Report To Pathfinder Mines Corporation

Seismological Characterization Options for the Lucky Mc Mill Tailings Site with Recommendation for Preferred Option

by

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Background

On February 28, 1996, the Wyoming State Geological Survey submitted a report to the U.S. Nuclear Regulatory Commission (NRC) titled "Recommendations Regarding Seismic Design Standards for Uranium Mill Tailings Sites in Wyoming". The report presented an analysis of the existing regulations or laws governing the seismic design requirements for uranium mill tailings sites, in addition to providing a critique of reference documents used by the NRC in their analysis of sites. In part due to that report, the NRC is in the process of evaluating the pertinent regulations. The report did not address the documents that the NRC uses to provide guidance to mines with sites needing reclamation.

The "Final Standard Review Plan" is the document that the NRC uses to guide the reclamation of uranium mill tailings sites. The review plan is meant to clarify federal regulations 10 CFR 40 Appendix A and 10 CFR 100 Appendix A. These are the federal regulations that were evaluated in the recommendations report, mentioned above. 10 CFR 40 Appendix A governs the reclamation of uranium mill tailings, and 10 CFR 100 Appendix A governs nuclear site criteria. The definition of a "capable fault" in 10 CFR 40 Appendix A is presented in 10 CFR 100 Appendix A.

The existing Final Standard Review Plan has three steps that are to be completed in order to generate a seismotectonic stability analysis of a site. The steps are as follows:

1) Determination of the Maximum Tectonic Province Earthquake
2) Identification of Capable Faults
3) Designation of the Maximum Credible Earthquake

The NRC has recently proposed amendments to 10 CFR 100 Appendix A, which could have an impact on the Final Standard Review Plan. The proposed amendments are addressed in the enclosed " Draft Regulatory Guide DG-1032". The term "capable fault", as used in the existing 10 CFR 100 Appendix A, is 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. The "capable fault" term in

10 CFR 100 Appendix A, will probably be changed to the term "seismic source", based upon changes suggested in the Draft Regulatory Guide. "Seismic source", as defined in the Draft Regulatory Guide, includes both "capable tectonic sources" and "seismogenic sources". The definition for "capable tectonic sources" in the Draft Regulatory Guide is very similar to the definition of "capable faults" in the existing regulations. "Capable tectonic sources" are usually specific active faults that can cause, or have caused, surface displacement at least once in the last 50,000 years, or recurrently over the last 500,000 years. The new term, "seismogenic source", is a portion of the earth that has an earthquake potential that is assumed to be uniform, but will not usually generate earthquakes that cause surface displacement. In other words, a "seismogenic source" is an area where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. If the seismic record is not extensive enough to define those buried faults, the earthquake distribution is often considered to be random. In this regard, "floating" earthquakes are associated with "seismogenic sources". Earthquakes in such areas are called "floating", because they can theoretically occur anywhere within that area of uniform earthquake potential. Unfortunately, that may not be true, as all earthquakes are associated with specific faults. As mentioned above, however, you have to assume that it is true if all buried faults have not been identified.

It is possible that the new definitions in the Draft Regulatory Guide will have an influence on the Standard Review Plan, but it is uncertain how the Standard Review Plan will be changed to accommodate the new definitions. As a result of this uncertainty, I have generated a series of options to assist Pathfinder Mines Corporation in doing a seismologic characterization of the Lucky Mc site, along with my opinion as to how I feel each option will be received by the NRC. I am not presenting a probabilistic seismic hazard option, as I feel that it is beyond what is required, and would be both time consuming and costly to generate. The options that are presented are as follows:

1) Deterministic Analysis on Nearby Active Faults
2) "Floating Basin Earthquake" Analysis for a Tectonic Province Defined by the Wind River Basin
3) "Floating Basin Earthquake" Analysis for a Regional Tectonic Province

<u>Deterministic Analysis</u>

There are three exposed active fault systems defined in the vicinity of the Wind River Basin, the South Granite Mountain fault system, the Stagner Creek fault system, and the Cedar Ridge/Dry Fork fault system. The Green Mountain segment of the South Granite Mountain fault system is closest to the Lucky Mc site, and will be used to represent the seismic hazard potential of that fault system.

The Green Mountain segment of the South Granite Mountain fault system and the Stagner Creek fault system were both identified as being capable of generating earthquakes with magnitudes as large as 6.75 (Geomatrix, 1988a, 1988b). A recent evaluation of the Green Mountain segment (Case, 1996), however, indicates that the segment is most likely capable of generating either a magnitude 6.2 or a magnitude 6.7 earthquake, depending on the estimated rupture length used for the fault. Geomatrix (1988a) estimated a recurrence interval ranging from 8.000 to 20,000 years for the Stagner Creek fault system, and from 2,000 to 6,000 years for the Green Mountain segment of the South Granite Mountain fault system (Geomatrix, 1988b). Both of these faults qualify as either capable faults or as capable tectonic sources.

The Cedar Ridge/Dry Fork fault system was also investigated by Geomatrix (1988 a). They found "only one locality with fault-related displacement of a Quaternary pediment surface", and determined that the most recent surface rupture event occurred during the early to middle Pleistocene. It is doubtful that this fault would classify as either a capable fault or a capable tectonic source.

Based upon the information available on the exposed active faults, it is suggested that only the Green Mountain fault segment of the South Granite Mountain fault system be analyzed (deterministically) to estimate what level of ground motion would result at the Lucky Mc site if the fault activates. The reasons for using the Green Mountain fault segment, rather than the Stagner Creek fault, are that the segment is closer to the site than the Stagner Creek fault system, the recurrence interval is shorter, and there are a range of magnitude values (6.2-6.75) that can be used and compared. A magnitude 6.75 earthquake on the Green Mountain segment should result in greater accelerations at the site than would a magnitude 6.75 earthquake on the Stagner Creek fault system.

The Lucky Mc site is approximately 30 miles (48.3 km) from the primary trace of the Green Mountain fault segment of the South Granite Mountain fault system. Based upon that distance, if the fault activates and generates a magnitude 6.75 earthquake, the expected horizontal ground acceleration at the Lucky Mc site would be approximately 0.056g. If activation on the fault generates a magnitude 6.2 earthquake, the expected horizontal ground acceleration at the Lucky Mc site would be approximately 0.04g. These estimates are derived by using attenuation relationships developed by Campbell (1987). The Final Standard Review Plan (U.S. Nuclear Regulatory Commission, 1993) suggests using similar attenuation relationships developed by Campbell (1981). Campbell's 1987 relationships were developed as part of a study of the Wasatch fault in Utah, and are more current than those derived for his 1981 report.

In summary, peak ground accelerations, derived from a deterministic analysis of the Green Mountain fault segment of the South Granite Mountain fault system, range from 0.04g - 0.056g at the Lucky Mc site. In my opinion, such an analysis should meet the requirements of the existing federal regulations (10 CFR 40 Appendix A and 10 CFR 100 Appendix A) for the reclamation of mill tailings sites, especially since the recurrence interval on the Green Mountain fault segment ranges from 2,000 to 6,000 years. Based upon the existing Standard Review Plan, however, I do not feel that the NRC will be satisfied. The deterministic analysis presented above appears to only satisfy one step of the Seismotectonic Stability portion (Section 1.3.5) of the Review Procedures (Section 1.3) Section in the Final Standard Review Plan. That step, "Step 2 - Identification of Capable Faults", is on page 13 of the June 22, 1993 version of the Final Standard Review Plan.

Floating Basin Earthquake Based Upon a Tectonic Province Defined by the Wind River Basin

Although the federal regulations that relate to the reclamation of uranium mill tailings sites (10 CFR 40 Appendix A and 10 CFR 100 Appendix A) do not require a "floating" earthquake analysis, the Final Standard Review Plan does. Step 1 (Determination of the Maximum Tectonic Province Earthquake) of the Seismotectonic Stability portion (Section 1.3.5)) of the Review Procedures (Section 1.3) section in the Final Standard Review Plan requires that " For those earthquakes not associated with known tectonic structures (i.e., "floating" earthquakes) the largest event that has occurred in each of the tectonic provinces expected to influence the seismicity of the site should be identified". In other words, the largest event that has occurred and has not been tied to a specific fault system, or related structure, should be considered to be the "floating" earthquake for the tectonic province. The Final Standard Review Plan then defines the site-to-source distance for "floating" earthquakes as 15 kilometers. Attenuation relationships between earthquake magnitude and distance are then applied to the "floating" earthquake and the 15 kilometer site-to-source distance.

With limited data, there are always some difficulties in accurately defining the extent and boundaries of a tectonic province. The problem is compounded when trying to define boundaries in areas with relatively low levels of historic seismicity.

Dr. J.F. Gibbons (1995) in a report for Umetco Minerals Corp. titled "Seismotectonic Stability East Gas Hills Site, Wyoming", presented a case for considering the Wind River Basin as a distinct tectonic province. Gibbons literally interpreted the following statement in the Final Standard Review Plan - "For those earthquakes not associated with known tectonic structures (i.e. "floating" earthquakes) the largest event that has occurred in each of the tectonic provinces expected to influence the seismicity of the site should be identified". He assumed that the largest "floating" event was the largest historic event, which would be a magnitude 4.8 earthquake that occurred on April 22, 1973, in the southern portion of the Wind River Basin.

Using the approach identified by Gibbons (1995), the approximate peak ground acceleration that would be felt at the Lucky Mc site if a magnitude 4.8 earthquake occurred 15 kilometers from the site, would be in the 0.06g range.

It is hard to defend using a magnitude 4.8 earthquake as the largest "floating" event that has occurred or could occur in the Wind River Basin. While it is the largest earthquake to have occurred in the last 120 years, it may not have been the largest earthquake to have occurred in the last 35,000 - 50,000 years, and it most likely is not the largest earthquake that will occur in the future. In cases such as this, geologists usually look at similar tectonic provinces in the region, and determine what magnitudes of earthquakes have occurred or could occur in those provinces. That data is then extrapolated back to the area of concern.

The U.S. Geological Survey identified similar tectonic provinces in a report (Algermissen and others, 1982) titled "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States". In that report, the Wind River Basin was classified as a distinct tectonic province, along with most other significant Laramide-age basins in the region. The U.S.

Geological Survey, however assigned a "floating" earthquake with a "maximum magnitude" of 6.1 to all of those basins. Using attenuation relationships developed by Campbell (1987), a magnitude 6.1 earthquake at 15 kilometers from the Lucky Mc site would generate a horizontal acceleration of approximately 0.14g at the site.

Based upon conversations that I have had with the NRC staff, I don't feel that there is much chance of them accepting a "floating" earthquake with a magnitude of 4.8. You may, however, want to determine which data the NRC applied to their review of the Umetco site. Gibbons (1995) did suggest that a ground acceleration of 0.07g be applied to that site. The 0.07g acceleration is only half of the acceleration that would be derived if the U.S. Geological Survey data, mentioned above, were used. In my opinion, I feel that the U.S. Geological Survey data may be acceptable to the NRC.

Floating Basin Earthquake for a Regional Tectonic Province

As mentioned in the previous section, it is difficult to accurately define tectonic provinces when there is a limited historic record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Small-event data can serve to distinguish one province from another. When the above conditions exist, it is common to delineate larger, rather than smaller, tectonic provinces. The U.S. Geological Survey started to take this approach in the previously mentioned report by Algermissen and others (1982).

Lawrence Livermore National Laboratory (Bernreuter and others, 1994) suggested using a more extensive tectonic province for central and south-central Wyoming. This "Central Seismic Zone" is within an even larger tectonic province, defined by Geomatrix (1988), called the "Wyoming Foreland Structural Province". The "Wyoming Foreland Structural Province" is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, latitude 40° North on the south, and latitude 45° North on the north. Lawrence Livermore National Laboratory (LLNL) defined their "Central Seismic Zone" by 109.7° West longitude on the west, 105.5° West longitude on the east, 41.5° North latitude on the south, and 43.0° North latitude on the north. LLNL determined that their "Central Seismic Zone" was distinct from the "Wyoming Foreland Structural Province" because it has a higher seismicity rate than the entire Foreland province, and it has exposed active faults within its boundaries (Bernreuter and others, 1994).

Geomatrix (1988) estimated that the largest "floating" earthquake that may occur in the "Wyoming Foreland Structural Province" would have a magnitude in the 6.0 - 6.5 range, and used a magnitude 6.5 earthquake in their analysis. A magnitude 6.5 earthquake located 15 kilometers from the Lucky Mc site would generate a horizontal acceleration of approximately 0.17g at the site.

The average of the range of magnitudes suggested by Geomatrix for a "floating" earthquake in the "Wyoming Foreland Structural Province" is magnitude 6.25. A magnitude 6.25 "floating" earthquake is what LLNL suggested for their "Central Seismic Zone". A magnitude 6.25

earthquake located 15 kilometers from the Lucky Mc site would generate a horizontal acceleration of approximately 0.15g.

The NRC would most likely accept a plan that incorporates a "floating" earthquake with a magnitude of 6.25 that is located 15 kilometers from the Lucky Mc site, resulting in a horizontal acceleration of 0.15g. At the present time, there is not strong justification for suggesting that a magnitude 6.5 earthquake be used for a "floating" earthquake in the central part of Wyoming.

Seismic Coefficients for Slope Stability

The Final Standard Review Plan (U.S. Nuclear Regulatory Commission, 1993) requires the analysis of "all natural and man-made earth and rock slopes whose failure, under any of the conditions to which they could be exposed throughout the design period, could adversely affect the integrity of the remedial action plan". This would, of course, include the final design slopes of the mill tailings piles. A portion of the slope stability analysis would include an investigation of the effects of the design earthquake on the natural and man-made slopes mentioned above.

The Final Standard Review Plan states that "The dynamic stability of slopes will be reviewed considering the maximum credible earthquake and potential site amplification of ground motions". The report also states that "Pseudostatic analyses in lieu of the dynamic analyses are acceptable if the strength parameters used in the analyses are conservative, the materials are not subject to significant loss of strength and development of high pore pressures under dynamic loads, and the resulting minimum factor of safety suggests an adequate margin. The design seismic coefficient to be used in the pseudostatic analysis should be either 67 percent of the peak acceleration of the MCE at the foundation level of the tailings pile or 0.10, whichever is greater. If the design seismic coefficient is greater than 0.20, then the dynamic stability investigation may be augmented by other appropriate methods". A similar approach is suggested by the U.S. Department of Energy (1989) in their report titled "Technical Approach Document, Revision II". This report provides guidance for the reclamation of uranium mill tailings sites that fall under the jurisdiction of the Department of Energy's Uranium Mill Tailings Remedial Action (UMTRA) Project. The design seismic coefficient at the Lucky Mc site should be 0.10g, which is 67% of 0.15g, if the above conditions are met. If the pile materials are subject to significant loss of strength and development of high pore pressures under dynamic loads, however, the design seismic coefficient of 0.10g may not be valid.

Summary and Recommendations

There appear to be some differences between the federal regulations governing the reclamation of uranium mill tailings sites and the Final Standard Review Plan that the NRC uses to provide guidance for reclamation. The existing federal regulations, 10 CFR 40 Appendix A and 10 CFR 100 Appendix A, address capable faults and their relationships to the reclamation sites. The capable fault that is nearest to Pathfinder's Lucky Mc site, the Green Mountain fault segment of the South Granite Mountain fault system, is capable of generating earthquakes as large as magnitude 6.75. If a magnitude 6.75 earthquake is generated on that fault, the Lucky Mc site may be subjected to a 0.06g ground acceleration. This is based upon a deterministic analysis. Upon first glance, it would appear that this is the acceleration that should be used for design purposes at your site.

The deterministic approach that was taken with the Green Mountain fault segment and the Lucky Mc site, however, satisfies only a portion of the NRC's requirements in their Final Standard Review Plan. The Final Standard Review Plan also requires that a "floating" earthquake be assigned to the tectonic province that contains a mill tailings site. The largest ground acceleration derived from either the deterministic approach or the "floating" earthquake approach, must then be applied to the site under consideration.

Based upon my analysis, I feel that the NRC will accept an approach that utilizes a "floating" earthquake in the magnitude 6.1-6.25 range. This size of earthquake would lead to ground accelerations in the 0.14 - 0.15 range, if the earthquakes occur 15 kilometers from the Lucky Mc site. This approach was utilized in the reclamation plan for American Nuclear Corporation's Tailings Pond #2 (Shepherd Miller, Inc. and AVI, p.c., 1996).

Since the site accelerations from a "floating" earthquake with a magnitude of 6.25 located 15 kilometers from the site are greater than those from a magnitude 6.75 earthquake on the Green Mountain Segment of the South Granite Mountain fault system, the floating earthquake will probably be used by the NRC in their analysis. As a result, the site may be subjected to peak horizontal ground accelerations in the 0.15g range, and the design seismic coefficient for slope stability analyses at the site should be 0.10g. Other site factors, however, may have an effect on both the peak horizontal ground acceleration and the design seismic coefficient values. If the slopes of a tailings pile or the area under a tailings pile are subject to liquefaction when peak ground accelerations are in the 0.15g range, the design seismic coefficient of 0.10g may not be valid. Local site conditions can also have an effect on the peak horizontal accelerations that may occur at a site.

It is your option, of course, to use any of the scenarios that I have presented. My above recommendation is based upon what I feel will have the greatest chance of success with the NRC.

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