Analysis of Multiple Seismic Events on the Long-Term Isoaltion Perfromance of a Yucca Mountain Repository

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ABSTRACT

A set of IMARC total system performance assessments (TSPA) have been performed to evaluate the potential safety and performance impacts arising from multiple seismic events for a Yucca Mountain repository. Potential impacts of earlier-than-expected containment failure of waste packages (WPs) are modeled based on separate geomechanical analyses of WP-WP collisions, accumulating static load of rock debris, and/or dynamic loading from large rock blocks falling onto WPs. Compared to the 10^6-year, reasonably expected, peak mean annual dose of 0.020 mrem/yr calculated by IMARC in the absence of failures induced by seismicity/ rockfall, the calculated peak mean annual doses for two, alternative multiple-seismic-event scenarios are calculated to be 0.035 and 0.090 mrem/yr, far below a 15 mrem/yr compliance level.

INTRODUCTION

Yucca Mountain, Nevada (YM) has been designated as the candidate site for permanent disposal of commercial spent fuel and defense high-level waste in a deep geological repository. The Yucca Mountain site is located in an arid, remote, and thinly populated region of southwestern Nevada. It is characterized by thick, hydrologically unsaturated tuff formations within the Basin and Range province.

The geological region in which Yucca Mountain resides currently exhibits a low level of seismicity. However, the potential for seismic slip along the faults that define the structural block bounding Yucca Mountain (i.e. the Solitario Canyon, Bow Ridge, etc.) must be considered in assessing the long-term possibility of seismic effects on the capability of the repository to isolate radioactive waste. Future seismic activity has been identified as a key scenario for performance assessment of a repository located at Yucca Mountain [1]. With respect to consequences from seismic activity, attention has been devoted to three broadly defined potential impacts [2]:

- fault displacement directly damaging components of the Engineered Barrier System (EBS),
- seismic (vibratory) ground motion damaging EBS components, and
- seismic-induced collapse of open drifts, potentially compromising EBS performance.

As discussed by EPRI [3], the first of these three potential impacts is readily addressed through drift construction and waste package emplacement methods, and is not anticipated to play a significant role in repository licensing. The potential effects of seismicity are, therefore, limited to consequences of vibratory motion and falling rocks on the EBS.

Previously, EPRI has carried out an analysis of the consequences of a single seismic event [3]. This present analysis extends the seismic analysis of EPRI [3] to account for the consequences associated with multiple seismic events spread through the post-closure performance period. As in other EPRI studies, the intent is not to present worst-case analyses, but rather to adhere to the ‘reasonable expectation’ intent of the EPA’s proposed regulatory structure in 40 CFR 197.

NOMINAL CASE

As discussed by EPRI [3], other potential effects on the repository from seismic activity have been eliminated from consideration, effects that could have required changing the process models or structure of IMARC [4, 5]. Examples of such potential effects, which have been eliminated from consideration, include seismic effects on groundwater levels, shear of EBS components located across an active fault, and structural modification of rocks by the formation or activation of fractures. These processes have been eliminated either because they have been shown to be inconsequential to TSPA, or in the case of shear because it is easily avoided by proper placement of waste packages with an appropriate offset [3]. These considerations have made it possible to evaluate seismic activity using IMARC 9, changing only input parameters for the analysis. As a result, results produced by IMARC 9 in the absence of seismic effects on the EBS provide a nominal case for comparison of the seismic analyses reported here. In the absence of seismic damage to the EBS, the sum of doses from all radionuclides increases gradually over the performance period, eventually peaking about 0.02 mrem/yr at 10^6 years [5].

BASIS FOR MULTI-SEISMIC EVENT ANALYSIS

Long-term seismic activity has, for the purposes of the present analysis, been abstracted to be represented by ten seismic events with a peak ground velocity (PGV) of 0.75 m/s [6]. This PGV is representative of a median seismic event with a 10^5-year return time. Note that the most important fault in evaluating potential seismicity, the Solitario Canyon Fault, has a return time on the order of 10^4 years, with associated smaller PGVs [6]. Therefore, the seismicity represented in the current analysis has much higher PGVs than the most significant nearby fault. Furthermore, these PGV analyses are representative of values characteristic of the ground surface; reductions of PGVs at depth have not yet been accounted for. Since ground motions are known to be less severe at depth than at the ground surface, this represents a potentially significant conservatism in the present analyses.

Rockfall associated with each of these events has been evaluated [6], accounting for differences in rock strength in the lithophysal and nonlithophysal portions of the repository, and accounting for rock stress corrosion, which decreases the strength of the rock in time. Rockfall can have a number of effects on the drifts and EBS. EPRI [3] showed that changes in seepage into drifts were small from changes in the morphology of the drifts and the presence of fallen rock filling the drift. Consequently, changes in the seepage between an intact drift and a collapsed drift have been neglected in this analysis.

Static and dynamic loading effects arising from rockfall might contribute to earlier-than expected failures of WPs compared to the nominal case [6]. Two seismic cases based on different assumptions of WPs failures arising from rock fall are evaluated.

For a Seismic Base Case of the multiple-seismic event scenario, WP failures are modeled to arise from WP-WP collisions, as well as dynamic and static loading effects. As shown in Figure 1, while the amount of rockfall increases for each successive event, WP-WP collisions become impeded, with a gradual decrease in this failure mode. While seismic-related failures dominate up to ~500,000 yrs, thereafter corrosion failures attributable to the nominal case becomes a more important failure mechanism. After 10^6 yrs, 15.5% of WPs are projected to have failed due to both seismic and corrosion mechanisms, compared with 14.8% of WPs in the absence of seismic effects (Figure 1).

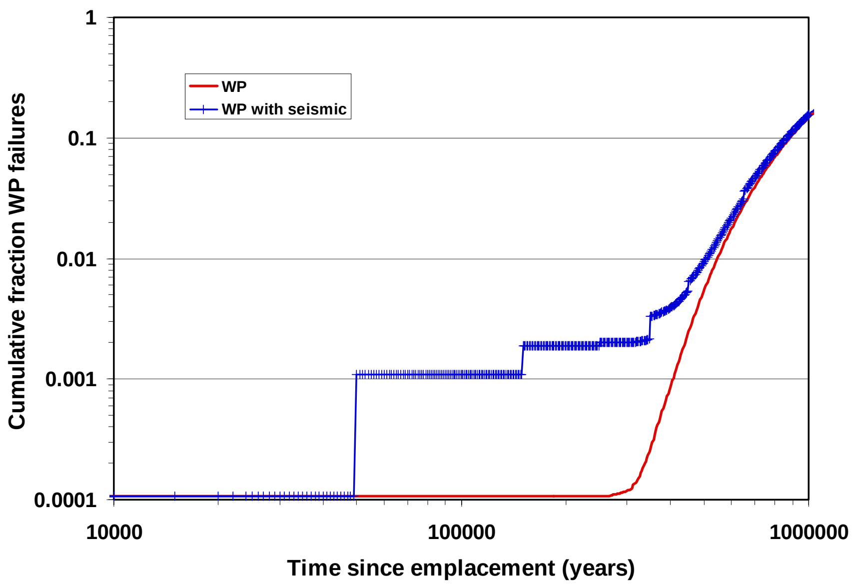

Fig. 1: Postulated time dependence of the cumulative fraction of failed waste packages for a seismic base case ("WP with seismic") compared to the nominal case ("WP").

As a Seismic Alternative Case (Figure 2), it is assumed that WPs might not become pinned by accumulating rock debris from rockfalls arising from successive seismic events. For this more conservative Alternative Seismic Case, 44% of the WP are estimated to fail after 10^6 yrs ("WP with seismic") compared with only 14.8% in the absence of seismic effects ("WP").

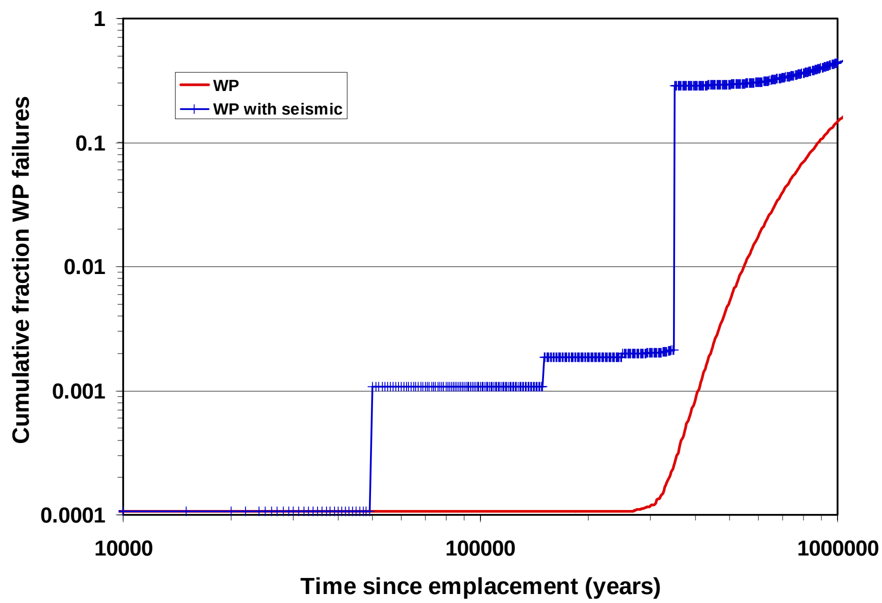

Fig. 2: Postulated time dependence of the cumulative fraction of failed waste packages for a seismic alternative case (“WP with seismic”) compared to the nominal case (“WP”).

IMPLICATIONS FOR SAFETY AND REGULATORY

Inclusion of the failure functions (Figure 1) for the EBS in IMARC for the Seismic Base Case produces mean annual dose rates depicted in Figure 3. This set of failure functions for the EBS represents the reasonable expectation analysis for the assumed set of seismic events with the 10^5-year reoccurrence interval and PGV= 0.75 m/s assumed in this analysis. The occurrence of seismic events at 10^5-year intervals results in perturbations to the dose curve, as a limited number of waste packages fail (or fail faster than for the nominal case scenario) attributable to each event. However, these perturbations are of relatively short duration and produce small changes in the total dose compared with the nominal-case analysis without seismically induced failures. Furthermore, the effect of the seismic events on peak dose is minor, increasing the peak annual dose at 10^6 years by less than a factor of two to a value 0.035 mrem/yr, much less than 15 mrem/yr.

The mean annual dose rates calculated using the cumulative WP failure behavior (Figure 2) for a more conservative Seismic Alternative Case are shown in Figure 4. The results show jumps in the total dose curve similar to the Seismic Base Case analysis, associated with waste packages that fail associated with particular seismic events. The large number of waste package that are assumed to fail after the 4^{th} seismic event (Figure 2) lead to a moderate increase in peak dose at 10^6 years, but the increase is less than an order of magnitude, and remains well below the 15 mrem/yr regulatory dose limit.

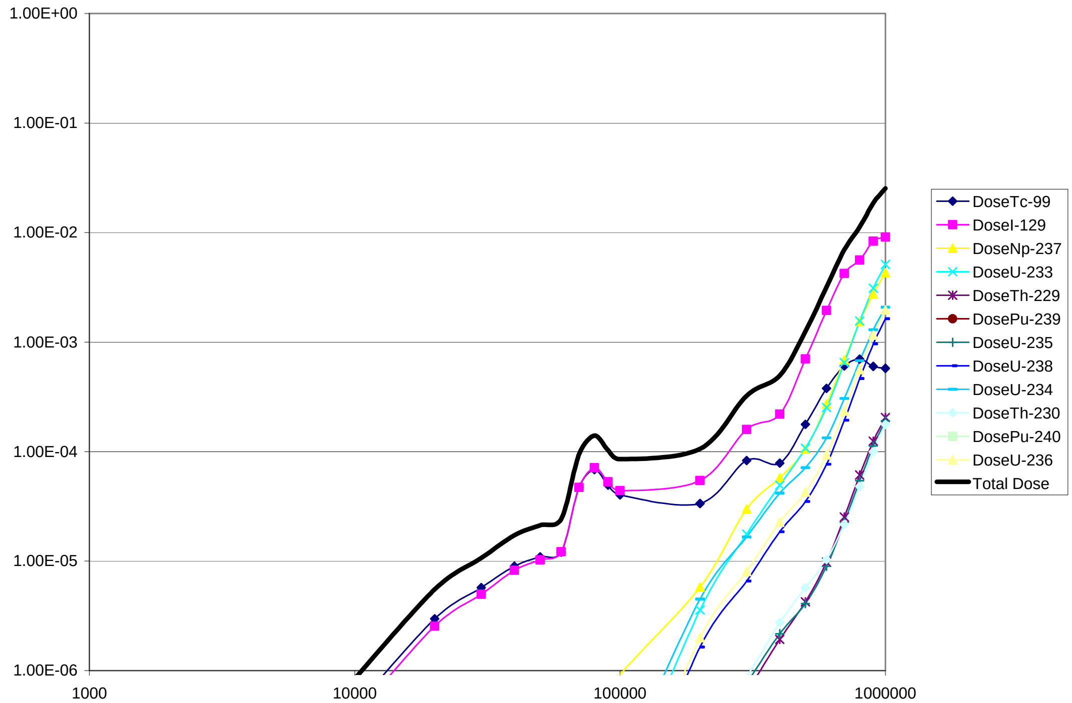

Fig. 3. TSPA results for the seismic base case failure functions shown in Fig. 1. These results represent the reasonable expectation analysis for the assumed series of seismic events.

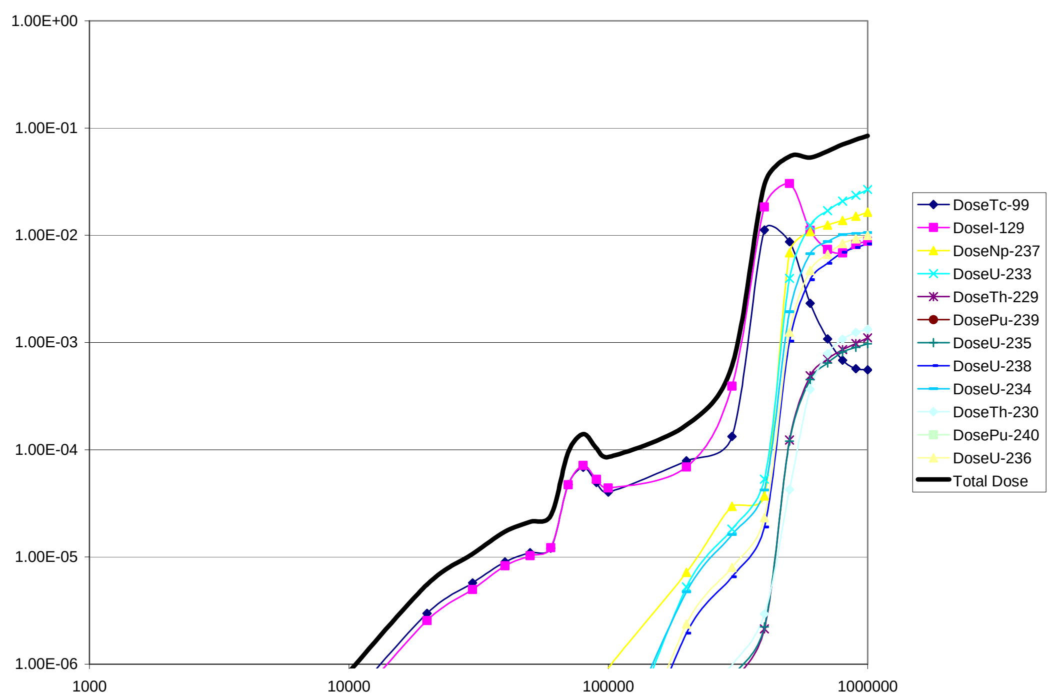

Fig. 4. TSPA results for the seismic alternative case failure functions Shown in Fig. 2.

SUMMARY

The purpose of these analyses is to evaluate the effects of multiple seismic events on the total system performance assessment (TSPA) of A repository located at Yucca Mountain. The illustrative seismic scenario for these TSPA calculations is characterized by a series of seismic events with a reoccurrence interval of 10^5 years and a peak ground velocity (PGV) of 0.75 m/s. Separate geomechanical analyses lead to two alternative cases for the time-dependent failure of waste packages (WPs) attribute to WP-to-WP collisions, mechanical failure of WPs by static loading of accumulated rockfall, and/or mechanical failure of WPs by dynamic loading from the dislodged rock blocks.

Compared to a calculated peak dose rate of 0.020 mrem/yr for a nominal case (i.e., no seismic impacts), the most likely Seismic Base Case, in which subsequent WP-to-WP collisions are mitigated by previous rockfall that pin WPs, leads to only a negligible impact (increase by about a factor of 2 to a value of 0.035 mrem/yr) in the calculated peak dose rate for a repository at Yucca Mountain. Even for a more conservative Alternative Seismic Case, that neglects the pinning of WPs and allows a much greater number of failures by repeated WP-to-WP collisions, only a moderate impact (increase by a factor of about 4 to a value of 0.090 mrem/yr) is calculated. The TSPA peak dose rates for both of these seismic cases are well below the 15 mrem/yr regulatory dose limit.

Furthermore, the most credible fault to produce significant seismic activity at Yucca Mountain, the Solitario Canyon Fault (SCF), has a significantly shorter median return time (30,000 years) for events than that assumed in this analysis, hence, with an associated smaller expected PGV for each of those events. Given the higher PGV conditions assumed in the analyses presented here, even if extreme PGV values for reoccurring SCF events are postulated, these highly unlikely PGV conditions would not be expected to produce large TSPA consequences. Therefore, consequences on TSPA, associated with seismic activity from the SCF that dominates seismic hazard at Yucca Mountain, are expected to be relatively minor.

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