DRAFT SITE TECHNICAL POSITION

The Gibson Dome Waste Isolation Project Site

by

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BACKGROUND AND INTRODUCTION

In its review of an application for a Construction Authorization for any geologic repository, the NRC staff will make a determination as to whether the site and design presented in the application satisfy the technical criteria of 10 CFR Part 60. The staff's determination will depend on whether a number of technical questions concerning groundwater flow, geochemical retardation, waste form and waste package, geologic and seismo-tectonic stability, and facility design have been adequately addressed. During the process of Site Characterization, the DOE performs the laboratory and field investigations that develop the information needed to address these basic technical questions. Prior to shaft sinking the DOE must make its Site Characterization Plan (SCP) available for comment by the NRC, the state, and the general public.

The Nuclear Waste Policy Act of 1982 has established an accelerated schedule for site characterization and selection. The Act requires the DOE publication of a SCP at an early stage of the process. In planning of any site characterization, it is essential that site characterization activities be organized so as to make possible a determination of whether the site is acceptable. A relationship between technical issues addressed by site characterization activities and the performance of the site should be established as a basis for the plans.

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This document establishes the NRC position as to the essential technical questions (specific issues) relevant to geology/geologic stability at the Gibson Dome Waste Isolation Project (GIDWIP) site. Future site Technical Positions (STP) relevant to geology/geologic stability will address both potential NRC staff concerns regarding selected specific issues and acceptable technical approaches for addressing those specific issues.

Terminology used by NRC staff to describe issues may require clarification. A site issue is defined as a question about a specific site that must be answered or resolved to complete licensing assessments of the site and design suitability in terms of 10 CFR 60. Site issues are not necessarily controversial questions. Site issues can be divided into performance issues and specific issues.

Performance Issues are broad questions concerning both the operational and long-term performance of the various elements of the overall geologic repository system (e.g., waste form, waste package, geologic setting). Performance issues are derived directly from performance objectives in 10 CFR 60 (including environmental objectives of 10 CFR 51). Development of performance issues for a geologic repository is explained in detail in Appendix C of NUREG-0960, "Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project", March 1983.

Specific Issues are, generally, questions about conditions and processes (information needed) that must be considered in assessing the performance issues. Therefore, performance issues include the integration of numerous specific issues thus establishing the relationship between specific issues discussed in this Site Technical Position and the performance objectives of 10 CFR 60.

Performance issues for a geologic repository, as developed in NUREG-0960 are:

1. How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?
2. How do the design criteria and conceptual design accommodate the retrievability option?
3. When and how does water contact the backfill?
4. When and how does water contact the waste package?
5. When and how does water contact the waste form?
6. When, how, and at what rate are radionuclides released from the waste form?
7. When, how, and at what rate are radionuclides released from the waste package?
8. When, how, and at what rate are radionuclides released from the backfill?
9. When, how, and at what rate are radionuclides released from the disturbed zone?
10. When, how, and at what rate are radionuclides released from the farfield to the accessible environment?
11. What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?
12. Have the NEPA Environmental/Institutional/Siting requirements for nuclear facilities been met?

Because geology/geologic stability effects both pathways for radionuclide migration and repossitory design, information on the geologic setting collected during site characterization at GIDWIP will be part of the total repository system information needs of the NRC staff required to assess the performance issues. Specific issues identified in the following section indicate in a broad but complete manner, information on the geology/geologic stability at GIDWIP needed by the NRC staff to assess adequately the performance issues. The sequential order in which issues are identified should not be interpreted as the relative order of importance.

The following technical issues have been identified as questions that should be investigated and assessed for the regional seismo-tectonic setting. The questions are also identified for each fault that affects the siting and design of underground repositories and their ancillary structures from considerations to final implacement operation.

1.0 Geology

1.1.0 Faults

1.1.1 What is the origin of the Shay graben?

1.1.2 What is the age of last motion, sense of movement, and amount of throw on the bounding faults and faults within the graben?

1.1.2.1 Do the faults offset the Quaternary deposits in the area northeast of the Abajo Mountains?

1.1.3 What is the maximum credible earthquake which could result from this system?

1.1.3.1 What is the significance of the deep (32-35 km) earthquakes associated with the study graben in February 1983?

1.1.4 How does the Shay Graben fit into a tectonic model(s) of the Colorado Plateau?

1.1.5 Does the Shay Graben or other faults parallel the trend of any geophysical anomaly?

1.1.6 What is the origin of the Salt Creek-Bridger Jack fault system?

1.1.6.1. Does this fault system extends into the Davis-Lavender Canyon area?

1.1.6.2 What is the maximum creditable earthquake likely to be associated with this system.

1.1.6.3 What is the relation between the Salt Creek-Bridger Jack System and the Shay graben system?

1.1.7 What is the underlying origin of the Needles Fault Zone

1.1.7.1 How does the Needles Fault Zone relate to the Meanders anticline?

1.1.7.2 What is potential for eastward migration of the Needles Fault Zone into respository area?

1.1.8 Is there currently activity on Uncompahgre/Paradox Basin fault zone?

1.1.9 What is potential for westward faulting along the north extension of the Combs Ridge Monocline?

1.1.10 What is the possibility of the existence of presently unrecognized fault activity in the area?

1.1.11 How have faults affected the hydrologic regime in the Paradox Basin?

1.11.1.1 What effect on salt dissolution has resulted?

1.1.12 What is (are) the cause(s) of any Quaternary faults?

1.1.13 How has faulting affected stratigraphy?

1.2.0 Folds

1.2.1 What is origin of Gibson Dome?

1.2.1.1 What is the potential for salt flowage, disolution and or collapse at the Gibson Dome?

1.2.2 What is origin of Meanders anticline, why is its axis trend perpendicular to most other anticlines in the Paradox basin?

2.0 Seismicity and Design Earthquakes

2.1.1 Has there been seismic activity on Shay Graben zone subsequent to February 1983?

2.2.1 Are there any northwest trending structures near the repository site which may be subject to normal fault motion as postulated to have occurred at Capitol Reef National Monument (Humphrey and Wong, 1983)

2.3.1 What are the design earthquakes for the Site?

2.3.2 What are the sources or source areas for earthquakes which could produce the maximum accelerations at the site?

2.3.2.1 What is the probable size (magnitude) of the largest earthquake that can be expected from sources or source areas that could affect the site?

2.3.2.2 What is the cause and magnitude, moment magnitude, or size of the largest earthquakes to be expected in the siting region, for which there is no evidence for seismogenic structures?

2.3.2.3 Can segmentation be used on sources (active faults) to determine maximum earthquake size?

2.3.2.4 What criteria are used to establish the earthquake recurrence intervals of active faults?

2.4.1 What attenuation do travel paths from earthquake sources and source areas to the site have?

2.4.1.1 Does the faulting mechanism (strike-slip vs. normal) affect the attenuation on travel paths?

2.5.1 What are the geologic and topographic focusing effects for seismic waves at the site?

2.5.2 What hazard exists at the site from surface to respository depths for aseismic deformation?

2.5.2.1 What deformation is possible as a result of salt solution?

2.5.2.2 What deformation is possible as a result of lateral migration of salt?

2.5.2.3 Do other types of surface to repository depth aseismic deformation present a hazard to the site?

2.6.1 What are the sources or source areas for eartnquakes which might cause other seismically related hazards in the site vicinity, e.g. landslides, lateral spreads and liquefaction of access roads and rail spurs?

2.6.2 What are the sources or source areas for earthquakes which might cause surface/near surface rupture at the site?

2.7.1 Does seismicity associated with isostatic adjustment pose a hazard to the site?

2.8.1 Does seismicity associated with volcanic processes pose a hazard to the site?

2.9.1 What is the seismic hazard at the site during construction vs. operation and long term storage?

3.0 Stress

3.1.1 What is the magnitude and orientation of in situ stress on both a local and regional scale?

3.2.1 Can seismotectonic processes adversely affect the site in non-seismic ways, e.g. stress buildup causing spalling or plastic flowage of excavations, walls, or rise of water table?

4.0 Igneous activity

4.1. What vol--nic processes pose a hazard at the site?

5.0 Tectonics

5.1 What is (are) the conceptual tectonic model(s) for the site region?

5.1.1 How does the Colorado Plateau Province relate to tne bordering tectonic provinces?

5.1.2 How does the behavior of the North American-Pacific Plate boundary affect the Colorado Plateau?

5.1.3 How does the geological, geophysical and seismological data fit the model(s)?

5.1.4 What changes in the present tectonic setting are possible?

5.1.4.1 Does eastward migration of Basin and Range type faulting pose a hazard to the site?

5.2 What effects will tectonics have on the mobilization and/or migration of salt?

6.0 Salt Migration and Dissolution

6.1.1 Is diaperisam of salt a potential problem in Gibson Dome area?

6.1.2 Can faults in addition to those associated with diapiric structures develop in the overlying country rock as a result of flowage in the salt?

6.1.3 What discontinuities are due to the behavior of salt?

6.1.4 What structures have resulted from salt flowage?

6.1.5 When has significant salt movement occurred and what event(s) caused this?

6.1.6 Is dissolution of salt in repository area a potential problem?

6.1.6.1 What are the rates and directions of dissolution presently occurring, especially in the Lockhart basin?

7.0 What are the probabilities and nature of human-induced changes that would affect repository performance?

7.1 What is the probability that methane leakage from host and adjacent rocks could affect repository performance?

7.2 What would be the effect on the repository of changes in the groundwater system resulting from repository construction?

7.2.1 What is the probability of onset or increase in dissolution within the host rock?

7.3 What is the probability of seismicity due to facility construction and/or operation?

7.3.1 What is the probability of induced seismicity due to waste emplacement?

7.3.2 What is the probability of seismicity caused by thermal emissions from waste canisters?

7.4 What is the probability of brine migration due to waste emplacement?

7.4.1 Could brine migration result in collapse structures in overlying rocks that could lead to introduction of fresh groundwater and large scale dissolution of salt?

7.5 What would be the effect on the repository of future mineral or petroleum extraction in the area?

1.0 Geology

1.1.0 Faults

1.1.1 What is the origin of the Shay graben?

1.1.2 What is the age of last motion, sense of movement and amount of throw on the bounding fault and faults within the graben?

1.1.2.1 Do the faults offset the Quaternary deposits in the area northeast of the Abajo Mountains?

1.1.3 What is the maximum credible earthquake which could be associated with this system?

1.1.3.1 What is the significance of the deep (32-35 km) earthquakes associated with the study graben in February 1983?

1.1.4 How does the Shay Graben fit into a tectonic model(s) of the Colorado Plateau?

The Shay Graben is located approximately eight miles southeast of the candidate area. This ENE trending fault system had four small (M_L = 2.1 and less), but very deep 32-35 km, earthquakes along its eastern trace in February, 1983 (ONWI-9 83-3). In ONWI 92 this fault system is not described, although it is shown in Fig. 6-4. The ENE strike of this feature is not parallel to either the very common northwest trend of the salt anticlines and associated faults or the northeast trend of the inferred Colorado lineament. Both these trends are believed to have been present in the Precambrian and to have influenced the development of subsequent structures. Thus the Shay Graben appears to be an anomalous structure.

The eastward extension of the Graben, where the earthquakes occurred, is concealed beneath Quaternary deposits. Because of the earthquakes and the potential for more. This fault system needs to be better characterized, by geologic and geophysical investigations.

The February, 1983 earthquakes were 32-35 km deep. Although the seismicity of the Colorado Plateau is low, shallow earthquakes appear to be more common than deep earthquake. A swarm of earthquakes occurred at Capitol Reef National Park in 1979 (Humphrey and Wong, 1983). Most were less than 10 km deep. Two occurred at depths of 28 and 33 km and earthquakes as deep as 58 km have been reported in the Colorado Plateau. There is some indication that movement along faults beneath the Paradox Formation might be taken up by flowage in the salt. How would this affect the repository?

The Shay Graben system is about 25 miles long. In other parts of the western United States this fault length could generate an earthquake with a M_s magnitude of 7 or greater.

The amount, type and timing of fault movement; how the Shay Graben fits into a tectonic model(s) of the Colorado Plateau and magnitudes of potential earthquakes are necessary information in order to access the systems effects on the potential repository.

1.1.5 Does the Shay Graben or other faults parallel the trend of any geophysical anomaly?

U.S. Geological Survey Open File Report 82-509 notes that VLF magnetic field tilt and ellipticity measurements appear to reliably locate faults. This technique has detected mapped faults north of the graben. Have similar anomalies identified other areas of potential unmapped faults?

1.1.6 What is the origin of the Salt Creek-Bridger Jack Fault System?

1.1.6.1 This fault system extends into the Davis-Lavender Canyon area?

1.1.6.2 What is the maximum credible earthquake likely to be associated with this system?

1.1.6.3 What is the relation between the Salt Creek-Bridger Jack System and the Shay graben system?

Tnis northeast striking fault system occur about 10 miles southwest of the repository location. This system is somewhat sinuous along its southwest extension and its northeast extension is about parallel to the Shay Graben trend. Projecting this trend to the northeast the fault passes near the repository location. Both Davis and Lavender Canyons also have northeast trends. Extension of these faults into the repository area may be postulated as controlling the trends of the two canyons.

The size of potential earthquakes along this system needs to be addressed. Renewed activity on the Shay Graben system may cause a higher probability of movement along the Salt Creek-Bridger Jack system. Knowledge of past interactions of the two systems may be necessary to predict future interactions.

The amount, type and timing of faulting, how the Salt Creek-Bridger Jack Fault System fits into tectonic model(s) of the Colorado Plateau, the potential for northeast extension and magnitude of potential earthquakes are necessary information in order to access the Salt Creek-Bridger Jack Fault Systems effects on the potential repository.

1.1.7 What is the underlying origin of the Needles Fault Zone?

1.1.7.1 How does the Needles Fault Zone relate to the Meanders anticline?

1.1.7.2 What is potential for eastward migration of the Needles Fault Zone into respository area?

The Needles Fault Zone is located approximately twelve miles west of the repository location. It is a series of small east to northeast striking faults. It has been suggested that these faults are related to dissolution of the salt by groundwater. However, why the dissolution of the salt was localized there, the dissolution mechanism and the potential for eastward extension of the Needles Fault Zone need to be addressed in terms of the potential repository site. The Meanders Anticline occurs along the Colorado River to the north of the Needles Fault Zone. Are they related in some way as to suggest a similar process could occur in the Gibson Dome area.

1.1.8 Is there currently seismic activity on Uncompahgre/Paradox Basin Boundary Fault Zone?

Although the fault zone which bounded the northeast side of the Paradox Basin in the Pennsylvanian Period is thought to be inactive, it is the largest fault system in the region.

The potential for renewed activity, its relationship to the regional stress and how it fits into tectonic model(s) of the Colorado Plateau need to be evaluated in order to access this faults effects on the proposed repository site.

1.1.9 What is the potential for faulting along the northwest projection of the Combs Ridge Monocline?

It has been postulated that many of the monoclinal folds in the Colorado Plateau originate by draping of sedimentary rocks over near vertical reactivated Precambrian fault zones, (Davis, 1978). The Comb Ridge Monocline is about 25 miles southwest of the proposed repository site. Along the projected axis of the monocline is a small N-S fault, an anomalous bend in the Salt Creek-Bridger Jack Fault System and the north south drainage of Salt Creek. This alignment of features needs to be accessed in terms of a subsurface fault system.

1.1.10 What is the possibility of the existence of presently unrecognized fault activity in the area?

Until the possibility arose for the development of a waste repository, this area had not undergone intense study for unrecognized faults. It is possible that there are minor faults presently undetected, from either tectonics or salt solution mechanisms. Often uplifts, such as the Monument Uplift and the Gibson Dome, have tensional faulting with minor seismicity and associated surface rupture at the surface due to folding (and stretching) of the upper layers. Definition and delineation of present fault activity in the region is necessary.

1.1.11 How have faults affected the hydrologic regime in the Paradox basin?

Changes in groundwater flow that have occurred due to these and other stratigraphic discontinuities need to be characterized and any potential changes quantified.

1.11.1.1 What effect on salt dissolution has resulted?

The areas where faulting has resulted in fluid-salt contact and led to dissolution need to be delineated and it should be determined if they result from direct fluid movement along a fault or secondary disturbances of stratigraphy as indicated above.

1.1.12 What is (are) the cause(s) of any Quaternary faults?

Some faults within a few miles of the site have been described as having Quaternary movement. The mecnanism of faulting needs to be addressed. Are they of tectonic origin or are they a result of some other process such as caving from salt solution or flowage?

1.1.13 How has faulting affected stratigraphy?

Has faulting disrupted stratigraphy in such a way as to affect fluid movement, other than direct transport along the fault? That is, have any permeable beds been sealed off or impermeable ones fractured significantly? Have these contained or trapped significant (with respect to repository design safety) amounts of petroleum, methane or brine?

1.2.0 <u>Folds</u>

1.2.1 What is the origin of the Gibson Dome?

1.2.1.1. What is the potential for salt flowage, dissolution or collapse at the Gibson Dome?

The axis of the Gibson Dome is about six miles north of tne proposed repository location. It is tne southwestern most dome and its axis snows more curving than the others. Does this indicate a greater potential for the dome to become breached and allow groundwater to enter the Paradox Formation and start solution of the salt?

1.2.2 What are possible origins for the Meanders Anticline? Why is its axis perpendicular to most other anticlines in the Paradox Basin?

Removal of the overlying overburden by the Colorado River and subsequent upward flowage of salt has been given as the cause of the Meanders Anticline. Are there other possible causes related to the tectonic character of the Colorado Plateau?

2.0 Seismicity and Design Earthquakes

2.1.1 Has there been seismic activity on the Shay Graben subsequent to February 1983?

Because of its remoteness from seismographs and the generally low magnitude of earthquakes seismic events may be more common than expected. In addition seismic swarms such as the one at Capitol Reef National Park (Humphrey and Wong, 1983) may be the style of activity in the Colorado Plateau. In addition to the Shay Graben, the Salt Creek-Bridger Jack System the Needles Fault System, and the possible extension of the Combs Ridge Monocline need to be monitored and characterized.

2.2.1 Are there any northwest trending structures, near the repository site which may be subject to normal fault motion, as postulated to have occurred at Capitol Reef Rational Monument (Humphrey and Wong, 1983)?

Based on two focal mechanisms determinations, at Capitol Reef National Park, at least one and possibly both earthquakes occurred along northwest trending normal faults. If the stress regime is similarly oriented in the Paradox Basin then structures with a northwest trend may have a high potential for earthquake than structures oriented in other directions.

2.3.1 What are the design earthquakes for the Site?

2.3.2 What are the sources or source areas for earthquakes which could produce the maximum accelerations at the Site?

Sources and source areas within the Candidate Area which could produce the maximum accelerations at the Site need to be delineated and characterized. This should include studies of active faults which intersect the surface, faults which do not intersect the surface, and source areas which are capable of producing seismic waves from unknown causes (phase changes, volcanic or man-made explosions, micro-earthquakes at depth, etc.).

After delineation as a source/source area, a structure needs to be characterized by such parameters as type of movement, amount of movement, length of rupture, amount of stress drop, and size of resultant earthquake. This characterization is necessary as differing mechanisms may produce differing magnitudes and frequencies of the various seismic waves. In addition to the ability to produce accelerations at the site, sources/source areas should be evaluated for their probability of producing these accelerations.

Design earthquake data needs to be presented in appropriate deterministic/probablistic terms, including exceedance probabilities.

2.3.2.1 What is the probable size (magnitude) of the largest earthquake that can be expected from sources or source areas that could affect the Site?

Each seismogenic (active) fault that is identified within the Candidate Area needs to be assessed for what size (magnitude or moment magnitude) the largest earthquake is able to produce. This assessment can be made by determining prehistorical rupture lengths and displacements and using relationships of these parameters to magnitude. Moment magnitude may best reflect earthquake size in the region as this scale considers fault plane width and length. If most surface faulting is the result of salt flowage or solution at a relatively shallow depth, fault plane widths will be small. Another method is the use of total or fractional fault rupture length determinations to predict rupture length of future events. This method generally involves segmentation of the fault or a percentage of total fault length, which varies by fault mechanism, to determine the postulated rupture length.

On faults where strain rate can be determined, relationships are published which give a maximum cutoff value for earthquake size, based on maximum magnitude vs. strain rate charts for historical events. Displacements for prehistoric earthquakes can sometimes be determined from sub-surface investigations (trenching or boreholes) and be used to compare with strain rate for recurrence interval and hence magnitude or seismic moment.

2.3.2.2 What is the cause and magnitude, moment magnitude, or size of the largest earthquakes to be expected in the siting region, for which there is no evidence for seismogenic structures?

In the historical seismic record, events have occurred which cannot be assigned to a known seismogenic structure. These areas are source areas for earthquakes and need to be evaluated in the Candidate area for positioning with relation to the site, maximum size (magnitude or moment magnitude) of the event they are able to produce, and hazards to the site from that event.

In many seismotectonic areas, source areas cannot be specifically identified and the entire area is considered as a source area, hence the assumption needs to be made that an earthquake has a random epicenter which can occur anywhere within that area ("floating earthquake"). If this determination is made, comparison with other seismotectonically similar areas with better historical records may be necessary to assess the maximum seismic event possible. Thus the maximum earthquake which can occur from non-identified seismotectonic structures must be assumed to be able to occur at the site, and assessment of the associated hazards should be made.

2.3.2.3 Can segmentation be used on sources (active faults) to determine maximum earthquake size?

Maximum earthquake size depends on the energy stored as elastic strain in stressed geologic formations. If a large area ruptures with a large amount of stored elastic strain released, a large earthquake occurs. Faults are seldom planar but have bends, changes in type of movement, changes from one geologic formation to another, an echelon and splaying geometries and splays. These in effect cause asperities or perturbations in the fault plane which may cause ruptures to end rather than encompass the entire length and width of the fault. Historically, faults seldom rupture their entire length, but are segmented and segments tend to rupture independently.

If segmentation can be shown on active faults affecting the site, the design earthquake may be calculated on fault length, using segment length instead of total length. Studies on fault character, prehistorical rupture lengths and geologic impairments to cause segmentation are needed to determine reasonable segmentation for faults.

Segmentation is well demonstrated in the historical ruptures along the Central Nevada Seismic Zones with segments rupturing in historical times but several gaps remain historically unruptured. The same relationship exists for prehistorical ruptures along the Wasatch-Hurricane Fault Zone west of the site. These gaps represent segments where more strain needs to accumulate before rupture occurs and rupture is not expected to re-occur in areas of historical rupture during repository operations, as strain has been recently relieved in these areas. Segmentation thus tends to reduce the size of earthquakes a fault is capable of producing by reducing the area (length and width) of the fault plane (or surface) which can rupture and release energy during a single event. However, it should be noted that the rate(s) at which strain accumulates needs to be assessed in order to determine the recurrence interval(s) for individual segments as well as for the entire fault length.

2.3.2.4 What criteria are used to establish the earthquake recurrence intervals of active faults?

Questions on possible seismic or tectonic cycles must be considered, discussed and evaluated for each active fault and the recurrence intervals, dating methods, size of associated earthquakes, and uniformity or variability of parameters for each fault needs to be determined. This analysis needs to evaluate the brittle or plastic behavior at the surface to shallow depths. The methods that need to be employed include soil and paleosol studies, particularly in excavations and boreholes on or through the fault trace or plane at the surface. This should be integrated with stress vs. time relationships.

2.4.1 What attenuation do travel paths from earthquake sources and source areas to the Site have?

Effects of ground shaking (acceleration, velocity displacements, and duration) at the Site are affected by the attenuation of the geologic material between the Site and the source/source area which generated the earthquake. Assessments need to be made for the travel paths of seismic waves between critical sources/source areas and the Site to determine if the properties of the various paths tend to enhance or mitigate hazards to the Site from these sources/source areas.

Possible attenuation changes with direction also need to be assessed, e.g. a source to the south may affect the Site differently than one to the west because of local or regional geologic conditions. Whether these attenuation values may change with time (e.g. higher or lower water table; climate; and strain changes in geologic formations) should be assessed as well.

2.4.1.1 Does the faulting mechanism (strike-slip vs. normal) affect the attenuation on travel paths?

When attenuations of travel paths from sources/source areas to the Site are determined (information need 3.2.3) the determined values need to be calibrated to the differing mechanisms of faulting (normal, reverse, thrusting, strike-slip, combination). The attenuation may vary because of different frequencies of waves emitted during seismicity on differing generation mechanisms. Geometry of the source/source area may also affect wave frequency and wave strength with relation to the Site.

2.5.1. What are the geologic and topographic focusing effects for seismic waves at the Site?

Local geologic and topographic geometries need to be considered for their ability to focus seismic energy into a small area. This focusing phenomenon may occur from the geometry of geologic formations and structure in an area, e.g. if the energy is across two Range Province mountain ranges and valleys, focusing may actually increase attenuation, while if the energy is released with only an alluvium-filled valley between the Site and point of energy release, and that valley becomes narrower towards the site, energy may be focused to the site and result in very high acceleration at the site.

Topographic may also focus seismic energy. Historical reports of the tops of ridges experiencing much higher acceleration than surrounding slopes and valleys are frequent and need to be assessed.

2.5.2 What hazard exists at the site from surface to repository depths for aseismic deformation?

2.5.2.1 What deformation is possible as a result of salt solution?

The possibility of salt solution caused subsidence at the repository poses a significant hazard. What extent of dissolution has been observed elsewhere in the basin? Sources for fluids causing dissolution should be identified.

2.5.2.2 What deformation is possible as a result of lateral migration of salt?

What has caused significant salt flowage in the past? Is this situation possible in the present setting? Will it be possible considering changes in present conditions? Can salt flowage result in folding of the overlying strata to an extent that poses hazards to the site?

2.5.2.3 Do other types of surface to repository depth aseismic deformation present a hazard to the site?

Is aseismic deformation from causes other than salt solution subsidence and salt flowage a hazard at the site? This can include folding, fault creep, etc.

2.6.1 What are the sources or source areas for earthquakes which might cause other seismically related hazards in the Site Vicinity, e.g. landslides, lateral spreads, liquefaction of access roads, and rail spurs?

Other hazards exist from seismic events, in addition to ground shaking and rupture. These are generally secondary phenomena, related to ground shaking and include seismic-induced landslides, lateral spreads, liquefaction and subsidence.

The need to assess these hazards for the Site and site vicinity involves slope stability studies for landslides and rockfalls, and soil stratigraphic studies for liquefaction and liquefaction-induced slope failures. Liquefaction studies are necessary only if shallow groundwater exists. Liquefaction, lateral spreading, and subsidence probably only affect access roads, power transmission lines, railroad lines, pipelines and wells near the Site, while landslides and rockfalls may directly affect the facility.

2.6.2 What are the sources or source areas for earthquakes which might cause surface/near surface rupture at the Site?

Sources and source areas at the Site or in the Candidate Area need to be evaluated for their ability to produce displacement at or near the surface which would pose a hazard to the Site. Possible displacements may be primary, i.e. fault plane rupture, or secondary, i.e. fracture movement, liquefaction, subsidence, secondary faulting, etc. The probability and the probable amount of displacement also need to be evaluated.

These evaluations are necessary to determine proper design parameters for the facility, with respect to amount of movement which could adversely affect facility performance, possible effect of displacement affecting groundwater flow paths, and possible effects on near facility engineered structures, e.g. power transmission lines, water lines and wells, and access roads.

2.7.1 Does seismicity associated with isostatic adjustment pose a hazard to the Site?

This information need is to determine if isostatic adjustment may occur with sufficient associated seismicity to pose a hazard to the Site. These processes may provide enough mass transfer over geologic time to create sufficient disequilibrium in isostasy to create an adjustment by brittle failure. These are the erosional-depositional processes, drastic changes in the water table from climatic changes, stream piracy or man's activities, and tectonic processes at depth which may create changes in the specific gravity of the materials at depth.

Tectonic activity which needs to be assessed with respect to these processes includes seismic energy release from brittle fracturing and tectonic creep in response to the movement of crustal materials in response to large changes in isostasy. The water table level may create similar phenomena by rising, lowering, and even be at the surface, forming free standing lakes. Reservoir loading from man-made structures has been accompanied by considerable increases in seismicity (reservoir-induced seismicity) at several large reservoirs in other areas.

Deep geologic processes, e.g. intrusion of high or low specific gravity magmas can also cause isostatic disequilibrium. These phenomena may include dikes, sills, batholiths. lopoliths, crustal underplating, etc. An assessment of stored : strain in intrusive bodies in the Site and Candidate Area vicinity should be accomplished.

2.8.1 Does seismicity associated with volcanic processes pose a hazard to the Site?

Volcanic processes in the Great Basin are known to produce considerable seismicity, e.g. at Mammoth Lakes. The information need is to assess the hazards of volcanic-generated seismicity at the Site or in the Site Vicinity. In general the seismicity associated with volcanic activity is not great, but the frequency of waves generated may differ from tectonic seismicity. How these are attenuated and hazards on engineered structures at the facility need to be examined.

Surface rupture hazard from near surface volcanic processes is also different than from non-volcanic seismicity. For example, at Mt. Shasta, California, an earthquake of $M_s \sim 4$ created up to 0.5 m surface displacements on secondary normal faults.

2.9.1 What is the seismic hazard at the site during construction vs. operation and long term storage?

The seismic hazard at the site needs to be assessed for the three phases - construction, operation, and long term storage. The assessment needs to encompass a probability of occurrence evaluation, but that evaluation cannot be made of a large area, except for farfield events. The assessment for near field events should consider the recurrence intervals on local sources/source areas, the amount of strain present at that source, and the differences in hazards posed by an event during construction, operation, and long term storage.

During construction, with no radioactive materials at the Site, the hazards are only to structures of the facility and the personnel present. During active operation, with movement, temporary storage, and an unsealed facility, hazards from seismic events are probably greatest. Long term storage is subjected to the longest time interval, and hence is most likely to be subjected to seismic hazards, but, during this phase seismic hazard effect may be mitigated by the sealed conditions of the facility. Thus not only must the facility, or stage in development of a facility, be considered, but also recurrence interval (probability of an event), or timing within an interval. For example, if the recurrence interval of a fault is 10,000 ± 500 years, and the last event was 10,000 years ago, an event is eminent and highly probable. Conversely, if the recurrence interval is the same and the last event was 1,000 years ago, an event is not probable.

3.0 Stress

3.1.1 What is the magnitude and orientation of in situ stress on both a local and regional scale?

Local stresses from salt dome or anticline formation, salt solution and tectonic forces needs to be quantified. The plasticity of the salt formations and their response to stresses on a local scale needs to be quantified. Local stress fields need to be characterized and integrated into the conceptual tectonic model.

3.2.1 Can seismotectonic processes adversely affect the site in non-seismic ways, e.g. stress buildup causing spalling or plastic flowage of excavations, walls, or rise of water table?

This information need covers studies related to non-seismic tectonic processes which could pose a hazard during construction, operation, and/or long term storage at the facility. It is necessary to determine if in situ strain can cause spalling within the excavations, or changes in strain affect the water table. It may be necessary to determine the long term behavior of geologic formations at the site to reasonably determine the percentage of strain which is elastic (vs. plastic) compared to strain rate accumulation. In addition to spalling, effects on borings for ventilation and water need to be assessed.

Strain accumulation in an area being stressed also leads to changes in rock porosity, which can affect the water table level(s). This could pose a hazard both as water affecting the facility and changes in attenuation on travel paths for seismic waves from sources and source areas outside the Site.

4.0 Igneous Activity

4.1.1 What volcanic processes pose a hazard at the site?

Although volcanic activity is not predominant in the site region, the effects of distant volcanism, e.g. associated seismicity and ash falls, need to be characterized.

5.0 Tectonics

5.1 What is (are) the conceptual tectonic model(s) for the site region?

5.1.1 How does the Colorado Plateau Province relate to the bordering tectonic provinces?

5.1.2 How does the behavior of the North American-Pacific Plate boundary affect the Colorado Plateau?

5.1.3 How does the local and regional geological, geophysical and seismological data fit the model(s)?

A model or models must conform to all data bases. Conflicts in data bases need to be resolved. A tectonic model of the repository area must be consistent with tectonic models of the entire Colorado plateau, which must be consistent with tectonic models of western North America.

5.1.4 What changes in the present tectonic setting are possible?

5.1.4.1 Does eastward migration of Basin and Range type faulting pose a hazard to the site?

Has the Basin and Range-Plateau transition zone migrated in the past, and is it likely to do so in the future? Several types of geophysical evidence suggests the geophysical boundary between the Basin and Range and the Colorado plateau is up to 100 km east of the physiographic boundary (Thompson and Zoback, 1979).

5.2 What will tectonic model(s) predict about the future flow of salt in the candidate area?

Evidence of salt flowage is abundant in the Paradox Basin, three diapiric structures, and the diapiric Meanders Anticline exists north of the proposed site. Mechanisms for these salt flowage structures need to be identified and the repository site evaluated in terms of those mechanisms.

6.0 Salt Migration and Dissolution

6.1.1 It is diaperism of salt a potential problem in the Gibson Dome area. See 5.2.1

6.1.2 In addition to those associated with diapiric structures, can faults develop in the overlying country rock as a result of flowage in the salt?

Is upwelling of salt likely to occur along fault planes or other structural discontinuities? Have discontinuities sealed off salt beds anywhere, thus preventing migration? What effect on salt migration does the Monument Uplift have? If flowage of salt is a possibility, will faults form in the overlying rocks, with the potential for surface facility disruption by ground rupture, creep, or earthquakes?

6.1.3 What discontinuities are due to the behavior of salt?

Salt flowage and dissolution can cause considerable disruption of stratigraphy. To what extend have these occurred in the area? Are lateral variations in thicknesses and pinchouts due to either of these factors?

6.1.4 What structures have resulted from salt flowage?

How much lateral migration of salt has occurred? What are the sizes and magnitudes of structures that have resulted? Are there structures, such as domes, resulting from salt flowage which do not have surface expression?

6.1.5 When has significant salt movement occurred and what event(s) caused this?

It needs to be determined how fast the salt can potentially move. Do rapid, sporadic episodes of salt flowage occur, or does movement take pace over time periods long enough to not be of concern? If the salt can migrate fast enough to potentially pose a problem, what conditions must be present in order to make this a possibility? Are these conditions likely to occur? The added effect of heat generated by thermal emanations from the repository on salt movement needs to be assessed.

6.1.6 Is dissolution of salt in the repository area a potential problem area?

Collapse structures similar to large sinkholes have formed in some basins underlain by evaporites. Various mechanisms for the introduction of water into the salt horizon and its subsequent dissolution exist. Are any of these mechanism applicable to the potential repository area?

6.1.6.1 What are the rates and directions of dissolution presently occurring, especially in the Lockhart Basin?

At past and present rates of dissolution, is there substantial room for safety to insure that the site will not likely be affected by those areas having experienced dissolution? What are the factors allowing fluid movement in these areas and are these factors likely to affect other areas, thus creating new centers for dissolution spreading?

7.0 What are the probabilities and nature of human-induced changes that would affect repository performance?

7.1 What is the probability that methane leakage from host rock and adjacent beds could affect repository performance?

Tunnels and shafts of the repository will cut through the host rock and adjacent layers. Some organic matter is found in the repository horizon and methane occurs in layers above and below it. All three are capable of releasing some amount of methane into the facility once they are exposed. Some estimation of the amount of methane and possible associated hazards needs to be made.

7.2 What would be the effect on the repository of changes in the groundwater system?

7.2.1 What is the probability of onset or increase in dissolution within the host rock?

Human activities which add to the groundwater in the area could lead to a rise in the water table into the repository horizon. Increased contact between groundwater and the salt will cause a corresponding increase in the occurrence of solution cavities, which can weaken the overall geologic structure and endanger the integrity of storage canisters. Some assessment needs to be made of possible groundwater changes and reaction of the host rock, or of provisions to protect the facility from dissolution cavities.

7.3 What is the probability of seismicity due to facility construction and/or operation?

7.3.1 What is the probability of induced seismicity due to waste emplacement?

7.3.2 What is the probability of seismicity caused by thermal emissions from waste canisters?

Construction of the facility and emplacement and storage of the waste may cause changes in the local in situ stress which could result in seismic activity.

7.4 What is the probability of brine migration due to waste emplacement?

7.4.1 Could brine migration result in collapse structures in overlying rocks that could lead to introduction of fresh groundwater and large scale dissolution of salt?

The salt of the candidate horizon contains a highly corrosive brine, which may migrate toward higher temperature areas, such as those around waste canisters. Estimates of the quantity of brine are uncertain. An assessment of risk to the canisters and repository based on brine migration should be made.

7.5 What would be the effect on the repository of future minerals or petroleum extraction?

Future mineral or petroleum needs may lead to economic development of the area around the repository. Oil producing horizons occur in and below the Paradox formation. Once the repository is completed and sealed, it will still be vulnerable to penetration by exploration drillholes, or to other such disturbances. What provisions can be made to protect the facility from the effects of other development projects in the future in the area?

A partial list of technical publications used and/or reviewed in preparation of this report is given below.

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