WYOMING STATE GEOLOGICAL SURVEY
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RECOMMENDATIONS REGARDING SEISMIC DESIGN STANDARDS FOR URANIUM MILL TAILINGS SITES IN WYOMING

by

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HAZARDS REPORT 96-1

Laramie, Wyoming

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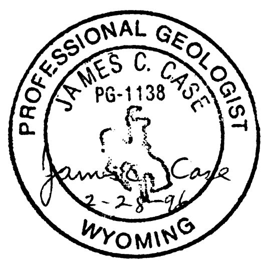

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Summary

In late October, 1995, the Geologic Hazards Section of the Wyoming State Geological Survey (WSGS) was provided a June 26, 1994, version of a report generated for the U.S. Nuclear Regulatory Commission (NRC) by Lawrence Livermore National Laboratory (LLNL). The report by Bernreuter and others (1991) is titled *"Seismic Hazard Analysis of Title II Reclamation Plans"*. The purpose of the report was to provide an evaluation of the seismic design assumptions for uranium mill tailings sites in Utah, New Mexico, South Dakota, and Wyoming. For the evaluation, LLNL estimated the design ground motion for each site under consideration, and compared their estimated design ground motion to the actual design assumptions. Nine sites were evaluated in Wyoming.

The WSGS has completed a thorough review of the report as well as an evaluation of the Federal regulations and history behind the report. The Wyoming sites are not critical facilities. Even if the sites are exposed to a significant earthquake, the resulting risk posed to the residents of the State is low. The WSGS concludes that reclaiming the sites to withstand a ground acceleration that has an annual probability of exceedance (PE)= 10-4 is unwarranted and would be unnecessarily costly. Given the conditions present in Wyoming, designing a reclaimed site to withstand a ground acceleration that has an annual PE=5x10-4 would provide adequate protection to residents of the State, and would be more cost effective. A ground acceleration with an annual PE=5x10-4 can be applied to a site with a 200-year design life.

The recommendations and discussions in this report refer only to uranium mill tailings sites in Wyoming. Presented below is a generalized critique of the report and regulations, as well as a suggested approach that would be most applicable to Wyoming.

Background of the LLNL Report

Using a probabilistic seismic hazard approach to all uranium mill tailings sites in Wyoming, LLNL (Bernreuter and others, 1994) estimated the ground motions [Peak Ground Accelerations (PGAs)] that they felt would be exceeded at annual probabilities of exceedance of 5x10-4 and 10-4 at each of the sites. A PGA with an annual PE=10-4 would approximately have a 10% chance of being exceeded in 1,000 years, and a PGA with an annual PE=5x10-4 would approximately have a 10% chance of being exceeded in 200 years.

A PGA with an annual PE=10-4 can be applied to a site with a 1,000-year design life, because in the next 1,000 years there would approximately be a 10% chance of having such a ground motion occur at the site. That 10% chance is apparently considered an acceptable risk. By the same token, a PGA with an annual PE=5x10-4 can be applied to a site with a 200-year design life.

Ultimately, the LLNL report is designed to be an arbitrary screening tool to sort out the sites that may be most at risk from an earthquake. On page 11 of the report, LLNL states that:

> *"Its main use is to determine if a detailed study is needed, that is if the estimates for the ground motion are used for safety assessments."*

Pertinent regulations

The regulations that govern the reclamation of uranium mill tailings are in 10 CFR 40 Appendix A. The seismic regulations are as follows:

> *"The impoundment may not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand." "The term "maximum credible earthquake" means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material."*

A capable fault is defined in 10 CFR 100 Appendix A as a fault that has had movement at or near the ground surface at least once within the past 35,000 years, or movement of a recurring nature within the past 500,000 years, or a fault that has a structural relationship to a capable fault.

An additional regulation in 10 CFR 40 Appendix A can also indirectly apply to seismic concerns. That regulation states that:

> *"In disposing of waste by-product material, licensees shall place an earthen cover* **Pertinent Regulations**
>
> *(or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 sears to the extent reasonably achievable, and in any case, for at least 200 years...".*

Analysis of Regulations

The regulations address capable faults that have had movement *"at or near the ground surface at least once within the past 35,000 years"*. The regulations do not specifically address probabilistic studies based upon an analysis of random background earthquakes.

All capable faults don't have to be exposed at the surface. With enough research, buried capable faults can be defined. Unfortunately, in many areas of the country, the available data on capable faults are limited and the historic earthquake record is incomplete. That is the case in central and eastern Wyoming. Under these conditions, analyses on capable faults may have to be supplemented with probabilistic hazard analyses. Probabilistic analyses are in large part based upon an estimate of all the possible spatial and temporal distributions of earthquakes that may occur, including earthquakes that are due to movements on specific faults as well as those that may occur randomly. Most active faults in Wyoming have long recurrence intervals, which means that probabilistic analyses are going to be more strongly influenced by the hypothetical random earthquakes than by the active faults. For that reason, PGAs can significantly differ between regional probabilistic analyses and deterministic analyses on a specific fault. For most site specific analyses in central and eastern Wyoming, the PGAs (probabilistic) at an annual PE=10-4 and an annual PE=5x10-4 will be larger than those associated with deterministic analyses on capable faults. It must be kept in mind, however, that if there are weaknesses in the background earthquake and active fault data that are used in the probabilistic analysis, there will also be weaknesses in the analysis.

The regulations present a range of values within which a site must be stable. In Wyoming. the application of the 1,000-year upper limit to the design of remote sites is overly conservative, especially hen the 1000-year design is based upon a highly conjectural PGA with an annual PE=10-4 . The ground motion that has a 10% chance of occurring in 200 years has an annual PE=5x104, which can approximately correspond to a 2,000-year return period. The probability of a 2,000-year event not occurring in 1 ;000 y ears is 65%, which appears to be a reasonable assurance of safety for even a 1,000-year design life. For the above reasons, using a PGA with a PE=5x10-4 appears reasonable. Ground motions associated with an annual PE=5x10-4, while still conjectural, are more defensible than those associated with an annual PE= 10-4.

The regulations are primarily designed to prevent or minimize damage to the sites that would lead to the release of radioactive materials, including radon. The regulations assume that large earthquakes could damage the earthen cover over the mill tailings, leading to the release of radon to the atmosphere or to the eventual migration of other radioactive materials. However, because impoundments are reclaimed with gentle slopes, any earthquake-induced failures should be shallow. Under such conditions, the probability of releasing radioactive materials is low.

Analysis of the LLNL Report

Since the regulations address capable faults exposed at or near the ground surface, a significant part of the WSGS analysis of the LLNL report, and other selected reports, addresses the ground motions associated with capable faults. In addition, the WSGS analysis compares ground motions associated with capable faults to those derived from probabilistic analyses.

The seismic history of Wyoming covers a period of only 120 years. Limited studies, however, have been done on exposed active faults in the vicinity of the mines. Based upon those studies, it does not appear that the faults near most of the sites would provide PGAs that are even close to the PGAs at an annual PE = 10-4 suggested by LLNL. The probabilistic analyses generated by LLNL are based upon an analysis of random events, and did not include analyses of specific Wyoming faults. On page 104 of the report, LLNL (Bernreuter and others, 1994) states the following:

> *"It should be noted that there is not enough data to develop recurrence models for any of the faults considered to be active. Thus it is not possible to include specific faults in the probabilistic hazard analysis."*

There are discrepancies between the LLNL report and other existing site-specific and regional reports. For example, LLNL has suggested a PGA (probabilistic) of 0.33g for Kennecott's Sweetwater uranium facility in the Red Desert at an annual PE=10-4. However, LLNL also estimated that a PGA (deterministic) of 0.08g to 0.14g at the site would be associated with a maximum credible earthquake with a magnitude of 6.75 on the Green Mountain segment of the South Granite Mountain fault system, and that a PGA (deterministic) of 0.18g to 0.22g at the site would be associated with a maximum credible earthquake with a magnitude between 6.4 and 6.8 on the nearby Chicken Springs fault system. In other words, the PGAs that are associated with identified capable faults are significantly less than the PGAs attained using a source consisting of random earthquakes at an annual PE=10-4.

Shepherd Miller, Inc. (1995) prepared a report titled, *"Addendum to the Sweetwater Uranium Project Revised Environmental Report, Regional Seismicity, for the Sweetwater Uranium Project, Sweetwater County, Wyoming"*. This report not only provides an estimate of the PGA that may occur if a nearby capable fault activates, but also the PGA for a random earthquake. If the Green Mountain segment of the South Granite Mountain fault system activates, and generates the postulated maximum credible earthquake (magnitude 6.75) assigned to the fault, Shepherd Miller, Inc. estimates the PGA would be between 0.08g and 0.14g. Those figures are comparable to LLNL figures. However, the WSGS agrees with Shepherd Miller, Inc. in questioning LLNL's analysis of the Chicken Springs fault system. The WSGS conducted a rapid field investigation on the Chicken Springs fault system in 1987. That investigation was not extensive enough to accurately determine a maximum credible earthquake for that system.

In 1988, Geomatrix, Inc. prepared two seismotectonic evaluation reports for large parts of Wyoming in order to provide guidance on the safety of dams for the U.S. Bureau of Reclamation. Using data supplied in those reports in addition to commonly used attenuation curves, Shepherd Miller, Inc. (1995) estimated a PGA (probabilistic) of 0.18g with a PE=10-5 for a random event. A PGA estimated at a PE=10-5 is very conservative.

Based upon the LLNL analysis, it appears that there is one Wyoming site that may be close enough to an active fault to result in deterministic PGAs at the site that are close to the probabilistic PGAs at an annual PE=10-4. Western Nuclear's Split Rock mill site, near Jeffrey City, is within 9.0 miles of the Green Mountain segment of the South Granite Mountain fault system. Based upon an analysis of the South Granite Mountain fault system conducted by Geomatrix, Inc. (1988), LLNL estimated that the site could have a PGA (deterministic) of 0.30g. LLNL also estimated a PGA (probabilistic) of 0.33g at an annual PE=10-4 for the site. Because there is no precise data available on the Green Mountain fault segment, there is reason to question the conclusions of LLNL. The Green Mountain fault segment of the South Granite Mountain fault system is of significance not only to the Split Rock mill site. but also to four additional sites that are within twenty-five miles of the fault trace. Kennecott's Sweetwater mill, American Nuclear's Gas Hills mill, Pathfinder's Lucky Mc mill, and Umetco's Gas Hills mill could all be affected by an activation on the Green Mountain fault segment. Because of this, available data on the fault segment are discussed in some detail below.

Geomatrix (1988) conducted basic field mapping on the Green Mountain fault segment. They estimated that the east-west trending fault segment is 14.9 miles (24 km) long, and from that inferred that if the entire segment activated, a magnitude 6.8 earthquake would result. There may be a problem with the magnitude determination, however. Geomatrix (1988) stated in their report that "The 10-km-long western part of the segment does not contain lineaments indicative of Quaternary faulting. This area is included as part of the Green Mountain segment because it is part of the same structural block". In other words, only 8.7 miles (14 km) of the entire fault showed evidence of Quaternary activity, which is supported by detailed mapping presented in the report. Using current formulas (Wells and Coppersmith, 1994) for estimating relationships between earthquake magnitude and fault rupture length, an 8.7-mile-long rupture length would result in a magnitude 6.2 earthquake, and a 14.9-mile-long rupture length would lead to a magnitude 6.7 earthquake.

In addition, approximately 2.5 miles (4 km) north of the 8.7-mile-long fault trace, Geomatrix mapped and described an east-est-trending lineament about 1.9 miles (3 km) long, composed of a series of scarps and vegetation lines. The exact relationship between the 1.9- and 8.7-mile-long fault traces was not addressed in the report. The significance of the short 1.9-mile-long segment and the rupture lengths of the faults in the area are of importance when estimating the seismic hazard at Western Nuclear's Split Rock mill site, however. The distance between the Split Rock mill and the 1.9-mile-long fault segment is approximately 6.5 miles (10.5 km). If it is assumed that a magnitude 6.75 earthquake originates in the near-vicinity of the short segment, the PGA (deterministic) at the mill would be approximately 0.26g, using ground motion curves generated by Campbell (1987). If it is assumed that a magnitude 6.75 earthquake originates on the 8.7-mile-long segment, which is 9 miles (14.5 km) from the mill, the PGA (deterministic) at the mill would be approximately 0.20g. Taking this analysis a step further, if a magnitude 6.2 earthquake originates near the short segment, the PGA (deterministic) at the mill would be approximately 0.20g. If a magnitude 6.2 earthquake originates on the 8.7-mile-long segment, the PGA (deterministic) at the mill would be approximately 0.15g. Without additional study of the Green Mountain fault segment, it is not possible to determine which set of estimates should be used. In any event, even if a PGA of 0.26g is applied to the Split Rock mill, it is 0.07g less than LLNL's PGA at an annual PE=10~. There does not appear to be a strong justification, however, to apply this worst case estimate to the site without additional study. If the PGA (deterministic) of 0.20g associated with a magnitude 6.75 earthquake that originates on the main segment of the fault is applied to the site, it would be comparable to the LLNL's probabilistic PGA of 0.18g at an annual PE=5x 10-4.

There are other criteria besides fault rupture length that can be used to estimate the magnitude of an earthquake resulting from activation of a fault. Those criteria, discussed in Wells and Coppersmith (1994) include rupture width, rupture area, and surface displacement. Unfortunately, accurate site-specific data for those criteria are not available for the Green Mountain fault segment. Downdip rupture widths are determined from analyzing the depths of earthquake aftershocks. Since no historic earthquakes have occurred or been studied on the fault segment, accurate widths have not been determined. Rupture areas are estimated by multiplying rupture lengths by rupture widths. Since rupture lengths on the Green

Mountain segment need to be accurately defined, and true rupture widths are not known, any estimates of rupture area on the fault segment are of limited value. Geomatrix (1988) did attempt to estimate earthquake magnitudes based upon the rupture width for the entire South Granite Mountain fault system and the rupture area for the Green Mountain segment, hoever, their estimates were not based upon any actual evidence. While their estimates may have some value as a screening tool, their limitations should be understood.

Average and maximum surface displacements per event can also be used to estimate the magnitude of an earthquake accompanying activation of a fault. Surface displacements per event are usually determined by an analysis of soils and bedrock in an exploration trench that is orientated at right angles to a fault scarp. While Geomatrix (1988) did excavate such a trench across the Green Mountain segment, they did not find the fault that formed the present scarp, although they did find evidence of an older zone of sheared bedrock. Geomatrix states that *"the faulting that formed the sheared bedrock zone but did not displace the overlying fluvial deposits probably pre-dated formation of the present scarp on the Q6g surface. The present scarp was most likely formed by a fault located lower on the scarp; this area was not trenched so existence of a different, younger fault strand has not been confirmed"*. In other words, the displacement per event for the fault that formed the current scarp was not accurately determined because the fault was not present in the trench. Geomatrix estimated the displacement per event, based upon limited data from other fault systems or segments in the Wind River Basin. Again, while the estimates may have some value as a screening tool, their limitations are significant.

On May 22, 1995, Gibbons prepared a report for Umetco Minerals Corporation titled *"Seismotectonic Stability East Gas Hills Site, Wyoming" (Gibbons, 1995)*. This report presents yet another method of seismic analysis with design recommendations to handle expected earthquakes. Gibbons estimated that the Green Mountain segment of the South Granite Mountain fault system is the most probable source of the maximum credible earthquake (magnitude 6.75) near the site. If that fault activates, Gibbons estimates that it should generate a mean PGA (deterministic) of 0.07g at the site. That figure is comparable to LLNL's estimate of 0.08g. LLNL estimated a PGA (probabilistic) of 0.18g at an annual PE=5x 10-4 and a PGA (probabilistic) of 0.33g at an annual PE=10-4 for the Umetco site. Both of these LLNL probabilistic estimates provide considerably larger PGAs at the site than those derived from the deterministic analyses discussed above.

Regardless of the approach taken with a probabilistic analysis, there are some inherent problems. The problems are especially apparent when general analyses are applied to specific sites. Unfortunately, if the seismic record is not extensive, and if few active faults are exposed at the surface, generalized probabilistic acceleration estimates may be all that are available. In such cases, they should be applied with caution and with an awareness of their limitations. This concern is presented on pages 10 and 11 of the LLNL study (Bernreuter and others, 1994):

> *"Because of the limited nature of this study and the lack of data, no attempt to perform an uncertainty analysis was made. Such uncertainty analyses are very important but very costly to perform properly. A poorly performed uncertainty analysis provides no information, Thus at best, this analysis for the random earthquake is only a simple estimate for the central value of the hazard. Its main use is to determine if a detailed study is needed, that is if the estimates for the ground motion are used for safety assessments."*

Unfortunately, the data used by LLNL are the data that are available. One of the most revealing statements made in the LLNL report summarizes the WSGS's concerns. On page 6, LLNL states the following:

> *"...because of the relatively low risk posed by the tailings piles, the choice of a PE level of 10-4 might be too conservative. For this reason estimates of the ground motion at 5xl0-4 level are also provided."*

The WSGS fully agrees with that statement.

U.S. Geological Survey's Probabilistic Acceleration Maps

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500, 1,000, and 2,500 year time frames. The USGS believes that 10,000-year return period ground motions are governed primarily by extremes of the uncertainty distributions, especially uncertainties in mean attenuation, rather than details of the source modeling. Source models for central and eastern Wyoming are uncertain because the seismic record is limited and there are few detailed studies on exposed active faults. On the other hand, 2,500-year return period ground motions can be estimated more reliably. As it turns out, the WSGS is in the process of revising draft versions of new probabilistic acceleration maps for the USGS. The 2,500-year PGAs on the new USGS maps compare rather well with the PGAs with an annual PE=5xl0-4 generated by LLNL, using distinctly different methodologies. It is interesting to note that the USGS is using a maximum credible earthquake with a magnitude of 6.5 for the upper limit of their analysis, while the LLNL is using a magnitude 6.25 event.

Conclusions

In today's economic and political climate, regulatory decisions that are going to incur costs for the public and private sectors must be well justified. In this regard, the above discussions have raised four significant issues:

1) The existing regulations refer only to capable faults, not hypothetical random earthquakes or probabilistic analyses. While regional probabilistic seismic hazard assessments do serve a useful purpose, they usually do not result in the same PGAs at a site near a capable fault as do analyses performed on that fault, and therefore should be used with caution. Probabilistic analyses are based upon analyses of active faults as well as random earthquakes. Most active faults in Wyoming have long recurrence intervals, which means that probabilistic analyses are going to be more strongly influenced by the hypothetical random earthquakes than by the active faults. For that reason, PGAs can significantly differ between regional probabilistic analyses and deterministic analyses on a specific fault. Analyses performed on a fault or on a fault system must be extensive enough to provide reliable data on recurrence intervals and the associated maximum credible earthquake. Fault systems need to be defined in enough detail that distances to mill tailings or other sites of concern can be accurately measured.

2) The 10-4 probability of exceedance is not well justified in an area with limited data. The application of such a PE to mill tailings sites in remote areas is even less justified. As stated by LLNL (Bernreuter and others, 1994):

> *"...because of the relatively low risk posed by the tailings piles, the choice of a PE level of 10-4 might be too conservative. For this reason estimates of the ground motion at 5xl0-4 level are also provided."*

3) The regulations provide for placing an earthen cover over the tailings so as to provide a reasonable assurance of controlling radiological hazards for at least 200 years, and up to 1,000 years. Impoundments are reclaimed with such gentle slopes, however, that most seismically induced failures should be shallow, and would not likely release radioactive material. Even if shallow failure were to occur, it is easily repaired, and the actual risk that would result from such an event is minimal. Should the earthen cover be breached, the sites are so remote and the environment is so arid that the most probable outcome would be the release of radon to the atmosphere.

4) The ground motion that has a 10% chance of occurring in 200 years has a 2,000-year return period. The probability of a 2,000-year event not occurring in 1,000 years is 65%, which appears to be a reasonable assurance of safety for even a 1,000-year design life. For the above reasons, using a 2,000-year period of analysis with a PE=5xl0-4 appears reasonable. Ground motions associated with a 2,000-year return period, while still conjectural, are more defensible than those associated with a 10,000-year return period.

Recommendations

For the remote mill tailings sites in Wyoming, there is not adequate justification for applying seismic design requirements based upon PGAs at an annual PE=10-4. An annual PE=5x10-4 is a more reasonable interpretation of the regulations as they apply to Wyoming. Furthermore, LLNL's values for PGAs at a PE=5xl0-4 are more consistent with values derived from other studies. The PGAs (probabilistic) at an annual PE=5xl0-4 are considerably larger than the PGAs associated with deterministic analyses on exposed active faults for most of the sites in Wyoming. For most sites, utilizing the probabilistic PGAs at an annual PE=5xl0-4 will provide for more rigid design standards and a greater degree of safety than would be achieved through the use of deterministic PGAs. Since the regulations make allowances for sites to have a 200-year design life, meaning that they are designed to withstand PGAs at a PE=5x10-4, the 200-year design life is the most appropriate and cost-effective for Wyoming sites.

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