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Some Observations on Variance Reduction Analysis for Verifying Influential Parameters

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I. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC), with assistance from the Center for Nuclear Waste Regulatory Analysis, has developed the Total-system Performance Assessment (TPA) code for the purpose of independently analyzing the safety of the proposed nuclear waste repository site at Yucca Mountain. The TPA Version 4.1 code [1] has 950 input parameters, 330 of which are sampled using the Latin Hypercube Sampler. To determine which of the 330 sampled input parameters are influential (in the sense that they cause a relatively large variation in output for a given variation in input) a series of sensitivity analyses are performed. Variance reduction analysis is then performed on the influential parameters to verify that these parameters are truly influential. The parameter variance is calculated by setting the input at its expected value and its influence on the output variance is estimated. It is expected that the output variance would decrease compared to the basecase variance if the uncertainty in the influential input parameter is decreased. However, there are cases where unusual results are observed, that is, an increase in output variance for a reduction in input range. This paper investigates and provides a basis for the observed results.

II. WORK DESCRIPTION

The TPA Version 4.1 code has 950 input parameters, 330 of which are sampled and the remaining 620 are held constant. Constants are used for well known parameters such as design characteristics (e.g., the length and diameter of the waste package) or scientific constants (e.g., the boiling point of water at Yucca Mountain). Sampled parameters are used when there is natural variability or uncertainty in a parameter (e.g., the amount of rainfall received by the region of interest in a year), or when a subsystem may fail (e.g., the drip shield). A variety of distributions are used for the sampled parameters based on best estimates of their behavior. Sensitivity analysis is used to determine the sampled parameters to which system response is most sensitive. If the influential parameters can be determined, then additional attention can be given to better characterize those parameters with the possibility of reducing their uncertainty. Some of the sensitivity analysis methods used were differential analysis, Morris method, Fourier Amplitude Sensitivity Test (FAST), fractional factorial method and parameter tree method [2]. By using a scoring method [2], the final list of influential parameters was selected.

To verify that the scoring method in conjunction with the sensitivity analysis is successfully identifying the influential parameters, a variance reduction calculation is performed in which the influential input parameter under investigation is set at a fixed value (generally the mean value) and the system model is run probabilistically. Because of sampling difficulties, the range of the parameter of interest is set at a fixed value using a spike function about its mean instead of setting it as a constant. The use of the spike function in the variance reduction case instead of a constant preserves the same random sequence of the parameters other than the one that is assigned a fixed value when the Latin Hypercube Sampler is used. With the identical random sequence, the reduction in variance from fixing one influential parameter can be easily compared with similar calculations using other influential parameters.

Variance reduction calculations were performed for the top 20 parameters chosen by using one of the several sensitivity analysis methods used in this study. A corresponding reduction in output variance is expected when the parameter of interest is limited to a small fraction of its original range. The drip shield failure time (DSFailTi), however, shows a large increase in output variance. This is shown in Figure 1, which is the complementary cumulative

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distribution functions of the basecase and DSFailTi. Analyses below revealed the reason for an increase in the variance.

III. RESULTS

The DSFailTi is represented by a lognormal distribution with a range from 2,700 to 20,400 years (based on tests of passive dissolution rate of Ti Grade 7 [1]). Its mean value is 7,422 years. In the TPA simulation, the drip shield failure time acts as a "gate" that sets the flow rate of ground water contacting the representative waste package in a subarea to zero while the drip shield is intact (i.e., before the drip shield failure time). During execution of the basecase, there are combinations of conditions (sampled parameter combinations) that would allow the peak dose to rise to levels that exceed the 0.00042 mSv/yr [0.042 mrem/yr] peak average if water was present, but because the drip shield is intact, no water enters the waste package to cause release of radionuclides. With the drip shield failure time reduced to a small range centered about the 7,422 year mean, those combinations that cause a peak in excess of the average and that previously had drip shield failure times exceeding the 7,422 year time frame now allow radionuclide release because the drip shield is no longer present to prevent water from contacting the waste form. These results are shown in Figure 2 which is a realization by realization comparison of the peak dose output for the 10,000 year time period of interest for 350 realizations. (Note, the 0.00042 mSv/yr [0.042 mrem/yr] is not the same as the basecase peak expected dose of 0.00021 mSv/yr [0.021 mrem/yr]). A clear example of the gating effect of the DSFailTi is seen at realization 42 where a large peak dose of 0.0156 mSv/yr [1.56 mrem/yr] is shown for the case with a narrow DSFailTi (i.e., the drip shield failing near 7,422 years) . The corresponding basecase realization has 0.0 mSv/yr [0.0 rem/yr] output because its DSFailTi value is 12,968 years (i.e., it is inhibiting water from contacting the waste form). There are 175 realizations (50 percent) in the basecase where the DSFailTi exceeds the 7,422 year average. Because there are more non-zero peak doses in the narrow DSFailTi case, the average peak dose for the 10,000 simulation period increases from 0.00042 mSv/yr [0.042 mrem/yr] to 0.00072 mSv/yr [0.072 mrem/yr], a 72-percent increase but still below the 0.15 mSv/yr [15.0 mrem/yr] regulation standard.

IV. CONCLUSION

Variance reduction analysis can be a useful tool in verifying whether selected parameters are influential to the system output. For most parameters that are part of a numerical calculation, the expected reduction in output variance will be observed for a reduction of the parameter's input variance. However, for parameters that have a gating effect (i.e., setting the output to zero under certain conditions) unusual results can occur for computationally valid reasons. Careful analysis of the simulated physical activity taking place on a realization by realization basis revealed why an unexpected increase in dose output variance occurred with a reduction in the variance of several influential parameters (e.g., DSFailTi). This parameter exhibits a gating characteristic that significantly alters the calculation when the drip shield is present, as compared to when the drip shield is absent.

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REFERENCES

1. Mohanty, S., T.J. McCartin, D. Esh. "Total-System Performance Assessment Version 4.0 Code: Module Description and User's Guide (Revised)," CNWRA Report, January, 2002.

2. Mohanty, S., R. Codell, R.W. Rice, J. Weldy, Y. Lu, R.M. Byrne, T.J. McCartin, M.S. Jarzemba, and G.W. Wittmeyer. "System-Level Repository Sensitivity Analyses Using TPA Version 3.2 Code." CNWRA 99-002. San Antonio, Texas: CNWRA. 1999.

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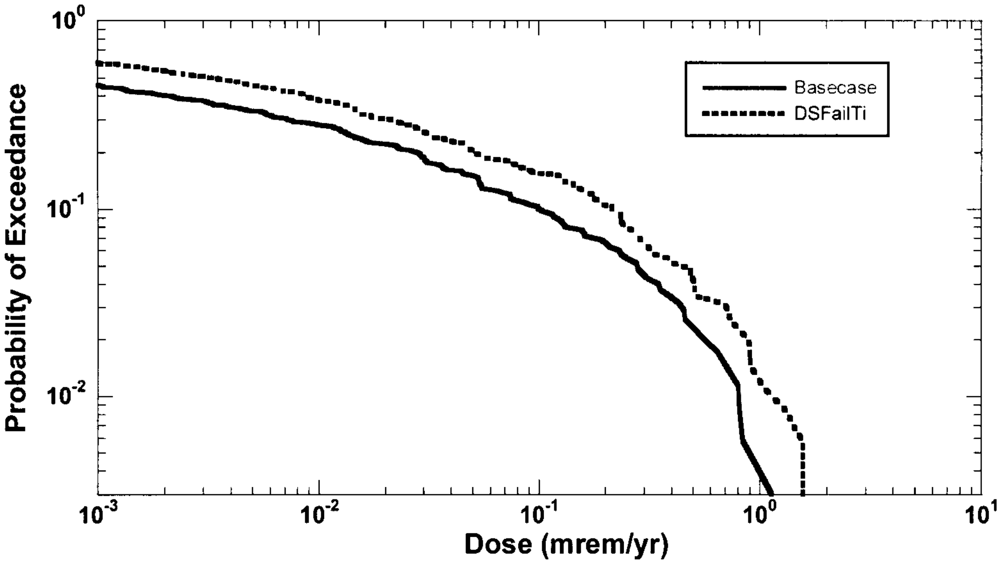

Figure 1. Complementary Cumulative Distribution Functions of the Basecase and Drip Shield Failure Time (DSFailTi)

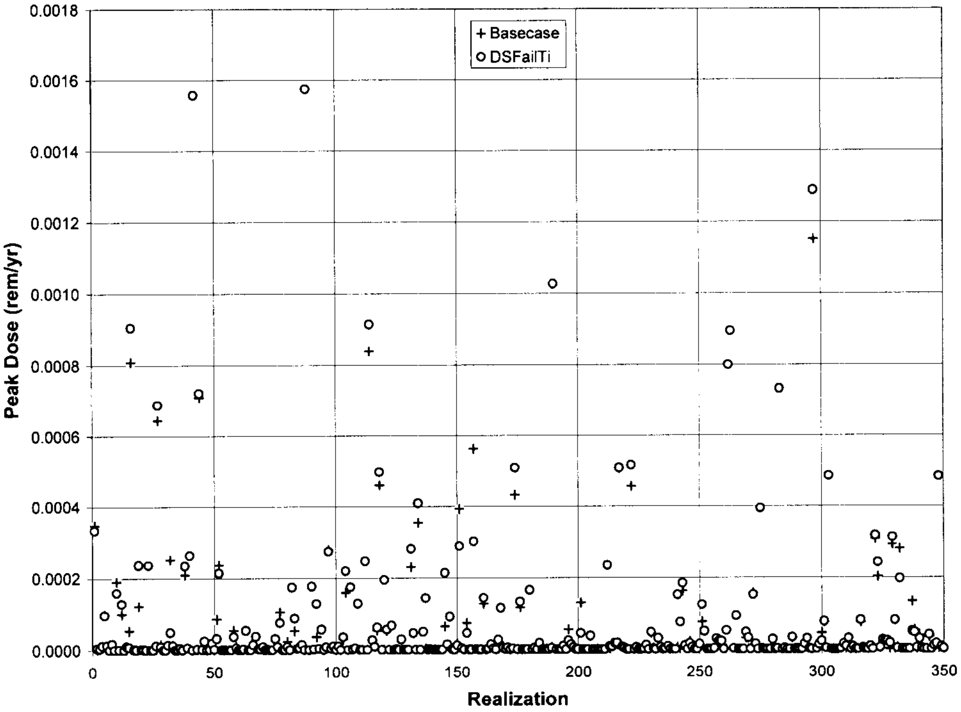

Figure 2. Realization by Realization Comparison of the 10,000 year Peak Dose Output of the Nominal Case and Narrow Drip Shield Failure Time case.