SAND2000-2439C

Threshold Assessment: Definition of Acceptable Sites as Part of Site Selection for the Japanese HLW Program

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Abstract

For the last ten years, the Japanese High-Level Nuclear Waste (HLW) repository program has focused on assessing the feasibility of a basic repository concept, which resulted in the recently published "H12 Report". As Japan enters the implementation phase, a new organization must identify, screen and choose potential repository sites. Thus, a rapid mechanism for determining the likelihood of site suitability is critical. The threshold approach, described here, is a simple mechanism for defining the likelihood that a site is suitable given estimates of several critical parameters. We rely on the results of a companion paper, which described a probabilistic performance assessment simulation of the HLW reference case in the H12 report. The most critical two or three input parameters are plotted against each other and treated as spatial variables. Geostatistics is used to interpret the "spatial" correlation, which in turn is used to simulate multiple realizations of the parameter value maps. By combining an array of realizations, we can look at the probability that a given site, as represented by estimates of this combination of parameters, would be good host for a repository site.

Introduction

In November 1999, the Japan Nuclear Cycle Development Institute (JNC) completed a second progress report on R&D conducted as part of a feasibility assessment for deep geological disposal of High Level Waste (HLW), which was entitled, "H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan" [1] also known as the "Year 2000" or "H12" report. The main goal of this report was to provide an understanding of the feasibility of constructing a deep geological repository in Japan. An associated goal was to provide the basis for future site selection. Within this report, uncertainty in concepts, models and data / parameters were analyzed using a deterministic point-wise simulation approach in order to cover a wide range of potential geological conditions and repository designs. In conjunction with the formal H12 analysis, a probabilistic analysis of the reference case or

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reference scenario was also performed. Preliminary results were reported last year [2, 3] with a more refined analysis being presented by Wakasugi et al. [4] at PSAM5 using the GoldSim simulation platform [5]. The goal of Wakasugi's work is consistent with the original, primary goal of the H12 report. Our presentation, on the other hand, provides a suggested means of using the previous H12 assessment as a foundation for site selection. The H12 reference case describes the expected conditions of a hypothetical repository in Japan [4, Figure 1]. Details of the model, the suite of uncertainty parameters and their distributions used as the foundation of the current assessment can be found in both Wakasugi et al [4] and in the English version of the H12 synopsis report [1].

Threshold Approach

The threshold approach, as described here, assumes development of an appropriate conceptualization of geologic conditions, repository engineering design and ranges of parameter values. Given a model representing this conceptualization, we can investigate the confidence in site safety for a combination of the most sensitive parameter values. For the case where the conceptualization can be represented by a simple, invertable equation, the boundary between the combination of parameters that indicate a "safe" site and those indicating a "poor" site would be distinct and can be represented by a threshold.

For such a case, the focus becomes definition of a set of "threshold values" for the set of input parameters such that any combination of parameter values selected from the area below the threshold would return the answer that the site is safe with a confidence of 1.0. Thus, a site whose effective properties correspond to any of the number of combinations of parameters below the threshold, would provide a safe repository location. Our task is thus, to decompose the model and find the relationship between acceptable sets of input parameter values. The process of deriving the parameter threshold values for simple models (e.g., a linear equation) is direct and quite simple. However, the models being proposed for a full performance assessment of a nuclear repository are neither linear nor simple.

In the case of a complex model, the direct relationship between a combination of parameters and the resulting output is difficult to derive analytically. Thus, an approach based on Monte Carlo techniques and spatial statistic was used. We start with both the model and the performance measure defined. In the case of the threshold analysis, the actual distribution of input parameter values over the range is not important, nor is the selection of maximum and minimum value critical. Instead, the analyst should focus on extending the parameter range beyond the possible range of site data to be encountered in site selection. Then, a standard Monte Carlo calculation is performed using the defined ranges of values to calculate an array of output. Next, the two or three most sensitive parameters should be selected. We can define "sensitive parameters" as those that contributed the most to the variation in model output, which in turn can be identified through standard regression sensitivity analysis. If more than three "sensitive" parameters control model output then the approach described here could be extended to n-dimensional space. Given the a set of x, y, z and output data combinations, where x, y, z are the sensitive parameters in a single Monte Carlo realization input vector, we apply spatial statistical interpretation and simulation in order to develop a probability map.

Threshold Analysis

The peak doses caused by Cs-135 in the results of Wakasugi et al [4, Figure 2] are used as an example to demonstrate the threshold based performance assessment technique. There are a total of 234 peak dose values that have Cs-135 as the dominant radionuclide; 211 of these values are used to complete this example analysis and the remaining 23 values are used to validate the approach. The cumulative distribution of these peak doses is shown in the left image of Figure 1. The sensitivity analysis results in Wakasugi et al [4] indicate that the Cs-135 peak doses are most sensitive to the values of the distribution coefficient for Cs-135 in the rock ("*KG*", in m^3/kg) and the average transmissivity ("*T*", in m^2/sec). The peak dose values are mapped into this *KG-T* space and shown in the right image of Figure 1.

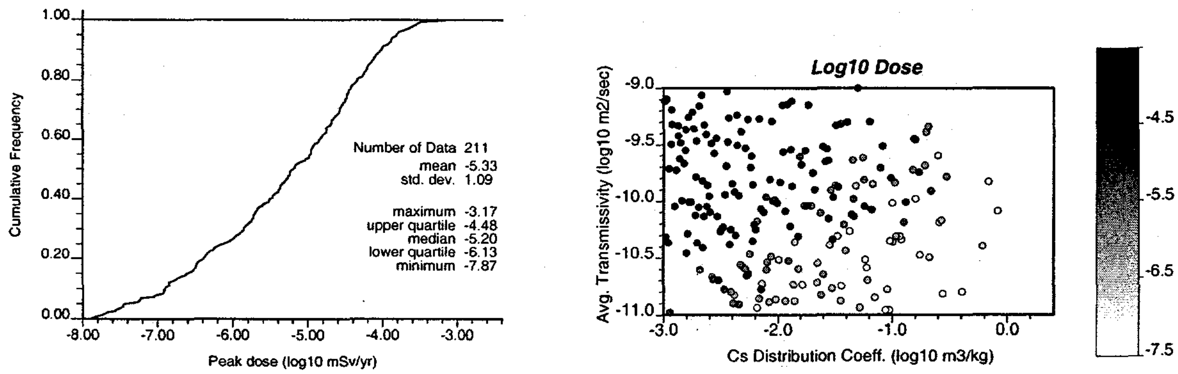

Figure 1. Cumulative distribution of the peak doses caused by Cs-135 (left image) and the location of these peak doses mapped into KG-T space (right image).

The objective of the technique proposed herein is to determine the probability of exceeding a specified peak dose at every location within the *KG-T* parameter space. This necessitates the construction of a local conditional cumulative distribution function (*ccdf*) at every location within the *KG-T* space. The local *ccdf's* are constructed as discrete distributions through post-processing of multiple geostatistical simulations.

Geostatistical simulation is a Monte Carlo process used for creating multiple, equally probable images of a property value across a 1, 2 or 3 dimensional domain [6]. These multiple images, or realizations, are conditioned to the measured property values within the domain and also honor the probability frequency distribution of the measured data as well as the two-point spatial covariance: *Cov(Z(x),Z(x+h))*. Where *Z(x)* is the property value at location *x* and *Z(x+h)* is the value of the same property at a distance *h* away from *x*. The spatial covariance is calculated as a function of h and an anisotropic covariance model is used here to define the spatial covariance of the peak dose values within the KG-T parameter space.

For this example, the *KG-T* space is discretized into 136x80 cells with each square cell having a length of 0.025 (*KG* and *T* units). This grid covers the *KG-T* space from –3.0 to 0.4 (*KG* axis) and –11.0 to –9.0 (*T* axis). A total of 100 realizations of peak dose are created and then processed to determine the empirical *ccdf* of the peak dose values at every point on the grid. These ccdfs are compared to two threshold levels of peak dose: 1.0×10^{-05} and 1.0×10^{-06} mSv/yr. The resulting probabilities of exceeding each threshold at every location in the parameter space is shown in Figure 2.

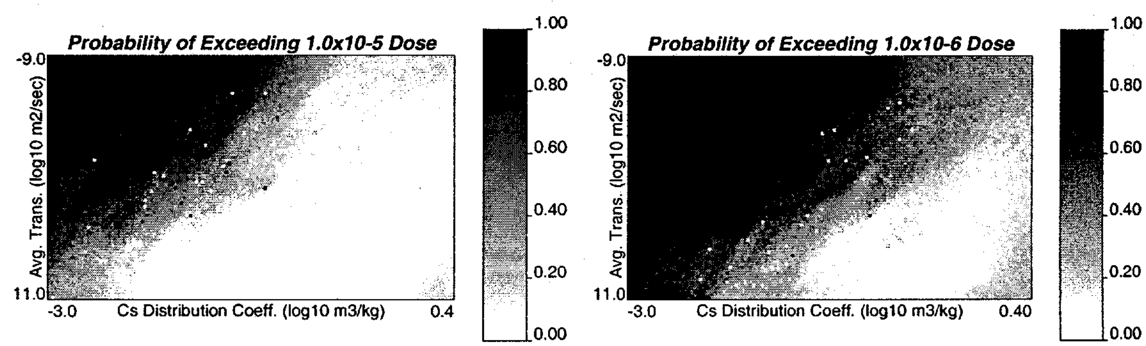

Figure 2. Probability of exceeding a peak Cs-135 dose of 1×10^{-05} mSv/yr (left image) and 1×10^{-06} mSv/yr (right image) for all points within the *KG-T* parameter space.

The images in Figure 2 show that low values of the distribution coefficient and high values of the transmissivity result in high probabilities of exceeding the peak-dose threshold level (upper left corners of images). Conversely, the combination of high values of *KG* and low values of T results in a low probability of exceeding the peak-dose threshold levels (lower right corners of images in Figure 2).

The location of the transition zone between the areas of high and low probability of exceedence is dependent on the chosen peak-dose threshold level. This transition zone defines the areas with the combinations of parameters that lead to the greatest uncertainty in whether or not the peak dose exceeds the threshold value. This region also constitutes the optimal locations in which to run additional simulations in order to reduce the uncertainty in exceeding the peak-dose threshold level. For the current example, numerous model simulations exist, however for complex simulation problems where individual Monte Carlo simulations are computationally expensive, understanding the region where additional realizations provides the greatest information is valuable.

The conditioning data locations shown in the right image of Figure 1 are evident in Figure 2 as the white or black cells. For every realization, the peak dose values are honored exactly at these conditioning locations in every simulation and these locations will have a probability of exceeding the peak-dose threshold level equal to either 1.0 or 0.0. It is noted that multiple peak dose values are possible given the same input values for *KG* and *T* if the other input parameters in the full performance assessment are allowed to vary. In this example of the threshold-based approach, only the two most sensitive parameters are used to predict the peak dose and thus there is only one estimated peak dose value for each combination of *KG* and *T* in the spatial statistical simulation.

Threshold Approach Validation

The approach used in this example is validated with the 23 data points held back from the analysis. The distributions of peak dose derived from the 100 geostatistical realizations are compared to the actual values of the peak dose at each of the 23 locations in Figure 3. The distributions are defined in Figure 3 by the mean along with the values at plus and minus one standard deviation from the mean (the 68 percent confidence interval about the mean). Results in Figure 3 show that at 16 of the 23 locations, the 68 percent confidence interval contains the actual value. This result is consistent with the theoretical result that dictates 15.6 of the 23 actual values should be contained within the 68 percent confidence interval.

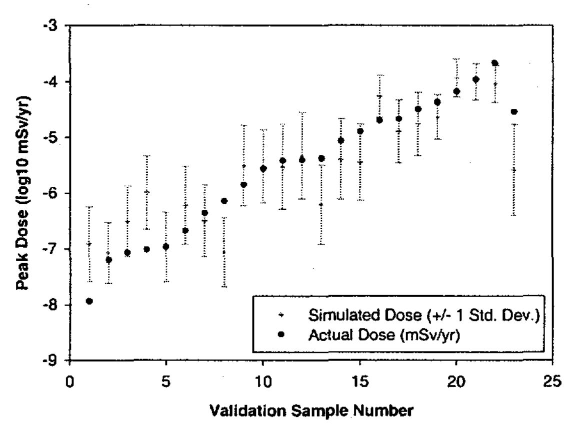

Figure 3. The results of the validation test comparing the distributions created through geostatistical simulation with the actual peak dose values at the same location.

Discussion

The threshold approach results in a list of sensitive parameters and an indication (probability map) of how a given site would perform as a deep geological repository given initial information on a small set of sensitive parameters. By comparing the probability of exceedence between sites, the most favorable sites could be identified along with their relative weaknesses.

The assessment presented here is simplistic in several ways, which would need to be refined for full application within a repository program. For instance, there are likely to be multiple possible conceptualizations for a given site prior to extensive site characterization. Thus, several scenarios or conceptualizations would need to be developed with their respective probability maps and the joint probability of exceedence given multiple conceptual models used as the screening value. Additionally, the data from a given site in this early phase of characterization may come from highly uncertain sources or may be somewhat contradictory. Thus, instead of being able to chose a single value for each of the sensitive parameters, we may need to define a range for each input. The resulting region on the probability map could then be integrated to provide an estimate of the overall exceedence probability. Also, the results of the threshold-based approach are not limited by the shape of the safe-unsafe boundary and can be used to determine the optimal parameter space locations (combinations of input parameters) for additional computer simulations to refine the exceedence probability map. This is particularly important if the models are computationally expensive. Finally, this analysis approach could be used as a first tier deconvolution of a complex model system to understand input-output relationships. Once these are established, then refinement of the complex models to simplied models can proceed with a knowledge of which critical parameter and functions need be retained in the final simplified analysis.

Conclusions

The H12 report supports the feasibility of long-term deep geological disposal of HLW in Japan. The next major phase in the Japanese HLW program is site evaluation, screening and selection. We propose that uncertainty based Monte Carlos simulation can provide the foundation for rapid screening of potential repository sites based on the threshold approach. The threshold-based approach can be used to estimate the result of a complex performance assessment / safety assessment using only a small number of the most sensitive input parameters. We have demonstrated the method is a slightly simplified form with an example based on the reference case from the Japan H12 HLW feasibility assessment. The probability of exceeding a specified safety threshold value for a specific site can be easily determined by reference to the resulting map of exceedence probability (Figure 2). Thus, given a small amount of data from each of several possible sites, the probability of exceeding the safety limits can be determined and compared providing a means of screening out potentially unsafe sites and guiding future site characterization efforts.

References

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.