Process is crucial for DOE to be able to establish how much investigation, testing, etc. is enough for each stage of the deployment process. It appears to the authors that the concepts of site suitability, site confirmation are vague and not useful since they have no meaningful relationship to numerical standards. The concept, on the other hand, of numerical levels of confidence defining reasonable assurance at each stage of the licensing process would provide a basis of defining a repository development program and schedule which can readily be established and then executed and still protect public health and safety.

The remainder of this paper briefly discusses alternative approaches of establishing the required level of confidence or reasonable assurance at each stage of the licensing process.

Philosophically, there are two extreme courses which can be programmatically pursued to demonstrate performance with reasonable assurance. We define these as: (1) the conservative approach and (2) the comprehensive approach. These two alternative approaches are shown diagramatically on Fig. 3. The conservative approach to the entire repository system is shown where the uncertainty distribution of values is lower than a single value specified either in 10CFR60 or Table 2 of the draft 40CFR191.

The comprehensive approach requires that a numerical level of confidence be specified along with each subcomponent of a repository system (i.e., from 10CFR60) and for the overall system at each stage of the licensing process. Thus, in Fig. 3 the single value standard bisects the distribution and the probability value above the standard in the acceptable level of confidence.

The conservative approach suggests that each item important to performance be described "conservatively", that is presuming a pessimistic performance. Then with this approach all performance models used would overestimate nuclide release and transport. In order for this approach to be acceptable, a site must possess outstanding performance characteristics such that even with the conservative approach, performance is predicted to be in regulatory compliance. Additionally, site characteristics must be sufficiently well defined to justify the "conservative" data and models and, hence, the performance will be equally conservative.

One possible result of this approach is to force a strong reliance on the engineered system to achieve long-term performance objectives rather than the geologic setting. It should be pointed out that such a course of actions would apparently violate the content of 10CFR60. Reducing the release rate from the waste package and engineering system below that specified in 10CFR60 may defeat the principle of multiple barriers. In the limit, it is possible to design and build a waste package and engineered system which would take minimal credit for the geologic setting. It is difficult to understand how such a system could be licensed under existing regulations.

Another ramification of the conservative approach is in the assertion that "conservative" conditions are used in the performance model. In order to demonstrate "conservatism", it is necessary to defensibly define conservative, and then to sufficiently characterize each performance characteristic to show that conservative conditions are used in performance assessments.

In summary, the conservative approach is likely to be unnecessarily expensive, and may lead to abandonment of the concept of geologic disposal since it may make it impossible to find a licensible site.

The alternative comprehensive approach, currently clearly favored by both NRC and DOE, is to arrive at some consensus on what is "reasonable assurance" for all components, *subsystems and the* overall repository performance at each stage of the licensing process. A significant problem currently facing the program is how to reach this consensus. As stated previously, it is necessary to first make sure that words associated with performance, methodology and uncertainty are all carefully defined. Once this is done then there are two alternative methods of reaching concensus.

The first alternative is a three step process. This process is called, for simplicity, the Calculated Level of Confidence Process (CLCP). The following summarizes CLCP:

1. The first step in CLCP would be to strive to obtain consensus on the uncertainty distributions of each data set and also the uncertainty distributions of all prediction models used to calculate performance. Prior to the license application for construction authorization it should be noted that this will involve the use of subjective opinions, particularly early in the process. There, therefore, needs to be explicit agreement in detail on how these opinions will be obtained and incorporated in the numerical uncertainty distributions of data and models.

2. The second step would be to use these distributions to calculate the confidence level of the system at each stage of the licensing process. This calculation or prediction would thus produce a probability of meeting a particular criteria (EPA or NRC). This probability, therefore, would "a priori" define the acceptable level of confidence of the system at that particular stage of the licensing process.

3. The last step of the process would be to repeat the previous two steps for each subsequent licensing stage (i.e., License to Emplace, and Decommissioning).

Thus, for CLCP to successfully operate EPA should not specify a minimum level of confidence in the overall repository system at the time of decommissioning since it would be derived by this process. It should be pointed out that this approach means that "reasonable assurance" or "levels of confidence" will be dictated by the form of the data uncertainty distributions for which there is consensus between NRC and DOE. In other words, the confidence in the data will decide the level of confidence in the system. This approach may, inevitably, lead to requiring that the level of uncertainty in the data be reduced at the time of the license application for construction to residual levels since experts will probably say that they need more information.

The second alternative is essentially a four step process which could operate in the reverse sense as the CLCP. This alternative process starts with EPA defining an acceptable level of confidence of the system at the decommissioning stage of the licensing process. With this definition in place and either a budgetry limit and/or schedule such as can be found in the N.W.P.A.; levels of confidence for preceeding stages can be formulated and defended. This process we have called Optimized Level of Confidence Process (OLCP). The following summarizes OLCP:

1. Using a level of confidence in the overall repository system at the decommissioning stage of licensing defined by EPA; a series of compatible levels of confidence in the subcomponents at that stage can be formulated. This will then define the "reasonable assurance" for the NRC subcomponents and, will enable the technical level of knowledge in the repository at the time of decommissioning to be described.

2. A series of alternative strategies for each site can then be postulated beginning from site selection going through all the licensing stages up to the stage defined above. These strategies may also be limited by a schedule and/or budget. This is necessary in order that questions concerning both the number of sites to be carried in the selection process at any time and the consequence of failure to meet the licensing objectives are to be incorporated in the process of optimizing the alternative strategies.

3. Once the preferred strategy is selected by DOE it would then be possible to specify all levels of uncertainty in the overall system and subcomponents at each stage of the licensing process.

4. Finally, with this information in place, a combination of data and model requirements with a range of acceptable uncertainty distributions can be specified. This will then allow DOE to proceed with a deployment program and NRC will be presented with a site investigation program in which reasonable assurance is defensibly defined.

The advantages of this approach of reaching consensus on "reasonable assurance" is that it starts from the standard and proceeds backwards through time to define an adequate site and, hence, appropriate data with defined uncertainty requirements at each stage of data acquisition. It should be pointed out that should EPA define acceptable levels of confidence at all stages of the licensing process the approaches outlined above would largely be redundant.

This paper has proposed two fundamental questions:

1. What is meant by uncertainty and how is subjective opinion about future events and postulated data from proposed programs to be incorporated in the licensing process?

2. What is meant by reasonable assurance for the overall system and the subcomponents at each stage of the licensing process?

We have strongly suggested that EPA define numerical level of confidence in the overall system at least at the time of decommissioning. With this in place the repository deployment program could have a defensible strategy once the fundamental questions listed above have been answered.