SAMPLE PERFORMANCE ASSESSMENT OF A HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY: SENSITIVITY ANALYSIS

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Introduction

The Yucca Mountain Project (YMP) is the USA's first attempt at long-term storage of High-Level Radioactive Waste (HLW). The YMP will store "commercial and military spent nuclear fuel, high-level radioactive waste derived from reprocessing of uranium and plutonium, surplus plutonium, and other nuclear-weapons materials." The HLW is currently stored at over one hundred sites, and the YMP seeks to incorporate the waste from these sites into one repository, built in rock above the water table [1].

In theory, the reasoning for such a repository seems sound. In practice, there are many scenarios and cases to be considered while putting such a project into effect. Since a goal of YMP is to minimize dangers associated with long-term storage of HLW, it is important to estimate the dose rate to which current and future generations will be subjected. Uncertainty exists as to the conditions to which the waste containers will be subjected and as to the mechanism of degradation in the waste containers. Thus, it is reasonable to perform a variety of sensitivity analyses to indicate how assumed degradation rates and conditions affect the projected dose rate to future generations.

Both engineered and natural barriers are integral in keeping the adverse environmental influence of YMP acceptably low. As the system is compromised over time, there is more opportunity for radioactivity to leak out. This evaluation includes examination of the effects on the performance assessment of varying the corrosion pit size in the YMP engineered barrier system component and the long term average percolation flux in the YMP natural barrier system component. Such analysis indicates the consequences of incorrect estimates in the corrosion mechanism and rate at which water percolates through the mountain. By varying the estimated values, trends in the projected performance are observed and analyzed.

The lifetime of the repository is simulated to indicate the radiation dose rate to the maximally exposed individual; it is assumed that if the maximally exposed individual would not be harmed by the annual dose, the remaining population will be at even smaller risk. The determination of what levels of exposure can be deemed harmless is a concern, and the results from the simulations as compared against various regulations are discussed.

Much more extensive analysis is required for a true indication of the sensitivity of projected dose rates to assumed conditions. This analysis only looks at the end result, and there have been changes to the engineered barrier system design since this performance assessment model was developed. The sensitivity analysis results should be reviewed while considering the key question, "Will YMP ' "contain and isolate the radioactive wastes so that the dose impact to humans is attenuated to a relatively benign level for periods as long" as a million years'? [1]"

The Maximally Exposed Individual

The lifetime of the repository is simulated to indicate the radiation dose rate to the maximally exposed individual. The situation is analogous to a worst-case scenario solution to a problem. It is assumed that if the maximally exposed individual would not be harmed by the annual dose, the remaining population will be at even smaller risk. The determination of what levels of exposure can be deemed harmless is a concern, and the results from the simulations as compared against various regulations are discussed.

It is postulated that the maximally exposed individual is the average Amargosa River Valley resident. The timeframes considered are so extensive (up to 1 000 000 years) that it is not clear what sort of civilization will exist. Thus, it is important to assume a civilization with as much contact with the nearby natural resources and therefore with the potential for as much contact with any radionuclides as possible. Average Amargosa River Valley residents are assumed to be non-nomadic farmers, living on self-sustaining farms. It is assumed that:

- Farmer and children was born on-site, wife from surrounding area.
- Family has never been outside five-mile radius from farm.
- All water comes from on-site wells and collected rainwater.
- All fruits and vegetables are from farmer's crops grown on-site.
- All meat, eggs, milk are from animals born and raised on-site.
- All food is processed on site or with help from neighboring farmer.
- All clothes are made from hides, cotton, wool, and other natural fiber from on-site sources.
- Hut from on-site materials used for shelter
- Wood and dung-chips produced on-site are used as heat source.

Model
The dose rate to the maximally exposed individual is calculated based on the Simplified Total System Performance Assessment (STSPA), a model developed by Golder Associates, Inc., Booz-Allen Hamilton, Stone and Webster, and the University of Nevada Reno. The model runs on the basis of GoldSim, a user-friendly graphics-based simulation tool.

In the STSPA Introduction to GoldSim, the authors describe the STSPA. "The long-term performance of a geologic high-level nuclear waste repository is evaluated using performance assessment (PA) models. PA is based on computer models of the features, events, and processes that could affect the performance of a repository over long periods of time. PA modeling is used to forecast how the repository system and its components evolve over time. The different process models are linked together to create a model of the total system performance (called a total system performance assessment or TSPA) that describes relevant aspects of the repository system and the biosphere. Comparing the results to performance requirements allows analysts to estimate whether the amount of harmful material that may become accessible in the environment is acceptably low."

Minor settings were altered, and Windows NT Pentium III computers ran the STSPA. Conclusions based on the simulation are dependent on the accuracy of the original model and the computer running the model.

STSPA Settings
The STSPA model divides the System Level Model into a variety of Repository System Model Components: the Biosphere Model, the Climate Model, the Infiltration Model, the Repository Models, the Unsaturated Zone Transport Model, and the Saturated Zone Transport Model.

<u>Corrosion Pit Size</u>
The "Corrosion Pit Size" sensitivity analysis is completed by varying the "Pit_Radius" term in the Waste Package Degradation Conceptual Model, a subcategory of the Repository Models. The Pit_Radius default value is 0.000 35m, or 0.35mm (comparable to the diameter of mechanical pencil lead, usually 0.5mm). The variable was varied by 1-3 orders of magnitude; i.e., Pit_Radius = 0.000 000 35m, 0.000 003 5m, 0.000 035m, 0.000 35m, 0.003 5m, 0.035m, 0.35m. The final value, 0.35m, is comparable to the length of an A4 sheet of paper.

This sensitivity analysis was run for timespans of both 100 000 years and 1 000 000 years. In both cases, there were 100 timesteps (i.e., 1000 year 10 000 year timesteps, respectively).

<u>Long Term Average Percolation Flux</u>
The "Long Term Average Percolation Flux" sensitivity analysis is completed by varying the "Repos_Avg_Perc_Flux_LTA" term in the Repository Average Percolation Flux due to Climate subcategory of the Unsaturated Zone Transport Model. The subcategory is indicative of the average percolation flux at the repository horizon for each climate state. The Repos_Avg_Perc_Flux_LTA default table value is as follows:

INFILTRATION_RATE (DIMENSIONLESS)	REPOS_AVG_PERC_FLUX_LTA (MM/YR)
1	13.5
2	40.7
3	122

Figure 1. Default values for the Long Term Average Percolation Flux.

Each Repos_Avg_Perc_Flux_LTA value is modified by a multiplier of 1/20, 1/10, 1/5, 1/2, 1, 2, 5, 10, and 20. It was not possible to modify the results by 1-3 orders of magnitude, since this caused physical impossibilities to occur; for example, the amount of water percolating through mountain cannot possibly be greater than amount of water seeping into mountain. When a multiplier of 100 was used, the GoldSim code halted and returned the error:

STSPA\STSPA_System_Level_Model\Repository\Drift_Seepage\Seepage_LTA\Seepage_Fraction_LTA (error 6305): 'Mean' must be less than 'Maximum.'

This sensitivity analysis was run for a timespan of 1 000 000 years with 100 timesteps (i.e., 10 000 year timesteps).

Explanation of Settings

The 1 000 000 year option allows a broad overview of the dose rate over extended time and meets the "basic tenet" requirements, which suggests YMP serve as a repository for "as long as a million years" [1]. The 100 000-year option allows a closer and more precise look at the initial time period. The 100 000 year span is likely to be more accurate than the 1 000 000 year span for its first 100 000 years, since the number of increments was set at 100 for both sets of runs. While the exact mechanisms of the model are not known, it appears from numerical approximations in general that the smaller the increments are, the nearer the result to the true value. The reader is probably aware of using Simpson's Rule to approximate a definite integral, for example.

For the Long Term Average Percolation Flux sensitivity analysis, the 100 000 year run was not performed, to avoid an overabundance of data.

Corrosion Pit Sensitivity Analysis

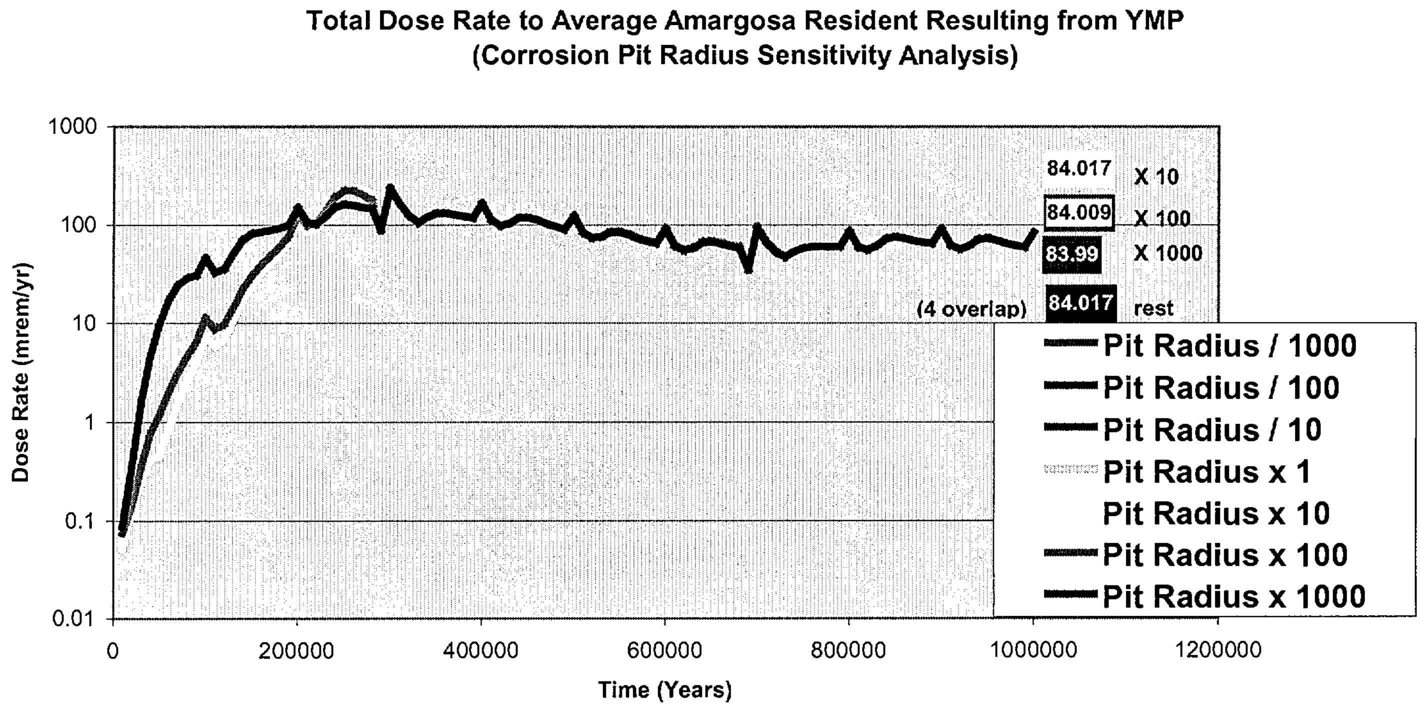

Figure 2. 1 000 000 year-run for Corrosion Pit Size.

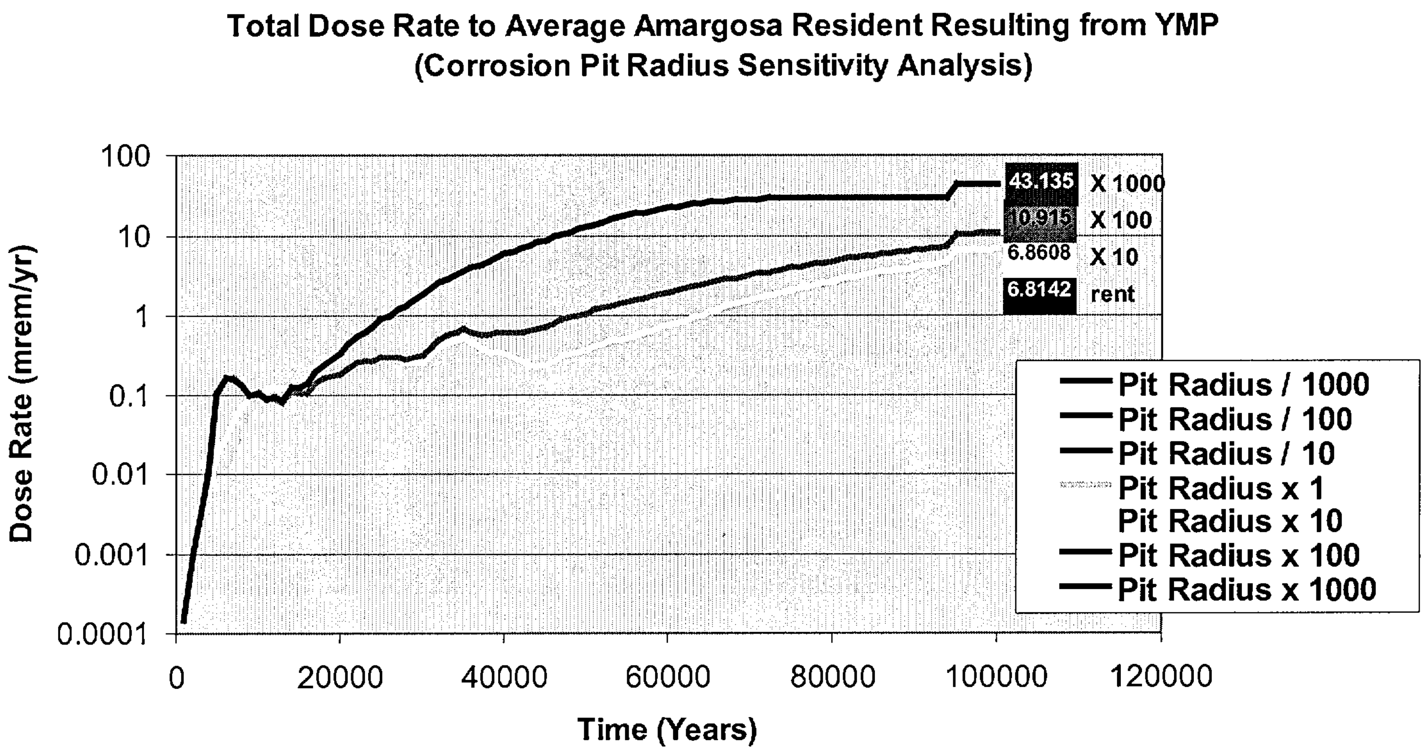

Figure 3. 100 000 year-run for Corrosion Pit Size.

LTA Percolation Flux Sensitivity Analysis (1 000 000 year runs)

Total Dose Rate to Average Amargosa Resident Resulting from YMP (LTA Percolation Flux Sensitivity Analysis)

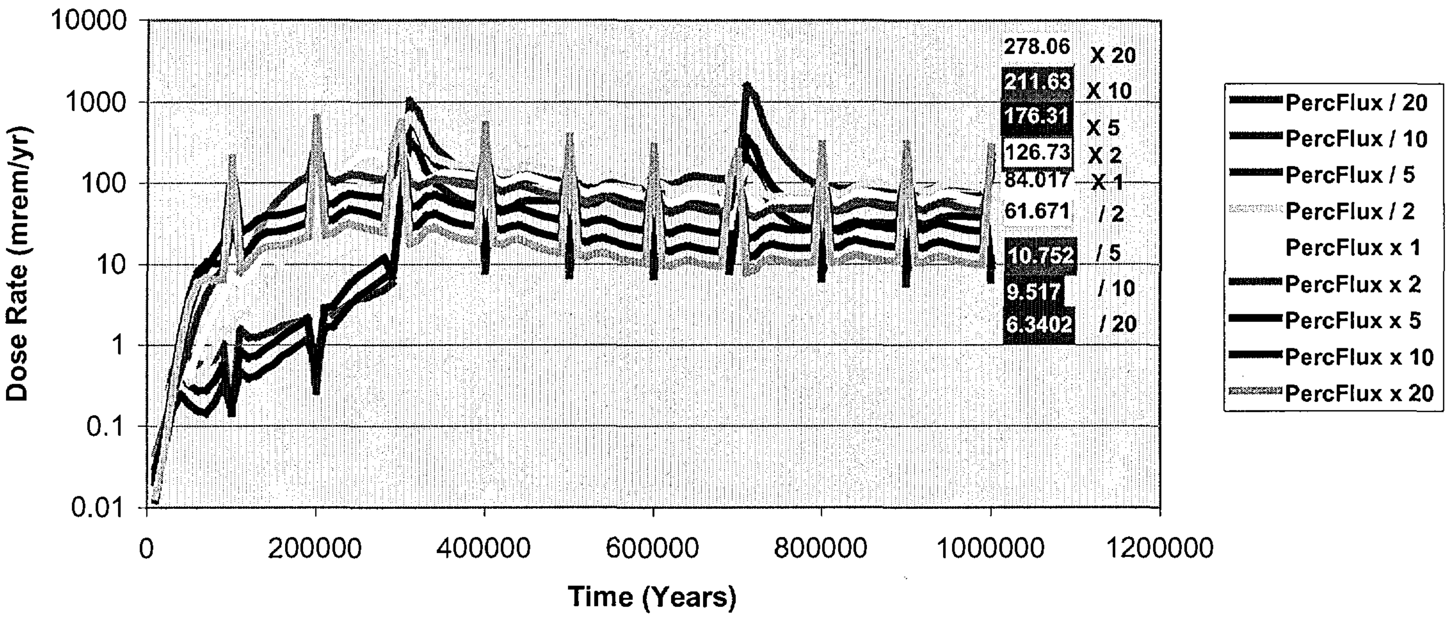

Figure 4. Total dose rate for all magnitudes.

Total Dose Rate to Average Amargosa Resident Resulting from YMP (LTA Percolation Flux Sensitivity Analysis)

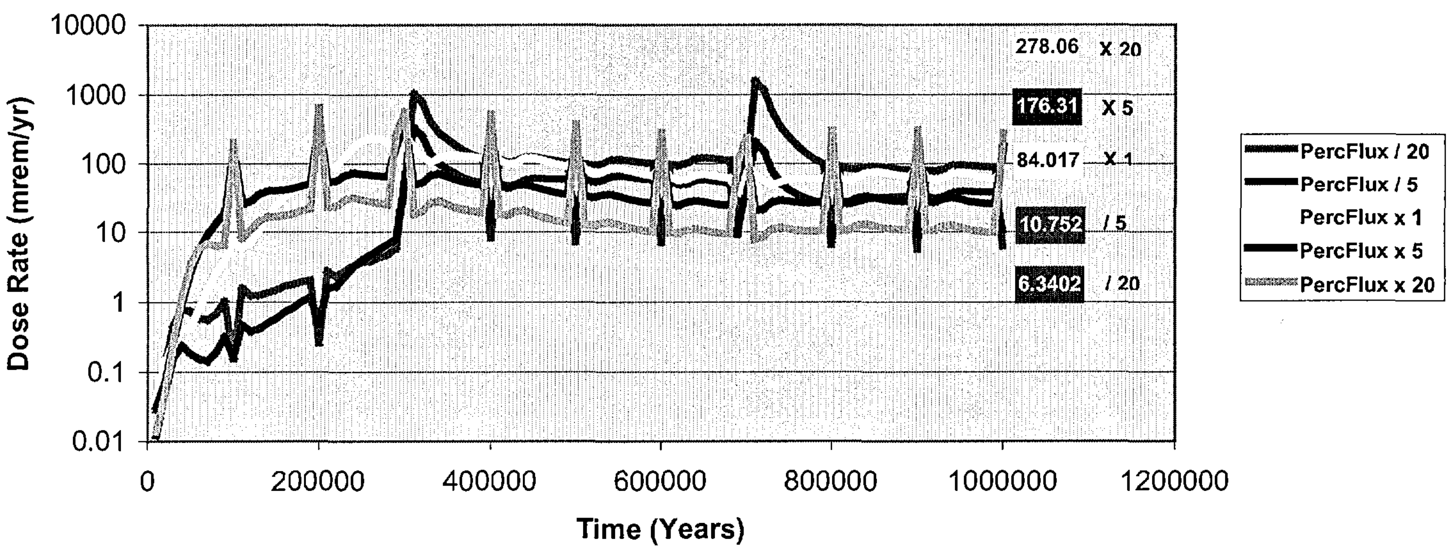

Figure 5. Total dose rate for two additional magnitudes.

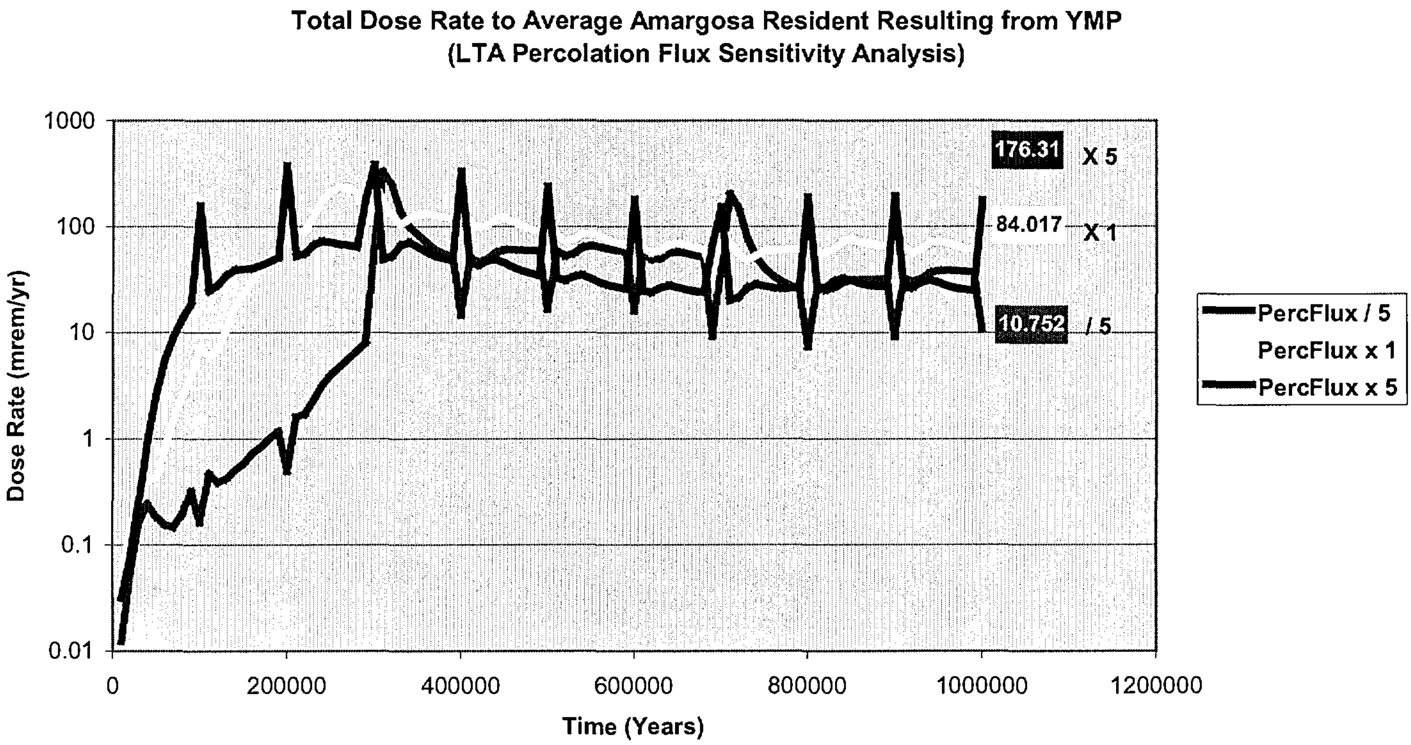

Figure 6. Total dose rate for one additional magnitude.

Discussion of Results

The key values to note in the preceding graphs are the proposed whole body standards:

- 15 mrem/yr, the proposed EPA (U.S. Environmental Protection Agency) Yucca Mountain Standard, found in 40 CFR 197.
- 25 mrem/yr, the proposed NRC (U.S. Nuclear Regulatory Commission) Yucca Mountain Standard, found in 10 CFR 63.

Corrosion Pit Size

The sensitivity of the STSPA model to corrosion pit size is minimal. As can be seen, a three-orders of magnitude increase or decrease in the postulated corrosion pit radius of 0.00035m has little effect on the long-term dose values. After 1 million years, the approximate value of 84 mrem/yr is reached. In the shorter term, it is evident that the corrosion pit radius does affect the dose rate; for the 100 000 year plot, it is clear that the 0.35m corrosion pit radius (1000x postulated) has about a six-fold increase in dose.

It is very possible that an assumed "cladding credit" in the model, taking into account that the zircaloy cladding protects the HLW from leaking out, is responsible for this lack of sensitivity. If "cladding credit" is not being taken into account, it seems unusual that such a large variation in corrosion pit size would not more dramatically affect the dose to the maximally exposed individual in the long term.

The 0.35m corrosion pit radius simulation exceeds proposed EPA and NRC standards at 53 000 years and 65 000 years, respectively. For the postulated 0.00035m corrosion pit radius case, these standards are exceeded at 130 000 and 150 000 years, respectively.

Long Term Average Percolation Flux

It is interesting to observe the LTA Percolation Flux Sensitivity plots. Despite alterations to the postulated long term average percolation flux, the dose rate continues to stay in the 10 – 500 mrem/yr range from 400 000 years onward. The higher percolation fluxes are seen to have the lowest average dose rate over the 400 000 year – 1 000 000 year time period. This seems quite logical, since as more water washes the radionuclides through the mountain, there is more chance for dilution.

Still, the 20 x postulated percolation flux value, for example, has peaks of ca. 500 mrem/yr, which occur likely during the times when there is a dry spell and the radionuclides once again have time to be absorbed into the soil and plant life. The extremely high peak comes from the smallest, 1/20th of the postulated percolation flux, case. This also is logical; when there has not been much percolation to allow for dilution, the radionuclides rest in the mountain and have time to get to the plant life. Suddenly, a peak can occur when the concentrated radionuclides are washed away in a super-pluvial time period.

The postulated LTA Percolation Flux term causes the proposed EPA and NRC standards to be exceeded at 130 000 and 150 000 years, respectively. For the 20 x postulated LTA Percolation Flux, these are met at 130 000 and 190 000 years. For the 1/20 x postulated case, these are met at approximately 300 000 years (although this is difficult to interpolate from the steep slope of the plot).

Conclusion

According to this simplified performance assessment model, with currently assumed degradation values the Yucca Mountain Project satisfies the proposed EPA and NRC radiation annual dose regulations in the short (<10 000 year) term. After approximately 50 000 years, the dose is on the same order of magnitude as proposed regulations. EPA and NRC proposed regulations do not appear to be met after 1 million years.

Acknowledgements

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Reference

[1] Hanks, Thomas C., et al. Yucca Mountain as a Radioactive-Waste Repository. United States Geological Survey Circular 1184. 25 November 1998.