PERFORMANCE ASSESSMENT METHODOLOGY AS APPLIED TO THE GREATER CONFINEMENT DISPOSAL SITE: PRELIMINARY RESULTS OF THE THIRD PERFORMANCE ITERATION*

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ABSTRACT

The U.S. Department of Energy has contracted Sandia National Laboratories to conduct a performance assessment of the Greater Confinement Disposal facility, Nevada. The performance assessment is an iterative process in which transport models are used to prioritize site characterization data collection. Then the data are used to refine the conceptual and performance assessment models. The results of the first two performance assessment iterations indicate that the site is likely to comply with the performance standards under the existing hydrologic conditions. The third performance iteration expands the conceptual model of the existing transport system to include possible future events and incorporates these processes in the performance assessment models. The processes included in the third performance assessment are climate change, bioturbation, plant uptake, erosion, upward advection, human intrusion and subsidence. The work completed to date incorporates the effects of bioturbation, erosion and subsidence in the performance assessment model. Preliminary analyses indicate that the development of relatively deep-rooting plant species at the site, which could occur due to climate change, irrigated farming or subsidence, poses the greatest threat to the site's performance.

SITE DESCRIPTION

The Greater Confinement Disposal (GCD) facility is located at the Nevada Test Site in the Area 5 RWMS at Frenchman Flat in Nevada (Fig. 1). Frenchman Flat is an alluvium filled basin, with maximum depth to bedrock of more than 450 meters. The site consists of 12 boreholes that are approximately 36.6 meters deep with 3 to 3.6 meter diameters. The disposal procedure consisted of filling the bottom 15.2 meters of the boreholes with waste then filling the remainder of the borehole with native sediments (1). In three of the boreholes the individual waste packages were separated by layers of probertite, a mineral which contains boron, a neutron absorber. The wastes are located within the unsaturated zone in the thick alluvial deposits of the basin, approximately 200 meters above the water table (2).

PLACE FIG. 1 HERE

PERFORMANCE ASSESSMENT METHODOLOGY

Four of the thirteen GCD boreholes contain transuranic (TRU) wastes and are regulated by 40 CFR Part 191 containment (191.13), individual protection (191.15) and groundwater protection (191.16) requirements (3). The purpose of this work is to provide the Department of Energy with enough information to determine if the site complies with these regulations. The compliance measure for the containment requirements is the calculated EPA sum. Due to the long regulatory periods (10000 years) and the complexity and uncertainty in the transport system, numerical models are required to

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simulate the release of the radioactive elements to the accessible environment.

The statistician George Box reminds us that no model can reproduce or predict exactly how a complex physical system behaves, but there are models that can calculate the probability of a future value lying between two specified limits (4,5). With the recent interest in the validation of groundwater flow models and the impossibility of that task (6,7), it is important to recall Box’s statement and consider which models will be the most useful in assessing the potential performance of a waste disposal site. The basic premise of this research is that the exact flow and transport system for the next 10,000 years at the GCD site cannot be predicted due to the uncertainty in the existing and future conditions at the site, but that it can be simulated and the maximum release rates bounded.

The performance assessment methodology applied to the GCD site is an iterative process of modeling and data collection (Fig.2). Sensitivity analyses of the performance assessment model are used to identify the most valuable data. In this case the most valuable data are those that minimize the uncertainty in the parameter values that cause the simulated releases to exceed the containment and protection requirements. In the first iteration of the performance assessment, the significant parameters and corresponding data needs were identified (2) and data were collected (8,9,10). The new data were used to reduce the uncertainty in the recharge rate (11), plutonium solubility (9) and plutonium adsorption coefficient (10). Additional modeling was performed using the revised parameter ranges along with refined models of plant uptake and erosion (12). As a result of the second performance assessment iteration, the conceptual model of the transport system was revised to one in which diffusion toward the ground surface provides the fastest pathway to the accessible environment. Due to the changes in the conceptual model, tortuosity and rooting depth became the most significant parameters.

The third iteration of the performance assessment involves the investigation of the diffusion pathway. This investigation includes an assessment of the combined effects of subsidence, bioturbation, erosion, plant uptake, upward advection and climate change on the site’s waste-containment ability. It is assumed that all of these processes will occur, consequently they are included in the base-case model. In addition to the base case processes, other potentially significant disruptive events must be considered in the performance assessment. Scenario analyses have narrowed the suite of likely, potentially disruptive events to inadvertent human intrusion into the GCD boreholes by drilling and irrigated farming at the GCD site (13).

CONTAINMENT PERFORMANCE ASSESSMENT MODEL

The performance assessment uses a 1-D model of diffusive transport. The modeling is performed in a Monte-Carlo fashion with the uncertain parameter values generated randomly, from predefined probability density functions (pdfs), for each simulation using Latin hypercube sampling. There are a total of 40 uncertain parameters in the model. Details on these parameters and the distributions used to capture the uncertainty in the parameter values can be found in the documentation for the first two performance assessments (2,12). The results of the transport model are post-processed to calculate the EPA sum for each realization and to combine the results into a single complementary cumulative distribution function (CCDF) to assess the probability that the site will exceed the release limits specified in the containment requirements.

The performance assessment model is based on the following major assumptions:

- Transport occurs by liquid phase diffusion.
• The radioactive contaminants are sorbed on sediment surfaces.
• Individual isotopes are depleted and generated by radioactive decay.
• There is no downward, advective transport.
• The concentration of each isotope, in the liquid phase at the source, is maintained at the solubility limit for that element.
• The concentration of each isotope, in the liquid phase, at the ground surface, is zero.
• The above-ground concentration of the contaminants in plants is a function of the amount of the isotope at the rooting depth.
• Erosion, bioturbation, subsidence and climate change will occur during the regulatory period.
• After the institutional control period, there is a significant probability that people will live at or near the GCD site.

The consequences of the potentially disruptive future events and processes are being evaluated to determine the best method of incorporating these events and processes into the performance assessment. The consequence models for bioturbation and subsidence along with the details on how these consequences are incorporated in the performance assessment are given below. The climate change and human intrusion consequence models are still in development and are not included in this preliminary analysis.

Bioturbation Consequence Model

The bioturbation model is based on the following assumptions:
• The contaminants are transported from the subsurface to the ground surface during burrowing.
• The effective burrowing depth is uncertain, but can be bounded by the known burrowing depths for the animal and insect species found or expected at the site.
• The effective depth is equal to the maximum depth of bioturbation.
• All the contaminants at the maximum burrowing depth are transported to the ground surface.

As a result of these assumptions, bioturbation can be treated as a reduction in the pathlength from the waste to the accessible environment. For the preliminary analyses, bioturbation is modeled by reducing the depth of burial. The uncertainty in the maximum bioturbation depth that will occur at the site is accounted for by using a pdf to represent the probability of occurrence of each possible bioturbation depth and running the simulations in a Monte-Carlo fashion.

A literature search of studies on the existing fauna in the vicinity of the NTS indicates there are 63 different species that can be classified as burrowers. The burrowing animals include 1 owl, 14 lizard, 17 snake, 3 tortoise and 28 mammal species (mostly mice, squirrels, voles, rats and shrews). The burrowing depths of these species is generally less than 1 meter and with a maximum burrowing depth of three meters. In addition to these animals, there are numerous arthropod species that are known to burrow. The possible burrowing arthropods at the site include species of spiders, scorpions, cockroaches, ants and termites. With the exception of termites, the burrowing depths recorded for arthropods are generally less than one meter with maximum burrowing depths less than 3 meters. The literature search shows that the deepest burrowing fauna may be the termite. In general the termite is found with the food supply. In this case the maximum rooting depth would provide a limit for the termite burrowing depth. The rooting depths used in the simulations for existing conditions range from one to ten meters. However, there is evidence that some African termites burrow to the water table, down to 70 meters, to obtain water (14). The burrowing depths of the termite species at the NTS are unknown and the probability of establishing the African species at the GCD site is unknown. Preliminary analyses of the effect of bioturbation on the site's performance were conducted to determine the potential impact of deep burrowing species.
Subsidence Consequence Model

The following assumptions are made regarding the effect of subsidence on the transport system:

- Subsidence will occur due to the compaction of the backfill, settling and compression of the waste containers in the boreholes and trenches.
- Subsidence decreases the effective depth of burial.
- The unconsolidated sediments surrounding the borehole cannot maintain a steep slope or a fracture due to the effects of weathering.
- Subsidence in the borehole is followed immediately by side wall cave-in that results in a slope of 40 degrees on the side walls.
- Subsidence will occur immediately after the institutional control period.
- Increased runoff into the subsidence depression results in increased plant growth.

As with bioturbation, subsidence is incorporated into the performance assessment by treating it as a decrease in the depth of burial of the waste. The subsidence depth is an uncertain parameter value. Preliminary analyses were conducted to evaluate the potential effects of subsidence and bioturbation on the site's performance. The range of potential subsidence depths was estimated by assuming that the total collapsible void space in the boreholes was between ten and fifty percent of the volume of the borehole containing the waste (the bottom 15.2 meters). This may or may not be a conservative estimate. It is an arbitrary range selected for a preliminary analysis of the effects of subsidence and the combined effects of subsidence and bioturbation on the site's performance. Increased plant growth due to subsidence was not considered in the preliminary analysis. The subsidence depth and increase in plant growth as a function of subsidence will be bounded based on natural analog data.

Preliminary Results

The preliminary analyses were conducted to evaluate the effects of the uncertainty in the new model parameter values on the simulation results and to aid in the development of the performance assessment model. The parameter distributions for the existing hydraulic conditions were used in these simulations. The final performance assessment model will combine all of the significant future processes and disruptive events.

The results of the preliminary simulations incorporating different consequence models of bioturbation and subsidence are summarized in Table I. The only model that results in simulated violations of the containment standard is the one with a large range for the simulated burrowing depth. This model was designed to assess the potential significance of deep burrowing species like the African termite. The distribution selected for this simulation has a maximum burrowing depth of 19.2 meters, deep enough to reach the waste packages after erosion is included. The CCDF generated by 5000 realizations of this model is shown in Fig. 3. The last model listed in Table I combines the effects of erosion, bioturbation and subsidence. This model uses a smaller range of bioturbation depths that are more representative of the existing burrowing depths in the vicinity of the GCD site. The CCDF for the combined model shows that the site is likely to meet the containment requirements when this model is used (Fig. 4).

Summary
As a result of the first two performance iterations, the performance of the GCD site is being assessed using a diffusion transport model linked to a plant uptake model. Sensitivity analyses of the second performance assessment model indicate that plant uptake is the most important process and tortuosity and rooting depth are the most significant model parameters in determining how much of the contaminant reaches the accessible environment. The addition of subsidence and bioturbation to the performance assessment model result in simulations that produce a significant number of failures only when the bioturbation depths are allowed to exceed the existing burrowing depths. Subsidence, erosion and bioturbation are modeled as additive processes that reduce the depth of burial. As a result, these processes decrease the length of plant roots required to reach significant concentrations of the radioactive contaminants. The results of this modeling and previous sensitivity analyses indicate several modeling refinements that could significantly reduce the simulated release rates. These potential refinements include reducing the uncertainty in the minimum tortuosity value and maximum burrowing depth, and separating the bioturbation model from the calculation of the depth of burial. These changes are only necessary if the consequences of climate change, drilling and irrigated farming result in higher simulated release rates or if natural analogue studies indicate a significantly greater maximum subsidence depth than the maximum value used in the preliminary simulations. The current model of the site, for the existing hydrologic conditions with bioturbation, erosion and subsidence, indicates that the site is likely to meet the containment standards.

REFERENCES


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Table I. Summary of the Results of Selected Preliminary Simulations

<table>
<thead>
<tr>
<th>DISRUPTIVE PROCESSES</th>
<th>RANGE OF VALUES (M)</th>
<th>DISTRIBUTION</th>
<th>ALL PASS (P) SOME FAIL (F)</th>
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<tbody>
<tr>
<td>BIOTURBATION EROSION</td>
<td>.02 - 2.7</td>
<td>LOGNORMAL</td>
<td>P</td>
</tr>
<tr>
<td></td>
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<td>UNIFORM</td>
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<tr>
<td>BIOTURBATION EROSION</td>
<td>.02 - 2.7</td>
<td>UNIFORM</td>
<td>P</td>
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<td></td>
<td>0 - 2.0</td>
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</tr>
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<tr>
<td>SUBSIDENCE</td>
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<td>UNIFORM</td>
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</table>
Fig. 1 Area 5 Radioactive Waste Management Site location map and GCD boreholes containing tansuranic waste
Fig. 2: Flow chart of the iterative performance assessment process for the GCD site.
Fig. 3 CCDF for simulation with extreme bioturbation depths (0.02-12.2 meters).
Fig. 4 CCDF for simulations with bioturbation and subsidence.
(bioturbation depths 0.02-2.7m, subsidence depths 1.8-3.3m).