ABSTRACT

A performance assessment of the operating Solid Waste Storage Area 6 (SWSA 6) facility for the disposal of low-level radioactive waste at the Oak Ridge National Laboratory has been prepared to provide the technical basis for demonstrating compliance with the performance objectives of DOE Order 5820.2A, Chapter III. An analysis of the uncertainty incorporated into the assessment was performed which addressed the quantitative uncertainty in the data used by the models, the subjective uncertainty associated with the models used for assessing performance of the disposal facility and site, and the uncertainty in the models used for estimating dose and human exposure. The results of the uncertainty analysis were used to interpret results and to formulate conclusions about the performance assessment. This paper discusses the approach taken in analyzing the uncertainty in the performance assessment and the role of uncertainty in performance assessment.

1. INTRODUCTION

Site-specific performance assessments of low-level radioactive waste disposal facilities are required by DOE Order 5820.2A, Chapter III to provide the technical basis for demonstrating compliance with the performance objectives contained in the Order. A performance assessment includes an analysis of the uncertainty in the method used for assessing site performance for the period of time over which the wastes are of concern with regard to protection of public health and safety.

The performance assessment for Solid Waste Storage Area 6 (SWSA 6) at Oak Ridge National Laboratory used a series of models to estimate the potential doses to the public and to inadvertent intruders as a consequence of waste disposal. Modeling was performed to provide a site-specific representation of the nine different types of disposal units included in SWSA 6. The inventory of wastes previously disposed in SWSA 6 was determined using historical disposal records and a most probable estimate of the disposed inventories based on an analysis of the methods of waste characterization. The recorded inventories were used to screen the disposed wastes to reduce the number of radionuclides requiring consideration. The most probable inventory was used to estimate the release of radionuclides from the disposal units over time using a model of disposal unit performance (SOURCE1/SOURCE2 models). These estimated releases of contamination from the disposal units were used as input to a series of transport models for the shallow subsurface (UTM model) and groundwater (USGS-MOC model) systems in SWSA 6 to estimate releases to on-site surface waters. The linkage of the separate models used to analyze the transport of contamination from the wastes to the point of exposure is illustrated in Fig. 1. The results of the transport models were used to estimate dose to a maximally exposed off-site member of the public according to a likely scenario for exposure to contaminated water. Doses to inadvertent intruders were estimated separately on the basis of reasonably likely scenarios for human intrusion into the disposal units following loss of institutional controls and failure of engineered barriers.

Since site-specific data for the analysis included in the performance assessment were incomplete, assumptions were incorporated into the analysis. As a result, the quantitative uncertainty in the data used for modeling was critical to interpreting the results calculated for the performance of the facility. Additionally, the acceptability of the models as
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reasonable representations of the site and facility was considered to be an important component of the uncertainty in the performance assessment and was addressed along with the quantitative uncertainties in parameters in the models.

II. METHODOLOGY

Quantitative estimates of the uncertainty in the analysis were calculated by first establishing probability distributions for selected parameters associated with each of the models applied to the transport of contamination. The parameter distributions were chosen using expert judgement gained from the application of models to SWSA 6. Once identified, the important parameter distributions for each model were sampled using Latin Hypercube sampling to obtain 50 input data sets. Each model was then run using these input data sets along with the 50 sets of output information generated by the previous model segment. Thus, the effects of parametric uncertainties were propagated through the models in the modeling sequence. The results of the analysis consisted of distributions of maximum surface water and groundwater radionuclide concentrations. Six radionuclides were chosen to be representative of nuclides in the waste inventory. The results from Latin Hypercube sampling established a probability of compliance for each of the radionuclides with the relevant concentration limit for environmental transport. The concentration limit was established from the dose analysis for the exposure of off-site individuals to contaminated water or the on-site consumption of contaminated drinking water.

The second phase of analyzing the uncertainty in the environmental transport of contamination was to identify subjective uncertainties associated with the modeling process. This was achieved by identifying the conditional probability of each model being a reasonable representation of the facility and site. Estimates of the conditional probability were obtained by expert judgement. This conditional probability was used to provide an estimate of the model acceptability and the overall probability of compliance of the disposal units with the performance objectives for low-level waste disposal. Bayesian techniques were employed to combine the conditional probabilities with the probability distributions determined using Latin Hypercube sampling of the models. Quantitative values of the uncertainty associated with the resulting probability distributions were determined using the concept of entropy defined in communication theory.

Uncertainties related to the estimation of dose and human exposure scenarios were treated separately using a more subjective evaluation method than used in the evaluation of the transport of contamination. This approach was adopted because the nature of dose estimation and human exposure scenarios is conceptually and quantitatively different than the modeling of the release and transport of contamination. In the estimation of dose from inadvertent intrusion, the assumption was made that no release of radionuclides had occurred prior to inadvertent intrusion. The apparent contradiction with the analysis of the transport of contamination is justified in that the analysis of contaminant transport was based on a conservative release scenario; however, using these computed release characteristics for an analysis of inadvertent intrusion would yield non-conservative results. Since the degree of conservatism incorporated into the release model is unknown, a conservative representation of the inventory remaining in the disposal units could not be determined. Other uncertainties identified in the dose analysis included the likelihood of the exposure scenario occurring, the dilution of wastes with uncontaminated materials, and the transfer factors for radionuclide migration in plants and soils. Several important parameters in the dose analysis (e.g., dose conversion factors for ingestion, inhalation, and external exposure) are assumed to have no uncertainty. The dose analysis probably results in estimates of dose for individuals that are far greater than doses that could reasonably be received by most individuals. However, the purpose of the dose analysis for inadvertent intruders is not to provide best estimates of dose that likely would be received, but to indicate whether disposal practices are adequately protective of public health for the assumed conditions. This aspect of analysis renders the uncertainty in dose assessment as being fundamentally different form the release and transport of contamination, which seeks to provide a reasonable representation of the long-term performance of the disposal facility.

III. RESULTS

The results of the quantitative uncertainty analysis demonstrated that the greatest source of uncertainty in the performance assessment was associated with the inventories of radionuclides in the wastes. Additionally, the uncertainty in the results increased as the period of time required for estimating site performance increased. Some isotopes exhibited no uncertainty in complying with the performance objectives for groundwater and surface water. However, when the conditional probability of the models being acceptable was
considered, the uncertainty associated with compliance for these same isotopes increased to 68% (Table 1, $^{137}$Cs). Hence, the incorporation of the subjective evaluation of the acceptability of the models in representing the performance of the facility was a significant factor in the interpretation of the results of the performance assessment. The results of the parametric and combined parametric and subjective uncertainties for one node in the groundwater domain for the isotopes considered are presented in Table 1. The methodology adopted also allowed for the identification of the effect of each model on the overall uncertainty of the results. Table 2 presents the effect of the various models contributing to the overall uncertainty of the groundwater calculations at one node in the groundwater domain for the isotopes considered in the uncertainty analysis. This allows for the identification of the chief contributors to the total uncertainty in the predicted values, thereby identifying the areas of analysis that would benefit most from further investigation.

The results of the uncertainty analysis affected the interpretation of the results calculated for the most probable case. Primarily, the uncertainty analysis results emphasized the significance of the uncertain estimates of the inventory. Major improvements in the quality of the existing records for the inventory of wastes disposed of at the facility are limited without undertaking drastic measures, such as the exhumation of waste for the purposes of waste characterization. However, changes in operations that will reduce the uncertainty in the inventory for future disposals are being implemented.

The uncertainty analysis also identified the inherent difficulty in estimating doses at distant times in the future because of the inherent uncertainties that build up over time. As a result, determination of compliance over extended periods of time can lead to conclusions with little justification.

REFERENCES


Table 1. Solid Waste Storage Area 6 probability of compliance (POC) and associated entropy-based uncertainty (U) at groundwater compliance node 166

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Parametric</th>
<th>Parametric + subjective</th>
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</thead>
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<tr>
<td></td>
<td>(1) POC</td>
<td>(2) U</td>
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<tr>
<td>$^3$H</td>
<td>0.70</td>
<td>0.88</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>0.30</td>
<td>0.88</td>
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<td>$^{34}$Cl</td>
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<td>0.68</td>
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<tr>
<td>$^{90}$Sr</td>
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<tr>
<td>$^{137}$Cs</td>
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<td>0.00</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>1.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Probabilities and uncertainties based on parametric uncertainty analyses.

*Probabilities and uncertainties based on parametric + subjective uncertainty analyses.

*(4) - (2).*
Table 2. Resultant probability of compliance (POC) and associated entropy-based uncertainty (U) for radionuclides in groundwater at node 166 from convolution of subjective uncertainties associated with each segment of the composite transport model (CTM) with groundwater concentration distributions obtained from the parametric, Latin hypercube (LHC) analysis.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>POC</th>
<th>U</th>
<th>POC</th>
<th>U</th>
<th>POC</th>
<th>U</th>
<th>POC</th>
<th>U</th>
<th>POC</th>
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<tr>
<td>$^3\text{H}$</td>
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<td>0.88</td>
<td>0.59</td>
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<td>0.68</td>
<td>0.90</td>
<td>0.68</td>
<td>0.90</td>
<td>0.63</td>
<td>0.95</td>
<td>0.65</td>
<td>0.93</td>
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<tr>
<td>$^{14}\text{C}$</td>
<td>0.30</td>
<td>0.88</td>
<td>0.45</td>
<td>0.99</td>
<td>0.32</td>
<td>0.90</td>
<td>0.31</td>
<td>0.89</td>
<td>0.34</td>
<td>0.92</td>
<td>0.33</td>
<td>0.91</td>
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<tr>
<td>$^{36}\text{Cl}$</td>
<td>0.19</td>
<td>0.70</td>
<td>0.37</td>
<td>0.95</td>
<td>0.21</td>
<td>0.74</td>
<td>0.20</td>
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<td>0.84</td>
<td>0.33</td>
<td>0.91</td>
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<tr>
<td>$^{90}\text{Sr}$</td>
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<td>0.47</td>
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<td>0.95</td>
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<tr>
<td>$^{137}\text{Cs}$</td>
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<td>0.74</td>
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<td>1.00</td>
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<tr>
<td>$^{238}\text{U}$</td>
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<td>0.00</td>
<td>0.69</td>
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<td>0.95</td>
<td>0.29</td>
<td>1.00</td>
<td>0.00</td>
<td>0.93</td>
<td>0.37</td>
<td>0.97</td>
<td>0.19</td>
</tr>
</tbody>
</table>

- POC and U based on parametric uncertainties only.
- POC and U for LHC results convoluted with subjective uncertainties associated with Inventory model segment.
- POC and U for LHC results convoluted with subjective uncertainties associated with UTM model segment.
- POC and U for LHC results convoluted with subjective uncertainties associated with SOURCE1 and SOURCE2 model segment.
- POC and U for LHC results convoluted with subjective uncertainties associated with WELSIM and TUMSIM model segments.
- POC and U for LHC results convoluted with subjective uncertainties associated with MOC model segment.
- CTM model segment whose subjective uncertainty results in the greatest change in total POC.

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Precipitation (hourly) → UTM → SOURCE1 SOURCE2 → TUMSIM WELSIM (annual lateral transport) → USGS-MOC → Aquifer Transport (annual)

Surface and Shallow Subsurface Transport (annual)

Water and chemical transport from disposal units

Water transport from the surroundings

Fig. 1. Linkage of contaminant transport models for performance assessment of Solid Waste Storage Area 6.