TECTONIC STABILITY ASPECTS OF HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY SITING AND LICENSING*

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ABSTRACT

Tectonic stability implies the relative absence of tectonic activity, such as earthquakes, volcanism, uplift and subsidence. Long-term tectonic stability is an important consideration for licensing of a mined geologic repository for containment of high-level radioactive waste. Stability is needed to insure that the repository system is not breached in such a way as to shorten the flow path or to increase the rate of transport of radionuclides to the biosphere (accessible environment). The effects of tectonic activity that should be considered during siting, design and licensing of a repository include: (1) changes in the groundwater regime by ground movement, (2) disruption of the repository and design features by vibratory ground motion during seismic events, (3) rupture of natural and engineered barriers by faulting, and (4) disruption of the repository or hydrologic regime by volcanic activity. The potential for each of these effects is dependent upon the tectonic environment in the area of a repository site. Careful siting investigations, detailed site characterization studies, and design studies are required to minimize the potential problems from any of these tectonic activities.

INTRODUCTION

The objective of a high-level radioactive waste repository is to assure safe containment of the waste for long periods of time (about 10,000 years). This requires the demonstration of a relatively stable tectonic environment in the repository area for a long period of time. Therefore, geologists must use methods that allow long-term prediction of future tectonic stability. For typical engineered structures, such as nuclear and hydroelectic power plants, geologists commonly predict future geologic and tectonic activity for only 50 to 100 years. For high-level radioactive repository siting and licensing, however, predictions must be made for a period of thousands of years. For this extended time frame, predictions require evaluation of the long-term geologic record extending through the Quaternary Period (past 2 to 3 million years), using data from numerous geologic disciplines, including geomorphology, stratigraphy, structural geology, tectonics, seismology, and volcanology. Such evaluations allow the development of probabilistic estimates of future tectonic behavior. Because of the increasing uncertainties with increasing periods of time for such predictions, a high degree of conservatism is required when such predictions are used to model parameters that can affect repository performance and design considerations.

Although important, the assessment of the stability of the geologic environment is only one of the considerations that must be taken into account in the overall risk assessment for a repository. Each repository will operate as a system with multiple and redundant barriers providing isolation of hazardous materials from the accessible environment. In addition to the geologic environment, other barriers may include the waste form itself, the waste canister, the overpack, and emplaced backfill used to control water mobility and to provide retardation of radionuclide migration. Although it may not be possible to assure that containment can be maintained by any single barrier, acceptable containment can be assured for very long periods of time using the system of multiple barriers.

During the repository siting and site confirmation process, ground movement, vibratory ground motion, faulting, and volcanism must be considered. Each of these tectonic factors would be evaluated independently to determine their potential effects on repository performance. Also, the level of risk resulting from each factor would be assessed. This evaluation would require analysis of various containment failure scenarios for each factor. Scenarios that have a low probability of occurrence would not require further evaluation for site confirmation. If the level of risk for any reasonable scenario is unacceptable, the site would be eliminated from further consideration. For example, if it is determined that the probability of fault rupture through the repository and the resultant migration of radionuclides to the accessible environment is unacceptably high, the site would not be considered further for waste emplacement.

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If all reasonable failure scenarios are considered improbable or if the level of risk is considered acceptably low for all factors, the effects of each failure mode or risk factor would be assessed and modeled to determine their potential impact on repository performance. Potentially adverse effects may require design considerations and engineered safety features to mitigate any adverse conditions that could affect repository performance. The following is a discussion of the significance of the tectonic factors that must be considered throughout the siting, development, and licensing process for each repository site. The factors could have both direct and indirect effects on the transportation of radionuclides to the accessible environment.

GROUND MOVEMENT

Vertical ground movement, including uplift, subsidence or tilting, resulting from tectonic activity are phenomena which could have both direct and indirect effects on repository performance. An extremely high rate of uplift throughout the containment period of a repository could result in high rates of erosion and potentially expose waste to the biosphere by exhumation. However, the rate of uplift would have to be extremely high and the movement would have to continue for long periods of time. Although the probability of such extreme activity is very low for any given geologic setting, tectonic uplift of this magnitude would be readily apparent during the siting phase since such uplift would be associated with widespread faulting, seismicity, and rapid erosion. Therefore, the repository sites that could have the potential for such large magnitude uplift would be eliminated from consideration due to other adverse tectonic conditions.

Changes in the groundwater flow regime could be an indirect effect resulting from smaller magnitude ground movements that result from tectonic activity. Potential changes in the groundwater regime as a result of uplift, subsidence, or tilting are important considerations because transport of radionuclides by groundwater is commonly considered the most likely mode for waste to reach the accessible environment. The effects of such ground movements on the hydrologic regime must be modeled and considered in repository design and performance evaluation. The likelihood of such effects can be minimized through careful consideration and interpretation of trends in the recent geologic record.

VIBRATORY GROUND MOTION DURING SEISMIC EVENTS

Vibratory ground motion can result from both tectonic earthquakes and volcanic activity. Vibratory ground motion needs to be considered only during the preclosure period of repository operations, when the repository is open and waste can be emplaced and retrieved. Vibratory ground motion has no significant impact on the repository after backfilling and final closure. The long-term effects on repository performance of faulting and fracturing of rock, resulting from seismic events, are discussed in the next section. The concern associated with vibratory ground motion is therefore limited to the direct effects on operations: hazard to onsite personnel, damage to surface and subsurface facilities, and disruption of emplacement operations, including disruption of the required retrieval option for waste prior to final closure. In order to minimize potential damage to surface and subsurface facilities, such facilities must incorporate seismic design to ensure safety. Seismic design parameters can be determined for these facilities using existing deterministic and probabilistic methods.

Subsurface openings can potentially fail if vibratory ground motion is severe enough to induce movement along pre-existing fractures or to rupture the host rock or emplaced repository lining. However, limited empirical observation of dynamic subsurface seismic motion and modes of damage to underground openings indicates that the intensity and amplitude of shaking below ground are significantly less than on the ground surface. Total collapse of a tunnel or mine in rock due solely to seismic events has not been recorded. The lack of significant damage in underground openings is probably due to a combination of factors, including the decay of surface wave amplitude with depth, and the increase of rock competency with increasing depth. Therefore disruption of a deep repository by vibratory ground motion during seismic events is not considered a major problem especially in areas with low earthquake activity.

FAULTING

The direct effects of faulting result from fault rupture through or near a repository and its natural and engineered containments. Faulting and related fracturing could potentially disrupt or breach all natural and engineered barriers to radionuclide migration and provide pathways for rapid movement of waste to the accessible environment. Uplift due to faulting could also result in accelerated erosion and the potential for exhumation. Therefore, the potential for faulting and related fracturing must be fully evaluated during the siting and site confirmation stages. As noted above, if an unacceptable potential exists for rupture by faulting, the site would not be acceptable or licensable.

A scenario also may be considered in which faulting could occur in the vicinity of a repository during the containment period, but not be severe enough nor close enough to require exclusion of the site from further consideration. In this case, indirect effects such as perturbation of the hydrologic regime must be considered. Development of faults and fractures could change pore pressures and permeability causing resultant changes in the groundwater flow paths and rates. Unfortunately, the magnitude and significance of these changes are not well known, so that a high level of conservatism must be allowed for in the analysis of groundwater flow models and in the design of engineered barriers.

VOLCANIC ACTIVITY

Volcanic activity could have both direct and indirect effects on repository performance. Direct effects could occur either during the preclosure period or after final closure. During the preclosure period, volcanic activity could disrupt both the emplacement operations and the retrieval option. Disruption could result from intrusion of magma into the repository host rock or from significant ash fall on surface facilities from distant eruptions. Furthermore, magma could physically transport the waste closer to the accessible environment either before or after final closure. The probability of possible volcanic activity in the vicinity of a repository must therefore be determined. Additionally, a determination of the possible types of eruptions must be made to predict the potential disruptive character of the volcanic activity.

The indirect effects of volcanism on repository performance are a result of thermal disturbance that could affect the retardation characteristics of the host rock or alter the groundwater flow regime. The heat generated by intrusion of magma near a repository could potentially alter the emplaced buffer or host rock, producing phase changes or dewatering, so that the retardation characteristics would no longer be sufficient to meet the repository performance standards. The heat from a nearby intrusion might also result in convective groundwater flow which could increase the groundwater flow rate or alter the flow path. Although the probabilities of these scenarios are low, such considerations are necessary if the potential exists for heating by magmatic activity during the period of containment. Careful consideration of the recent geologic record during site selection should minimize the probability of any volcanically related effects on repository performance.

SUMMARY

Tectonic factors must be considered in all phases siting and licensing of high-level radioactive waste repositories. The potential for ground movement, vibratory ground motion, faulting, and volcanism must be considered as part of the overall risk assessment for a given site. In the evaluation process, failure scenarios are developed for each factor and the effects on containment evaluated. Only those sites whose failure scenarios have a non-negligible probability of occurrence would be considered further. If the level of risk for any reasonable scenario is unacceptable, the repository site would be eliminated from further consideration.

Ground movements, including uplift, subsidence, and tilting, can have direct and indirect effects on repository performance. The one major direct effect, uplift and resulting exhumation of the waste, is, however, very improbable since sites subject to such high rates of movement would be eliminated from further consideration. The indirect effects of smaller magnitude ground movement have a higher probability of occurrence. Changes in the groundwater regime as a result of uplift, subsidence, and tilting must be considered throughout the siting and licensing process if the potential for ground movement exists.

Vibratory ground motion during seismic events has primary significance only during the preclosure period of repository operations. Additionally, only the direct effects related to disruption of emplacement operations and risk to personnel need be considered. Because damage to underground openings is typically less significant than at the ground surface, disruption of a repository by vibratory ground motion is not considered a major problem, especially in areas with low seismicity.

Rupture by tectonic faulting could have both direct and indirect effects on repository performance. Faulting and fracturing through the repository could disrupt or breach natural or engineered barriers to radionuclide migration or cause uplift and lead to exhumation. The indirect effects of fracturing in the area around the site could alter the hydrologic regime. A site that has an unacceptable potential for faulting at the repository would be eliminated from further consideration. Careful analysis of indirect effects of faulting on groundwater flow would be required for sites in which faulting could occur in the vicinity of the repository.

Volcanic activity could also have both direct and indirect effects on repository performance. Direct effects are disruption of the repository by instrusion of magma into or through the repository or by significant ash fall on surface facilities from distant eruptions. Indirect effects resulting from thermal disturbances could affect hydrologic or geochemical parameters. The site would be eliminated from further consideration if the calculated risks from either direct or indirect effects are unacceptable.

Analysis of these tectonic factors is required for all high-level waste repository siting and development activities. The licensing process requires that the associated failure scenarios be modeled and assessed so that repository performance during the containment period can be reasonably assured.