FINAL

TECHNICAL EVALUATION REPORT

for the

PROPOSED REMEDIAL ACTION

of the

MOAB, UTAH
URANIUM MILL TAILINGS SITE

July 2008

Division of Waste Management
and Environmental Protection
Office of Federal and State Materials
and Environmental Management Programs
U.S. Nuclear Regulatory Commission

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1.0 INTRODUCTION

The Moab site was added to the sites to be remediated by the U.S. Department of Energy (DOE) under Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) by the Floyd D. Spence National Defense Authorization Act for fiscal year 2001. UMTRCA requires, in part, that the U.S. Nuclear Regulatory Commission (NRC) concur with DOE's selection of remedial action, such that the remedial action meets appropriate standards promulgated by the U.S. Environmental Protection Agency (EPA). This final Technical Evaluation Report (TER) documents the NRC staff's review of the DOE remedial action plan (RAP) and site design (DOE, 2008).

1.1 EPA Standards

As required by UMTRCA, remedial action at the Moab site must comply with regulations established by EPA in 40 CFR Part 192, Subparts A-C. These regulations may be summarized as follows:

1. The disposal site shall be designed to control the tailings and other residual radioactive materials for 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years [40 CFR 192.02(a)].

2. The disposal site design shall prevent radon-222 fluxes from residual radioactive materials to the atmosphere from exceeding 20 picocuries/square meter/second or from increasing the annual average concentration of radon-222 in air by more than 0.5 picocuries/liter [40 CFR 192.02(b)].

3. The disposal site design shall provide reasonable assurance that identified constituents entering the groundwater from the site will not exceed established concentration limits in the uppermost aquifer [40 CFR 192.02 (c)].

4. The remedial action shall ensure that radium-226 concentrations in land that is not part of the disposal site averaged over any area of 100 square meters do not exceed the background level by more than 5 picocuries/gram averaged over the first 15 centimeters of soil below the surface and 15 picocuries/gram averaged over any 15-centimeter-thick layer of soil more than 15 centimeters below the land surface [40 CFR 192.12(a)].

1.2 Site History and Proposed Action

The Moab mill site is located in Grand County, Utah. The site is located on the northwest shore of the Colorado River, 5 km (3 miles) northwest of the center of Moab. The site can be accessed from U.S. Highway 191 north of Moab. The mill site encompasses 162 hectares (400 acres) on the outside bend of the Colorado River, at the southern terminus of the Moab Canyon. The site is surrounded on the north and west sides by high sandstone cliffs. To the north and east is Moab Wash, to the east and south is the flood plain of the Colorado River, and across the river is Moab Marsh. The city of Moab is southwest of the marsh. The elevation at the mill is approximately 1130 meters (3700 feet) above mean sea level (MSL).

The Uranium Reduction Company (URC) built and began operations at the Moab Mill in October 1956. Atlas Corporation acquired URC in 1962 and operated the mill until 1984 when it was placed in stand-by status. A decommissioning plan for the mill was approved by NRC on

November 28, 1988. Atlas submitted a reclamation plan for the site in 1992 and subsequently revised it several times in the following years. The reclamation plan called for stabilization of the existing tailings pile in place at the Moab site. On May 28, 1999, NRC approved the reclamation plan with several conditions.

On September 22, 1998, Atlas filed a petition for relief under Chapter 11 of the Bankruptcy Code. On December 27, 1999, the NRC license for the site was transferred to PricewaterhouseCoopers, LLP, as trustee.

In October 2000, the Floyd D. Spence National Defense Authorization Act for fiscal year 2001 amended UMTRCA Title I, giving DOE responsibility for remediation of the Moab site in accordance with the requirements of UMTRCA. The NRC license was terminated and the title to the site was transferred to DOE in October 2001.

The remedial action proposed by DOE consists of the removal and subsequent relocation of all residual radioactive material and contaminated materials from the Moab site to a disposal cell at Crescent Junction, Utah. DOE proposes to construct an approximately 250-acre engineered cell, partially below grade, to encapsulate the material. The proposed disposal cell is generally trapezoidal in shape. The cover of the cell is designed to limit radon release from the cell and infiltration of precipitation into the cell and to protect the cell from erosion.

Figure 1-1 shows the location of the processing and disposal sites.

The remedial action proposed by DOE does not address the requirement in 40 CFR 192.12(c) that groundwater at the Moab site be remediated. As was done with other UMTRCA Title I sites, DOE will address cleanup of contaminated groundwater at the Moab site separately.

1.3 Review Process

The NRC review process was performed in accordance with the Final Standard Review Plan for UMTRCA Title I Mill Tailings Remedial Action Plans (NRC, 1993) and consisted of comprehensive assessments of DOE's site design and remedial action plan. The remedial action information assessed by the NRC staff during this review was provided primarily in the "Final Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah, Disposal Site" (DOE, 2008).

1.4 TER Organization

The purpose of this TER is to document the NRC staff review of DOE's RAP for the Moab site. The chapters of this report have been organized by technical discipline relative to the EPA standards in 40 CFR Part 192, Subparts A-C. Chapters 2 (Geology and Seismology), 3 (Geotechnical Stability), and 4 (Surface Water Hydrology and Erosion Protection) provide the technical basis for the NRC staff's conclusions with respect to the long-term stability standard in 192.02(a). Section 5, Water Resources Protection, summarizes the NRC staff's conclusions with regard to the adequacy of DOE's compliance demonstration with EPA's groundwater protection requirements in 192.02(c). Chapter 6, Radon Attenuation and Site Cleanup, provides the basis for the staff's conclusions with respect to the radon control standards in 192.02(b) and soil cleanup standards in 192.12.

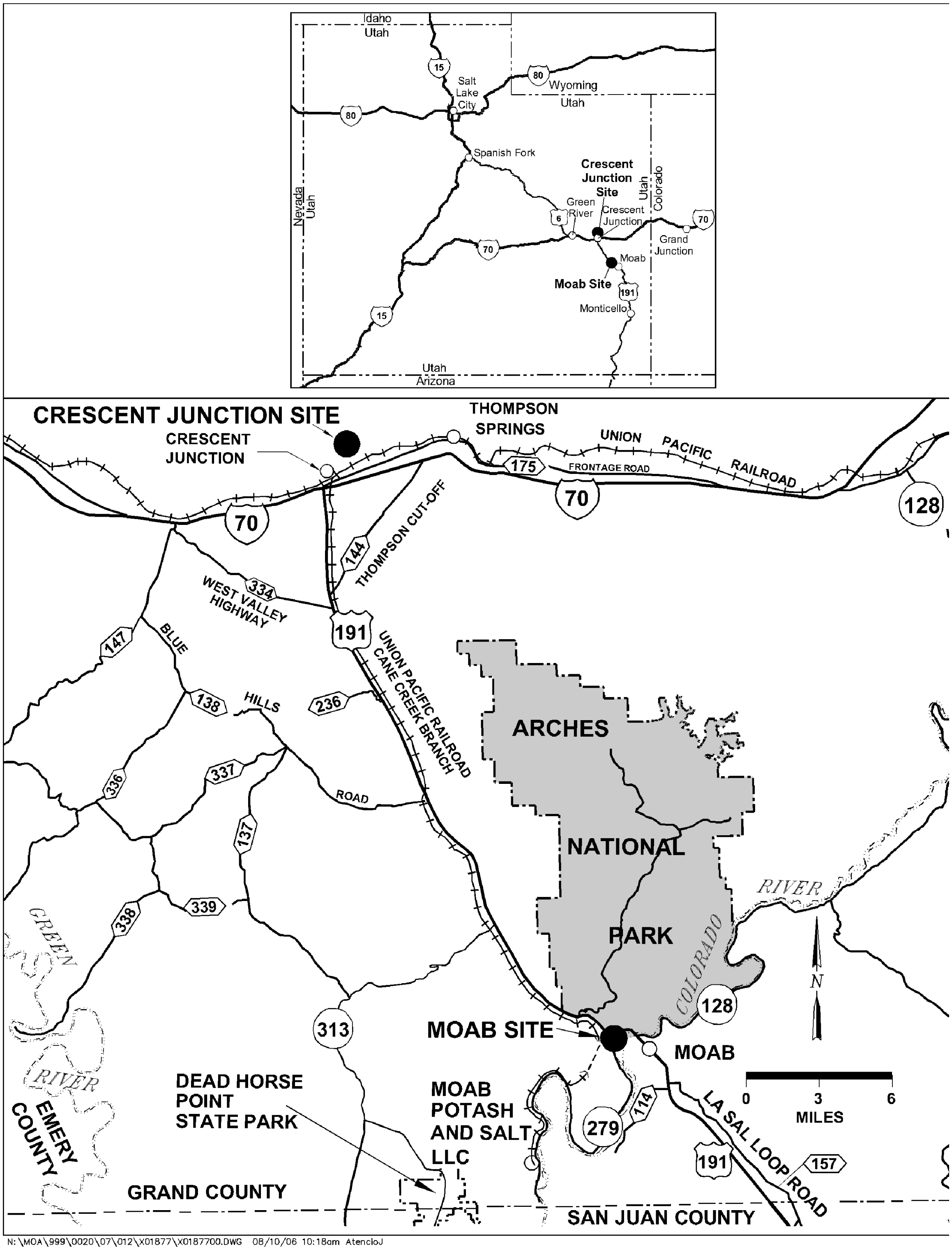

Figure 1-1. Location of the Moab and Crescent Junction sites

1.5 Conclusions

The NRC staff's review of DOE's RAP and all associated documentation pertinent to the proposed remedial action for the uranium mill tailings site at Moab, Utah, has not identified any issues that suggest that NRC should not concur in the proposed remedial action. However, the RAP does not address remediation of groundwater contamination at the Moab site. Although the staff considers DOE's deferral of groundwater cleanup to be acceptable, it precludes us from fully concurring at this time. When groundwater cleanup is adequately addressed, NRC will provide its final concurrence on the remedial action for the Moab site.

2.0 GEOLOGY AND SEISMOLOGY

2.1 Introduction

NRC staff reviewed geology and seismology in accordance with the review procedures contained in the Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites under Title I of the Uranium Mill Tailings Radiation Control Act (SRP), Section 1.3. The review procedures outlined in the SRP section 1.3.1 through 1.3.5 serve as review guidelines for determining if the site investigations were adequate enough in scope and technique to provide the necessary data to support findings and conclusion reached in this TER. Areas reviewed by the staff included geologic and seismologic characterization, geologic stability, bedrock stability, geomorphic stability, and seismotectonic stability.

2.2 Geologic and Seismologic Characterization

DOE determined local and regional geology by using published information, field reconnaissance, and aerial photography. DOE has provided extensive references in support of the geologic and seismologic characterization provided. DOE performed field investigations, exploration, and conducted an on-site sampling program to define the stratigraphy, structural setting, and properties of the surface and subsurface material at the site. Aerial photographs (including high-altitude vertical and low sun-angle) of the area were produced to analyze structural and geomorphic conditions that may affect the site. Historic aerial photographs dating back to 1944 were also used in the analysis of site conditions. Additional geologic and geomorphic site characterization was accomplished by walking and mapping surface features of the site and in the surrounding area.

The DOE literature review of published information, maps, and aerial photography of geologic and seismologic data was thorough and provided an adequate basis for additional field studies undertaken at the site. On-site investigations and additional field reconnaissance were adequate in scope to characterize and provide the necessary stratigraphic, geomorphic, seismic and tectonic data used to formulate conclusions and findings in the areas of geologic, bedrock, geomorphic, and seismic stability.

2.3 Geologic Stability

The Crescent Junction Site is in the north end of the Canyon Lands section of the Colorado Plateau physiographic province. The Canyon Lands section is characterized by deeply incised drainages, isolated mesas, gently dipping bedrock, and anticlines formed by salt intrusion that have been breached in places by erosion to form anticlinal valleys. North of the Canyon Lands section is the Uinta Basin section of the Colorado Plateau; the boundary between the two sections is the Book Cliffs, an erosional escarpment just north of the site. The Uinta Basin section is characterized by a rugged, intricately dissected plateau bounded on the south by sets of cliffs (one of which is the Book Cliffs) that are highly irregular with many salients and canyons (reentrants). Further physiographic subdivisions recognized in the State of Utah place the site in the Mancos Shale Lowland (DOE, 2008, Attachment 2).

The Crescent Junction site is situated in the Mancos Shale Lowland at the foot of the book cliffs, a broad gently sloping area that is underlain by several thousand feet of Mancos Shale. DOE has estimated that the thickness of the Mancos Shale at the site is approximately 2400 feet.

This estimate is based on a test hole drilled by Tidewater Oil and Gas Company approximately 1750 feet south of the disposal cell location and on published geologic maps and literature of field and geologic mapping of the area. Ten coreholes were drilled to depths of approximately 300 ft into the Mancos Shale. Core samples were logged in the field using visual soil- and rock-classification procedures, and the coreholes were geophysically logged. DOE has differentiated the Mancos Shale into the “weathered” and “unweathered” Mancos Shale. The primary difference between the weathered vs. unweathered Mancos Shale is the spacing of natural bedding plane fractures and high-angle fractures, both which decrease or are non existent with depth in the unweathered Mancos Shale. This transition occurs at approximately 50 feet below the top of the Mancos bedrock surface. The transition point between the weathered and unweathered shale is subjective, is not clearly defined, and is not easily quantified. However, a quantifiable definition between the two does not appear to be a critical factor in the overall geologic characterization of the site.

Overlying the Mancos Shale is approximately 20-30 feet of alluvial and outwash material that has originated locally from the Book Cliffs. The depth of this material overlying the Mancos Shale bedrock was determined by DOE. One hundred geotechnical boreholes were drilled to depths of as much as 26 feet through the surficial unconsolidated material into the shallow weathered Mancos Shale with samples being logged in the field. Additionally, DOE dug five test pits ranging from 15 to 23 feet deep spread out over the site that assisted with the geologic characterization, and these locations were used to perform several hydraulic and geotechnical tests on the weathered Mancos Shale. Through these investigations, DOE was also able to determine geotechnical properties of the unweathered Mancos Shale and adequately map the depth to the weathered Mancos Shale throughout the site.

Underlying the Mancos Shale is the Dakota Sandstone, which DOE has defined as the uppermost aquifer. The Dakota Sandstone is considered the uppermost aquifer because the Mancos Shale has an extremely high-saline content and poor quality and water quantity. Additional hydraulic and geochemical characteristics of the site are discussed in the Hydrology and Water Resources section of this TER.

The primary surface features include active and abandoned fluvial washes and a series of low mounds that form a linear feature along the northern boundary of the proposed disposal cell footprint and that trends east/west. Drill holes and surface reconnaissance did not reveal any structural component to this linear feature. This feature is speculated to be associated with the Prairie Canyon Member of the Mancos Shale, and the strike of the feature is consistent with this interpretation.

NRC staff reviewed the information provided by DOE. This information included geologic maps, cross sections, borehole logs, references, and aerial photography. NRC staff focused its review on the thoroughness of published historical geologic information DOE used to provide overall geologic characterization of the site and surrounding area, as well as information provided from onsite investigations from coreholes and test pits. NRC staff studied aerial photograph stereo pairs to determine if there were any liniments, geologic structures, or other physiographic features warranting further analysis. NRC staff visited the site on December 5 and 6, 2006 to field verify geologic information reported in the RAP. During the site visit, NRC staff observed alluvial material and the top of the weathered Mancos Shale in one of the onsite test pits. NRC staff also observed the linear low-cuesta like mounds at the site, borehole cores, rock falls, and several of the onsite channels and fluvial features at the site. NRC staff looked at the Crescent

Wash channel and the landslide feature noted to the rear of the Book Cliffs, just north of the cell location.

Local and regional geologic information has been adequately defined and produced in the RAP and supporting documents. DOE has provided plans showing all site explorations such as borings, trenches and remediated pile limits. These locations are shown in the RAP, Attachment 2, Appendix B, plates 1, 2 and 3 (DOE, 2008). Stratigraphic profiles and cross sections have been provided showing the location of borings, monitoring wells, and trenches where the information in the cross sections is derived. These locations are shown in the RAP, Attachment 2, Appendix B, plate 2. Logs of core borings, monitoring wells, and test pits have been included. Logs of borings, wells, and test pits are included in the RAP, Attachment 5. A description on the exploration techniques has been provided. Exploration techniques included field and laboratory testing, as well as on site field exploration and field verification. These techniques are summarized in the RAP, Attachment 2, Appendix B, and in Attachment 5 (DOE, 2008). A description of each lithologic unit and its characteristics is provided in the RAP, Attachment 2, Appendix B. A discussion of the relationship of the site stratigraphy to regional stratigraphy is provided. This discussion is located in Attachment 2, Appendix A.

The data derived from investigations employed adequate and generally accepted procedures and employed a DOE QA/QC program. The technical terminology used follows generally accepted industry practice. The evaluation considered and referenced a large volume of information that is captured in the reference section of the RAP and various attachments to the RAP. Data procedures appear to be used properly and documented. These procedures are captured in the Appendices to the RAP. Geologic hazards relating to geologic stability appear to have been gathered using acceptable procedures. Uncertainties and alternative interpretations were considered in several of the analysis. The information presented in the RAP follows the format of the SRP and is presented in a logical manner. The attachments to the RAP include supporting information referenced in the RAP.

DOE has demonstrated an understanding of the geology and stratigraphy occurring at the site and thoroughly analyzed the site to provide reasonable assurance of long-term geologic stability.

2.4 Bedrock Stability

DOE has determined the overall bedrock geology and structural setting using a variety of published geologic maps and published geologic literature. The site is located within the Colorado Plateau, an intercontinental subplate with a greater crustal thickness than the adjoining provinces that provides a stable geologic setting for the site. The plateau has been gradually uplifting since Neogene time. Within the plateau, principal structural elements in the site region include the Uinta Basin, Paradox Basin, and Uncompahgre Uplift. The site is near the south edge of the Uinta Basin and in the northwest part of the ancestral Paradox Basin, where salt was deposited in Pennsylvanian time. Northwest-striking anticlines and synclines that formed as a result of movement of the deeply buried salt are in the north part of the Paradox Basin in what is called the Paradox Fold and Fault Belt (DOE, 2008, Attachment 2). The Paradox Fold and Fault Belt is characterized by elongated salt diapirs and resulting faulting, folding, and incipient collapse that has deformed the subsurface and influenced the regional bedrock immediately south of the site.

Published data regarding known faults in the expanded study area were assembled by DOE. Fifteen faults (or fault zones) were identified as having potential to impact the site. Most of the faults and structural features in the study area are associated with salt deformation. Salt deposits in the area have deformed over time and may have been active in the Quaternary and may be active today. Surface faults, as a result of salt dissolution, are not expected to extend below the contact with the salt, making the faults shallow and less than 2 km in depth. Due to the shallow nature of the faults and gradual process of salt deformation, salt dissolution and flow, sheer stresses are minimized and significant earthquakes are not likely. Although some of these structures may have had movement in the Quaternary, the movement is very slow and unlikely to generate large earthquakes. Of the 15 faults, five were either determined active in the Quaternary or of unknown age. The remaining 10 faults were determined inactive in the Quaternary.

No evidence of faulting in the Crescent Junction area was observed during the photogeologic evaluation and follow-up field investigations. The only faults noted were outside the withdrawal area, which encompasses the Crescent Junction Disposal Site.

DOE has assessed the potential for natural resource recovery in the region and at the site. DOE has identified current oil and gas leases in the region and at the site. Oil leases currently exist at the site and DOE is discussing access to those resources with lessees. DOE has determined that the oil and gas under the site could be accessed by directional drilling such that drilling would not have to occur on or in the immediate vicinity of the tailings impoundment. DOE has determined that if oil and gas were recovered from under the site, the target zone would likely be several thousand feet deep and not likely affect the stability of the tailings impoundment. Mineral resource extraction such as potash, salt, coal, uranium, vanadium, copper, silver and gold was considered. However, mineral concentrations in the Mancos Shale are very low and would likely not be economically viable in the foreseeable future.

NRC staff reviewed the information provided by DOE. NRC staff focused its review on the thoroughness of published historical geologic information DOE used to provide overall bedrock stability and seismicity of the site and surrounding area. DOE has furnished a determination of the structural geologic conditions at the site and surrounding area, including tectonic history. This information included geologic maps, seismic maps, references, and aerial photography. The structural setting and tectonic history are discussed in the RAP, Attachment 2, Appendices A, E, and F. Tectonic features, both regional and site-specific, including faults, have been identified and described in the RAP, Attachment 2, Appendices A, E, and F. The structural and tectonic province that influences the local seismicity has been identified and described in the RAP, Attachment 2, Appendix A. Surface faulting has been adequately identified and described in the RAP, Attachment 2, Appendices E and F.

DOE identified several faults within a 40 mile radius of the site. DOE examined 10 boreholes drilled 300 feet into the Mancos Shale and did not see evidence of faults such as slickensides on fracture surfaces. DOE and NRC staff examined aerial photography of the site and did not identify faults or offsets that were not otherwise known from published information. Historic literature of field surveys of faults and fault zones was used by DOE to determine if several faults were active or not. In most of the cases where DOE relied on published information to determine if the fault was active, authors of the information had field verified their findings. For some of the faults closer to the site, DOE contractors also field verified lack of quaternary movement and general lack of tectonic activity. Using this information, DOE determined if various faults in the regions are capable or not capable faults. Volcanic activity was not identified in the vicinity of the site.

The presentation of bedrock stability is acceptable. The methods used to determine the number of faults in the area and if the faults are capable are acceptable. DOE has demonstrated an understanding of the bedrock processes occurring at the site that provides reasonable assurance that compliance with 40 CFR 192 will not be jeopardized.

2.5 Geomorphic Stability

The site is located in the Mancos Shale lowland physiographic province. Physiographic provinces surrounding the Mancos Shale lowlands have been identified and are adequately described in the RAP, Attachment 2, Appendix A. Fluvial processes, related to the drainage system of the withdrawal area and the nearby surrounding area, appear to have the most significant effect on the site area and the footprint of the proposed disposal cell. DOE has identified the long-term incision advance of the tributaries of the West Branch of Kendall Wash to have the greatest potential to affect the disposal cell. DOE estimates that the headward incision rate to the north, measured from historical aerial photographs of an eastern tributary to the West Branch, could reach the southwest corner of the disposal cell in about 500 years. Increased flows in the drainage created by channeling of several drainages around the west side of the disposal cell will accelerate headcutting and shorten the time for erosion to reach the disposal cell corner. DOE has proposed rock armoring of this drainage path that will be included in the engineering design of the disposal cell to mitigate this headward erosion. Photographic evidence and field survey has shown that erosional incision advance of the present East Branch of Kendall Wash resulted in capture of an earlier drainage long ago. Incision advance of this wash and its tributaries will continue, but this erosion is 0.5 to 1.0 mi or more east of the disposal cell and is not expected to affect the site.

Crescent Wash is located to the west of the disposal cell location. DOE indicates that the tendency of Crescent Wash is to migrate eastward toward the disposal cell. However, DOE believes that the threat to the cell is low because the wash channel will likely soon follow an incipient cutoff channel, resulting in a straightening of the wash course. Long-term incision advance of a tributary of the West Branch of Kendall Wash could capture the Crescent Wash drainage after approximately 1,600 years, based on estimates of current headward erosional rates. At that time, it is estimated that the high-energy Crescent Wash channel will be about 1,000 feet west of the disposal cell, which is far enough away not to pose an erosion threat to the cell.

Mass movement processes of rock fall, landslides, and scarp retreat are confined to the Book Cliffs, which are far enough away (approximately 900 ft at the closest point) to not affect the disposal cell. DOE has calculated the expected approximate rock fall run out of large boulders falling from the face of the Book Cliffs. DOE has determined that large boulders falling from the face of the Book Cliffs would not likely pose a threat to the cell. Large boulders are located at the foot of the Book Cliffs but none are located near the footprint of the cell, supporting determination that large boulders from the Book Cliffs are not likely a threat to the cell.

Sediment will also be produced in the area between the Book Cliffs and the disposal cell. DOE intends to divert and/or capture this sediment, boulders, and other debris by the construction of a large mass of material (the “wedge”) excavated from the disposal cell. This wedge will divert surface water flows to the east and west away from the disposal cell. Additional discussion may be found in Section 4.4.1.4 of this TER.

Areas of natural subsidence have been identified. These are primarily located over 6 miles to the south of the site and are associated with the Salt Valley Anticline and the Paradox Fold and Fault Belt. DOE has determined that faulting and subsidence related to the Paradox Fold and Fault Belt is shallow and would not have an effect on the site. Eolian deposits are scarce at the site indicating wind processes are not significant.

NRC staff visited the site and observed various geomorphic features noted and evaluated by DOE. Geomorphic studies by DOE included high-altitude aerial photographs, low-angle sun aerial photographs, as well as historical aerial photography going back to 1944 and is presented in the RAP, Attachment 2, Appendix G. These photos were provided to NRC staff and evaluated by NRC staff. Geomorphic features and hazards were mapped on the RAP, Attachment 2, Appendix D, plate 1, and RAP, Attachment 2, Appendix G, plate 1.

Through the evaluation process, several hazards identified with erosion related to drainage networks were identified by NRC staff. Using historical and recent aerial photography, DOE estimated incision rates for the West Branch Kendall Run. Based on head-cutting rates, the toe of the disposal area would be at risk within approximately 200 years. DOE has taken this into account and has provided for additional erosion protection to ensure head-cutting rates are minimized and the impoundment is protected. NRC staff has reviewed the approach by DOE to protect the disposal cell from erosion and has determined that the disposal cell will be adequately protected from erosion and head-cutting by the construction of engineered rock riprap structures. Additional discussion and evaluation may be found in Section 4.4 of this TER.

Relevant geomorphic processes were identified including slope failures, rock falls, the potential for stream capture, and erosional head-cutting rates. Rock falls from the Book cliffs were analyzed by DOE and reviewed by NRC staff and determined not likely to be a hazard. Slope failures on the Book Cliffs were identified, but determined to have occurred primarily in the past, likely during wetter times in the Pleistocene. Similar conclusions were reached by others in published literature. Slope failures are not likely to be a hazard under current climatic conditions. Stream capture of Crescent Wash by West Branch Kendall Wash was considered by NRC staff. DOE subsequently determined it to be a possibility, but not likely for approximately 1600 years, based on head-cutting estimates. As discussed in Section 4.4 of this TER, the staff concludes that adequate erosion protection is provided by engineered riprap structures.

The presentation of geomorphology is acceptable and DOE has demonstrated an understanding of geomorphic processes that provides reasonable assurance that compliance with 40 CFR 192 will not be jeopardized by these processes.

2.6 Seismic Stability

2.6.1 Vibratory Ground Motion

DOE's determination of the ground motions at the Crescent Junction Disposal site from possible earthquakes in the site area and region is described in Appendix E and Appendix F of Attachment 2 of the RAP (DOE, 2008). Appendix E describes the site and regional seismicity and the results of literature search while Appendix F provides the results of the maximum credible earthquake estimation and peak horizontal acceleration.

NRC guidance suggests that DOE investigate the geologic, seismologic, and engineering characteristics of the proposed site and its environs with sufficient scope and detail to support estimates of the seismic design ground motion and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. The ground motions at the site should be estimated based on possible earthquakes that might occur in the site region and beyond. The seismic design represents the vibratory ground motion for which certain facilities must be designed to remain functional.

DOE stated that the information provided complies with NRC guidance and uses the procedures recommended.

DOE described the earthquake catalog used to define the seismic sources for the site and used the NEIC seismicity catalog, which covers the period from 1850 to 2005, and the USGS preliminary determination epicenter listings. In addition, the staff examined earthquake location maps within 100 miles of the site provided by the University of Utah.

In its review, the staff has evaluated tectonic provinces and the association between earthquakes and faulting to determine the vibratory ground motion corresponding to the maximum credible earthquake as discussed in Criterion 4 of Appendix A to 10 CFR Part 40. The standards in 40 CFR Part 192 require the disposal cell to be designed to remain stable for 1000 years to the extent reasonably achievable but in any case for at least 200 years. The staff has determined that designing for the maximum credible earthquake will meet the seismic design aspects of the 1000 year requirement in 40 CFR Part 192. In addition, the staff has engaged in oral consultations and discussion with the University of Utah Staff with respect to the seismic activities in Utah.

The Crescent Junction disposal site is located approximately 20 miles (mi) east of the town of Green River and 30 mi north north-west of the town of Moab in Utah. Utah is subdivided in three major physiographic and tectonic provinces: 1) the Basin and Range; 2) Middle Rocky Mountain; and 3) the Colorado Plateau (Wong and Humphrey, 1989). The Crescent Junction site is located in the Paradox Basin in the interior of the Colorado plateau. The Paradox Basin is characterized by systems of north-west trending normal faults and landslide features. The plateau is generally considered to be relatively stable. The historic record of seismicity in the plateau is short, and adequate seismic coverage of the area did not occur until 1970. In 1970, the University of Utah, Los Alamos National Laboratory, and the United States Geological Survey installed a regional seismic network which improved the detection of earthquakes above magnitude 2.0. Along the western margin of the Colorado Plateau lies the Intermountain Belt (IBM). This belt exhibits moderate to high level of seismicity of magnitude up to 7.4. The IBM boundary is about 125 mi from the Crescent Junction site, so the contribution of a large seismic event in the IBM at the site will be negligible.

The Crescent Junction site is located in an area characterized by low level infrequent earthquakes. Prior to 1961, the location of the earthquakes was based mainly on the felt area. Principle relevant technical resources used for describing this site are based on two other studies for Uranium Mill tailings Remedial Action (UMTRA) sites. Specifically, the seismotectonic studies from the RAP for the Green River, Utah, UMTRA site (DOE, 1991a) and the Grand Junction UMTRA site (DOE, 1991b) are heavily used in describing the tectonics at Crescent Junction.

In addressing the potential for capable faults at the site, DOE evaluated the Quaternary faults using the USGS Quaternary fault database. In addition, DOE tabulated all faults which could generate an acceleration of 0.1 g or greater at the site. RAP Appendix F, Attachment 2, Geology, lists the MCE associated with Quaternary faults and faults of unknown ages.

In its review, the staff noticed that two earthquakes, July 30, 1953 with an estimated intensity of V, and a March 31, 1954 event with an estimated intensity of IV, are located close to the Little Grand Wash Fault (Fault No. 9). In response to the staff request for additional information regarding the association of these two events with the Little Grand Wash fault, DOE stated "Based on the lack of offset in the alluvial, colluvial, and the talus materials overlying the fault, it was concluded during that study that the fault is not capable." In addition, the staff, in private communication with University of Utah seismologist, learned that the locations of these earthquakes were not accurately located and their locations were mainly associated with the closest felt area.

2.6.2 Seismotectonic Stability

The staff evaluated the seismological, geological, and geotechnical investigations DOE conducted to determine the ground motion for the site. The technical information used in the evaluation resulted from DOE's surface and subsurface geological, seismological, and geotechnical investigations performed in progressively greater detail as they moved closer to the site. The design earthquake is based upon a detailed evaluation of earthquake potential, taking into account regional and local geology, Quaternary tectonics, seismicity, and specific geotechnical characteristics of the site's subsurface materials.

The staff focused its review on DOE's efforts to correlate seismicity with known geologic features. Based on a comparison of the earthquake catalogs, DOE concluded that none of the earthquakes within the site region can be associated with a known geologic structure. In addition, DOE concluded that the catalogs do not show a unique cluster of seismicity that would suggest a new seismic source in the region surrounding the site.

In order to determine the seismic design for the site, the staff investigated and evaluated the seismicity in the area and its surroundings. The staff compared DOE's seismicity maps with the ones obtained from the University of Utah and concludes that DOE has adequately investigated the correlation of earthquake activity with known geologic sources. Based on the information submitted by DOE, the staff determined that none of the major faults within 100 miles of the site that potentially could contribute to design basis ground motion greater than 0.2 g are capable faults. DOE stated, "These features [major faults] have been active during Quaternary time and may be active today. However, since they result from very gradual processes of salt dissolution and flow, they are not likely capable of generating large earthquakes." RAP Table 3, Appendix F of Attachment 2, Geology, identifies these faults and their distances from the Crescent Junction site.

The Crescent Junction site is located about 30 miles north of the Moab site and they both lie in the same Colorado Plateau tectonic province. Probabilistic and deterministic approaches were used in estimating the seismic design at Moab (NRC, 1997). At the Moab site the mean acceleration based on a probabilistic study is estimated to be 0.21 g for a return period of 10,000 years. This value is found to be comparable to that at the Crescent Junction site. Also, the staff, using the United States Geological Survey Probabilistic Seismic Hazard map available on the internet, estimated the peak ground acceleration at Crescent Junction to be 0.2 g for a return period of 2500 years.

The staff focused its review on DOE's incorporation of the seismic wave transmission characteristics of the material overlying the base rock at the site into the determination of the design ground motion To explain how it factored the properties of the site-specific subsurface materials into the determination of the design ground motion, DOE provided a description of the shear wave velocities of the site material and stated the following, “In Campbell and Bozorgnia (2003) attenuation relations, the Peak Horizontal Acceleration equations account for site conditions of the upper 30 meters of rock or soil.”

As result of its review of the geologic and seismologic aspects of the Crescent Junction site, the staff considered the pertinent information gathered by DOE during the regional and site-specific geological, and seismological investigations. As a result of this review, the staff concludes that DOE performed appropriate investigations and provided an adequate basis to establish that no capable tectonic sources exist in the site vicinity that would cause surface deformation in the site area in the next 1000 years. The staff concludes that the site is suitable from the perspective of tectonic surface deformation and the seismic design ground motion, 0.22g, is adequately estimated.

2.7 Conclusions

DOE has determined that there are geomorphic hazards related to natural head-cutting rates of the West Branch Kendall Wash and they have the potential to affect the disposal cell during the 1000 year performance period. DOE is incorporating engineering controls into its site design to preclude destructive effects on the disposal cell during the 1000-year performance period. Other geomorphic processes are occurring at rates and locations such that they will not have a destructive effect upon the disposal site during the 1000 year performance period. The site appears to be geologically and tectonically stable and no faults or other mass movement processes were identified that would likely impact the site. The seismic design for ground motion, 0.22g, is adequately estimated. The disposal site occurs over the Mancos Shale that is sufficiently old (late Cretaceous age) that there is reasonable assurance that the site is and will remain stable for the 1000 year performance period.

3.0 GEOTECHNICAL STABILITY

3.1 Introduction

The staff has reviewed the geotechnical engineering aspects of the Final Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah Disposal Site (RAP), submitted July 2008 by the Department of Energy (DOE, 2008). The preferred action presented by DOE in this document is the relocation of the Moab Processing Site tailings and associated Residual Radioactive Material (RRM) by truck or rail to the Crescent Junction Disposal Site. The Crescent Junction Disposal Site is located approximately 31 miles north of the Moab site, and 1 mile northeast of Crescent Junction in Grand County, Utah. Disposal will consist of constructing an approximately 230-acre engineered cell partially below grade. The depth of the cell is based on fully keying into the weathered Mancos Shale bedrock, and having sufficient materials generated from cell excavation to construct the perimeter embankments and cover layers.

The RAP was reviewed against the EPA requirements presented in 40 CFR Part 192, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings using Section 2.0 of the Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites Under Title I of the Uranium Mill Tailings Radiation Control Act (NRC, 1993). This staff review includes a geotechnical engineering assessment of: 1) general information on the processing and disposal sites; 2) characterization data for materials associated with the remedial action activities, including the RRM at the Moab site, and the disposal cell foundation and excavation materials; 3) disposal cell design and construction details; and 4) the long-term stability of the waste disposal cell and its cover.

3.2 Characterization of Contaminated Materials and Disposal Site Stratigraphy

Geotechnical investigations were performed at both the Crescent Junction Disposal Site and the Moab Processing Site to define the occurrence and engineering properties of the contaminated materials and subsurface materials. Information on these materials was obtained from test pits, boreholes, coreholes, geophysical investigations, and laboratory testing.

The subsurface investigations in the area of the planned disposal cell included 5 excavated test pits, 100 soil borings to depths of practical refusal in the weathered Mancos Shale, 10 deep coreholes to a depth of 300 feet below land surface, 3 additional shallow coreholes for hydrologic testing, and seismic refraction lines to determine the ripping characteristics of the subsurface materials. Bulk, borehole, and core samples were collected and used to determine material classification, compaction characteristics, hydraulic properties, and strength properties. Three additional test pits were excavated to confirm the ripping characteristics of the weathered Mancos Shale.

Unconsolidated Quaternary material reaching a maximum thickness of 23 feet covers most of the disposal site. The deposits are typically 10 to 12 feet thick and consist of alluvial silt and clayey-silt, and some eolian sandy silts. These surface soils cover Mancos Shale bedrock, which has a thickness of approximately 2,400 feet beneath the center of the disposal cell. The top 50 feet of the Mancos is weathered.

Materials that will be used in construction of the disposal cell cover, including the radon barrier, will be obtained from the disposal cell excavation. The estimated volume of material to be excavated within the footprint of the cell is 3.19 million cubic yards of colluvial material, and 3.46 million cubic yards of weathered Mancos Shale.

At the Moab Processing Site, 24 geotechnical borings, 12 test pits, and 15 cone penetrometer soundings were advanced into the pile of RRM (tailings). Soil samples from the RRM characterization were classified for index properties, hydraulic properties, and strength properties. The results were used to develop preliminary materials-handling recommendations, and to ascertain the volume and weight of the RRM.

DOE has acceptably described the stratigraphy and geotechnical engineering characteristics of the disposal site, and the characteristics of the processing site RRM. Geotechnical engineering characteristics were determined using acceptable sampling techniques. Investigations and analyses were conducted with acceptable standards and engineering practices. Laboratory procedures and testing techniques were adequately described and appropriate standards were referenced. The geotechnical engineering characterization of the site and waste materials is sufficient to support engineering assessments related to waste isolation characteristics, permeability characteristics, and long-term stability of the disposal cell for controlling radiological hazards. On the basis of the information presented in the RAP and the review conducted of the site characterization, the NRC staff concludes that the characterization information is sufficient and acceptable, and that its use with other information, such as the results of design analyses, provides an acceptable basis to enable the staff to make a finding on compliance with applicable criteria in 40 CFR Part 192.

3.3 Slope Stability

The critical cross-section location used in DOE's analysis of the cell's slope stability was chosen, because it represents a combination of both the highest slope face of the disposal cell, and a down-sloping natural grade (see DOE Figures 1 and 2, Calculation C-10, Addendum D to the RAP). The cell cover was modeled as a 9-feet-thick layer with average properties from tests on remolded overburden and weathered Mancos Shale. The geotechnical properties of the clean fill dike and cover materials used in construction of the cell were tested at densities and moisture contents that are consistent with placement specifications. Geotechnical properties of the tailings materials were assumed based on available test results on the Moab tailings. The critical slope section was analyzed for both short-term (end of construction) and long-term conditions, under static and seismic loading.

Seismic stability was analyzed under pseudo-static conditions. Based on its Maximum Credible Earthquake estimation, DOE arrived at a predicted Peak Horizontal Acceleration (PHA) of 0.22g (see Section 2.6 of this TER). In accordance with accepted practice, the seismic coefficient for a pseudo-static analysis is equivalent to ½ of the PHA (0.11g) for an end-of-construction analysis, and 2/3 of the PHA (0.15g) for the long-term analysis.

Analyses were performed with the computer program SLIDE, version 5.0, which analyzes the slope with multiple methods to determine the lowest factor of safety. The methods include Bishop Simplified, Janbu Simplified, Janbu Corrected, Spencer, Morganstern-Price, and Corps of Engineers. In this analysis, the Spencer method results yielded the lowest factor of safety.

DOE has acceptably presented the slope stability evaluation by 1) providing an appropriate cross section and profile to accurately represent slope and foundation conditions; 2) establishing a slope steepness of five horizontal (5h) to one vertical (1v); 3) providing measurement and selection of static and dynamic properties of soil and rock using acceptable assumptions, tests, and standards; and 4) selecting a location for slope stability analyses that considers the maximum slope angle and slope height, and the weakest materials and foundation conditions. The static load analysis is acceptable and includes conservative selection of material parameters, and consideration of appropriate failure modes. The dynamic analysis is acceptable and includes: 1) a selection of an appropriate design-level seismic event; 2) computer modeling with appropriate assumptions and methods; and 3) appropriate use of the pseudo-static approach.

Regarding the geotechnical engineering evaluation of the slope stability of the disposal cell design, the staff concludes that the slopes of the cell are designed to endure the effects of the geotechnical forces to which they may be subjected, as provided in Table 3.1. The stability of the cell with respect to slope failure exceeds the generally acceptable design requirements for both short-term (end of construction) and long-term conditions, under static and seismic loading.

Table 3.1: Slope Stability Analysis Factors of Safety

Loading Condition	**Required Minimum Factor-of-Safety**	**DOE Analysis Factor-of-Safety**
End of Construction - Static	**1.3**	**2.15**
End of Construction - Pseudo-static	**1.0**	**1.31**
Long-term - Static	**1.5**	**2.78**
Long-term - Pseudo-static	**1.0**	**1.51**

Based on the information presented in the RAP and the review conducted on the slope stability of the cell, the staff concludes that, under static and dynamic conditions, the cell foundation, the slopes of the disposal cell, and the cover system will not adversely affect the cell performance due to slope failure. The results of the slope stability analyses and the associated models used provide an acceptable basis to demonstrate compliance with the applicable long-term stability criteria in 40 CFR Part 192.02(a), which requires that impoundment designs provide reasonable assurance of control of radiological hazards to be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

3.4 Settlement/Swelling

The Moab RRM will be placed and compacted in a new cell at the Crescent Junction site. The DOE evaluation of settlement in the disposal cell included calculation of the magnitude of post-construction RRM settlement, and assessment of the extent of differential RRM settlement and its impact on the cover performance.

The magnitude of primary and secondary settlement was calculated based on the following construction scenario. Natural overburden will be removed and the excavation will extend at least two feet into the Mancos Shale. Therefore, foundation settlement will be negligible. The RRM will be placed in the cell as an unsaturated material near optimum moisture content, spread in lifts, and compacted to 90% of maximum dry density with conventional construction equipment. In addition, the multi-year construction schedule for the disposal cell provides significant time for RRM drying and settlement prior to cover placement. DOE has calculated that the total settlement of the 46.7-feet-thick zone of RRM will be approximately 1.58 feet. After completion of the disposal cell, DOE plans to monitor the settlement of the cover for confirmation of cell performance.

Differential settlement of the RRM is limited to areas of the disposal cell with varying RRM thickness and loading. Cover cracking was evaluated and found not to be a concern, since the allowable strain for the cover materials (.065%) exceeded the maximum calculated strain due to differential settlement of the cover (approx .01%).

The Mancos Shale can exhibit characteristics of moderate swelling due to the possible presence within the shale of expansive clays and thin gypsum lenses. However, expansion of the shale is not considered problematic because: 1) the thickness of the shale that would be wetted is likely less than two feet; 2) there is nothing in place during the wetting period that can be damaged by swelling; and 3) the moisture content of the cell floor should remain fairly constant.

DOE has acceptably described settlement due to construction of the disposal cell. Material properties, thicknesses, and load increments used to calculate settlement are representative of site conditions. Methods used to determine settlement are appropriate for the disposal cell design and soil conditions at the site. The results of the settlement analyses are properly documented. An acceptable analysis for the development of cracks in the radon/infiltration barrier has been provided. Potential swelling impacts have been acceptably discussed.

On the basis of information presented in the RAP and the review conducted of the characteristics of the settlement and/or swelling resulting from the disposal cell construction, the NRC staff concludes that DOE's settlement and swelling analysis and associated conceptual and numerical models demonstrate compliance with the criteria in 40 CFR Part 192 applicable to stability and cover integrity.

3.5 Liquefaction

The staff has evaluated DOE's analysis of the potential for liquefaction of the RRM in the disposal cell. In this regard, the RRM materials will not be saturated, and will be placed as a structural fill. Therefore, liquefaction of the RRM is highly unlikely. However, DOE elected to perform a liquefaction analysis in the unlikely event the RRM becomes saturated. DOE conducted analyses of this liquefaction potential based on the classic Seed and Idriss methodology (Day, 1999). This involves comparison of the seismic stress ratio due to the design seismic event with the seismic stress ratio that would cause liquefaction of the RRM at a specific depth of analysis.

For the design Floating Earthquake of magnitude 6.2, the design Peak Horizontal Acceleration is estimated to be 0.22g, with no site amplification (see Section 2.0 of this TER). The DOE analysis was performed assuming the extremely unlikely situation that the entire RRM thickness is saturated. For the relative density and the measured fines content of the compacted RRM, and for the depths analyzed (top and bottom of RRM), the stress ratio required to cause liquefaction was higher than the seismic stress ratio from the design earthquake, resulting in factors of safety of from 1.4 to 3.0. Based on this, DOE concludes that liquefaction is not a concern.

DOE has acceptably evaluated liquefaction potential based on results from properly conducted laboratory tests and analyses. The methods used for interpretation of test data and calculation of stress ratios are consistent with current practice. On the basis of the information presented in the RAP and the review conducted of the liquefaction potential at the Crescent Junction disposal cell, the NRC staff concludes that the results of DOE's evaluation of liquefaction potential demonstrate compliance with the criteria in 40 CFR Part 192 applicable to stability and cover integrity.

3.6 Cover Design

The staff has completed a geotechnical review of the disposal cell cover design. The typical UMTRA Project cover used at this site would consist of: 1) an interim cover of clean native materials excavated from the cell and placed to a minimum thickness of 1-foot; 2) a 4-feet-thick compacted clay radon barrier constructed from conditioned on-site Mancos Shale; 3) a 6-inch-thick infiltration and biointrusion layer; and 4) a 3.5-feet-thick frost protection layer that includes 3 feet of random fill and the 6-inch-thick rock mulch erosion protection layer (see DOE Figure 5.1, page 5-2, Remedial Action Selection Report). The integrated components of the disposal cell cover are designed to control the release of radon from the contaminated materials, limit infiltration of precipitation, shed precipitation from the cover surface, and protect the cell from erosion and from freeze-thaw effects.

Interim Cover – A compacted interim cover will be placed on the contaminated RRM material where it has reached its full height of disposal. This layer will consist of a uniform fine-grained material that will be produced on the site by modifying the existing overburden and weathered Mancos Shale excavated from the cell. The 1-foot-thick interim cover will protect the RRM from erosion by wind and water during construction, and will minimize worker exposure to the RRM.

Radon Barrier – The first layer of final cover over the interim cover will be the radon barrier. Details of this layer's design are found in Section 6.2 of this TER. The radon barrier material will be produced by pulverizing, mixing, and wetting the excavated Mancos Shale to form a uniform fine-grained fill soil near its optimum moisture content for compaction. The purposes of the radon barrier are to limit the emanation of radon gas from the RRM into the atmosphere, and to minimize the infiltration of precipitation into and through the RRM. DOE modeling results indicate that a 4-feet-thick Mancos Shale radon barrier will control radon flux to levels below the EPA standard in 40 CFR Part 192.02(b).

Biointrusion/Infiltration Barrier – The layer immediately above the radon barrier will be a 6-inch-thick infiltration and biointrusion barrier which has two basic functions. Its sandy-gravel composition provides positive drainage off the cell for any surface water seeping through the erosion protection and frost protection layers. Also, coupled with the overlying 4 feet of erosion protection and frost protection layers, it provides a barrier to root and burrowing animal penetration into the radon barrier.

Frost Protection – Above the biointrusion/infiltration layer will be a 3.5-feet-thick random fill layer to protect underlying cover layers from degradation due to environmental factors such as freezing and thawing. Regarding the cover's frost protection aspects, DOE compiled climate data, established soil thermal properties, calculated annual frost depths using the modified Berggren formula, and extrapolated beyond the record of observed data for added conservatism. With this process, DOE established a design extreme frost penetration of 45 inches. The frost depth calculations acceptably demonstrate that this layer and the erosion protection layer above will provide adequate protection for the radon barrier from freeze-thaw effects.

Erosion Protection – The final erosion protection layer consists of three different designs, depending on location on the cell. The top of the cell will have a 6-inch-thick layer of sandy-gravel with a d_{50} of 2 inches. The east, west, and north slopes and edges will be protected by riprap with a d_{50} of 8 inches and a 3-inch-thick bedding layer. The south slope and edge will be protected by riprap with a d_{50} of 12 inches and a 4-inch-thick bedding layer. See Section 4.0 of this TER for a detailed discussion of the erosion protection design.

DOE has acceptably defined the disposal cell cover design by presenting detailed descriptions of the disposal cell excavation material types and/or soil mixtures, and the basis for their use in the cover layers. DOE has provided an acceptable schematic diagram displaying the various disposal cell layers and thicknesses. DOE also has provided a description of the applicable field and laboratory investigations and testing, and identification of design material properties for the cover layers. The properties of the cover materials have been addressed properly using appropriate methods. Adequate amounts of borrow materials with the desired material characteristics have been identified (cell excavation material) to construct the cell cover.

The staff concludes that the type and thickness of the cover materials will limit infiltration, control the release of radon, and protect the radon barrier from potential damage from freeze-thaw cycles. The staff's conclusions regarding the adequacy of the cover design to protect the disposal cell from adverse effects of erosion are presented in Section 4.4 of this TER. Additional conclusions regarding the radon emanation design and infiltration design are presented in Sections 6.2 and 3.8 of this TER respectively. From a geotechnical engineering perspective, the cover design will facilitate compliance with 40 CFR Part 192.02, which establishes requirements for disposal cell stability and control of radon.

3.7 Construction Considerations

The staff has reviewed the information provided on specifications, testing, and other construction considerations for the Crescent Junction disposal cell excavation, embankment construction, contaminated material placement, cover placement, and quality control. The construction of the disposal cell will be performed in stages to prevent excessive areas of the cell from remaining open while awaiting shipments of contaminated material, and to minimize uncovered exposure of the contaminated material. Construction of the first phase of the cell will begin at the west side of the cell and progress eastward. Excavated material from the cell will be segregated into four stockpiles for use in constructing the embankments and cell cover, i.e., topsoil, Mancos Shale, common fill, and unsuitable material. The volume of material to be excavated for the cell is 3.19 million cubic yards of colluvial material and 3.46 million cubic yards of Mancos Shale. The perimeter embankments and the cover require 0.46 million cubic yards and 2.26 million cubic yards of fill respectively, leaving 3.93 million cubic yards of excess material. The excess material will be placed as an embankment between the cell and the Book Cliffs to the north to divert surface water away from the cell.

DOE has provided a set of specifications for construction of the disposal cell. The specifications include requirements for: 1) general earthwork, including construction of the cell embankments; 2) material characteristics, placement, compaction, and testing of the RRM and interim cover; 3) material characteristics, placement, compaction, and testing of the final cover layers; 4) erosion control features; and 5) rock aggregate and riprap characteristics and placement. Table 3.2 provides a general summary of the requirements for the various materials in the cell and cover.

Table 3.2. Material Specifications Summary

	RRM	Interim Cover	Radon Barrier	Inf/Bio Barrier	Frost Protect	Rock Top	Rock Slopes	Embank-ment
Liquid Limit			>35					
Plasticity Index			10-40					
Gradation			<1”= 100% <#4= 80% <#200=50%	d_{50}=2”		d_{50}=2”	d_{50}=12” (S) d_{50} =8” (E,W,N)	
Moisture	±3% of optimum	±5% of optimum	±3% of optimum		±5% of optimum			±5% of optimum
Compaction Std Proctor	>90%	>90%	>95%		>90%			>90%
Lift Thickness	12”	12”	12”		12”			12”
Durability				Scoring criteria		Scoring criteria	Scoring criteria	

DOE will implement a third party Quality Assurance program for the duration of the project. This function is intended to ensure that all construction by the Remedial Action Contractor is in accordance with project specifications, that proper testing and inspection are performed to assure project compliance, and that the construction process is properly documented. Quality assurance audits will be performed by DOE’s Technical Assistance Contractor. The audits will review construction progress and review all inspection records and testing reports. DOE’s Remedial Action Inspection Plan (RAIP) provides details of the methods, procedures, and frequencies for testing and inspection of construction materials to verify compliance with the design specifications. It addresses cell floor (Mancos) inspection, embankment construction, contaminated material placement, interim cover and final cover (radon barrier, biointrusion/infiltration barrier, and frost protection) construction, rock armoring, settlement monitoring, and records management.

DOE has acceptably described the construction considerations by: (1) providing complete engineering drawings showing all design features; (2) describing sources and quantities of borrow material, including acceptable field and laboratory testing; and (3) identifying methods, procedures, and requirements for excavations, haulage, stockpiling, and placement of materials and demonstrating that all are consistent with accepted engineering practices for earthen works. An acceptable plan for embankment construction is provided. An acceptable plan for settlement measurement is provided and details will be provided with the future Long-Term Surveillance Plan. All tailings and contaminated materials have been demonstrated to fit within the planned configuration of the stabilized pile. An acceptable construction sequence has been described. Appropriate quality control provisions are in place to ensure that construction will be in accordance with the reclamation plan and that appropriate records will be maintained.

The construction considerations and associated specifications, inspection, and testing plans are acceptable and provide input to compliance with the EPA standards. The RAIP will provide a framework for quality control to ensure that the disposal cell will be constructed in accordance with the approved design and will meet the regulatory requirements.

3.8 Disposal Cell Hydraulic Conductivity

The staff has completed its review of the hydraulic conductivity aspects of the disposal cell. The cell cover will be constructed using fine-grained silts, clays, and weathered Mancos Shale to shed surface water and prevent long-term steady-state percolation. Engineered compaction of these materials will be used to lower the hydraulic conductivity of the cover. DOE has performed permeability tests on the weathered Mancos Shale that will be used in the radon/infiltration barrier, and has determined that the hydraulic conductivity of the Mancos compacted to 92 percent of maximum density ranges from 5.9×10^{-9} to 1.4×10^{-12} cm/sec. In addition, the sandy-gravel biointrusion/infiltration barrier will serve to drain entering water off the cell and thus limit water actually penetrating the radon barrier. For analysis purposes, the net infiltration rate through the cover is conservatively assumed to be 1×10^{-7} cm/sec. Based on the in-place conductivity of the weathered Mancos Shale being approximately 2×10^{-3} cm/sec and greater than the cover permeability, any vertical mounding and lateral spreading of leachate would occur entirely within the 50-ft-thick weathered zone, and “bathtubbing” in the cell would be prevented. Nevertheless, DOE will monitor the accumulation of any transient drainage with a standpipe tapping a sump at the down-gradient toe of the disposal cell.

For the UMTRA cover as described above, DOE has acceptably evaluated the disposal cell cover material hydraulic conductivity by providing a sufficient technical basis for the design infiltration rate for the disposal cell. It would include a 4-foot-thick compacted Mancos Shale layer, which DOE has tested and determined to have a hydraulic conductivity of less than 10^{-8} cm/sec. Therefore, the results of these permeability tests indicate that the constructability of the disposal cell with a hydraulic design infiltration rate of less than or equal to 10^{-7} cm/sec is likely, for this cover. Furthermore, the additional 4 feet of cover layers above the radon barrier will protect it from degradation mechanisms that could threaten to increase the permeability of the radon barrier.

On the basis of information presented in the RAP and the review conducted of the disposal cell hydraulic conductivity analyses, the NRC staff concludes that the determination and design of hydraulic conductivity aspects of the cell includes the information necessary to demonstrate compliance with the criteria in 40 CFR Part 192 applicable to stability and water resources protection.

3.9 Conclusions

DOE has adequately addressed all of the key geotechnical areas required for demonstrating an acceptable plan for relocation and disposal of the Atlas, Moab RRM through construction of a disposal cell at Crescent Junction, Utah. The staff concludes that from a geotechnical engineering standpoint, DOE has provided an acceptable design, and has demonstrated its compliance with applicable criteria in 40 CFR Part 192.

4.0 SURFACE WATER HYDROLOGY AND EROSION PROTECTION

4.1 Introduction

This section of the TER describes the staff's review of surface water hydrology and erosion protection issues related to long-term stability. In this section, the staff provides the technical bases for the acceptability of the licensee's erosion protection design. The RAP was reviewed against the EPA requirements presented in 40 CFR Part 192, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings using Section 3.0 of the Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites Under Title I of the Uranium Mill Tailings Radiation Control Act (NRC, 1993). Review areas that are covered include: estimates of flood magnitudes; water surface elevations and velocities; sizing of riprap to be used for erosion protection; long-term durability of the erosion protection; and testing and inspection procedures to be implemented during construction.

4.2 Hydrologic Description and Site Conceptual Design

To comply with 40 CFR 192, which requires stability of the tailings for 1000 years to the extent reasonably achievable and in any case for 200 years, DOE proposes to construct a disposal cell to protect the contaminated material from flooding and erosion. The design basis events for design of erosion protection include the Probable Maximum Precipitation (PMP) and the Probable Maximum Flood (PMF) events, both of which are considered to have very low probabilities of occurring during the 1000-year stabilization period.

As shown in Figure 6-3 of the Remedial Action Selection Report (RAS), the top surface of the cell will be configured to drain in various directions at a slope of about two percent, and the embankment side slopes will be constructed on a 1 vertical (V) on 5 horizontal (H) slope. To protect against erosion, the top and side slopes will be covered with layers of rock riprap. At the toes of the side slopes, rock riprap aprons will be constructed to provide protection against the potential migration of gullies toward the disposal cell. Several drainage channels will be constructed to convey flood flows off the disposal cell and away from the disposal area.

4.3 Flooding Determinations

The computation of peak flood discharges for various site design features was performed by DOE in several steps. These steps included: (1) selection of a design rainfall event; (2) determination of infiltration losses; (3) determination of times of concentration; (4) determination of appropriate rainfall distributions and intensities, corresponding to the computed times of concentration; and (5) calculation of flood discharge. Input parameters were derived from each of these steps and were then used to calculate the peak flood discharges to be used in the final determination of rock sizes for erosion protection.

4.3.1 Selection of Design Rainfall Event

One of the phenomena most likely to affect long-term stability is surface water erosion. To mitigate the potential effects of surface water erosion, the staff considers that it is very important to select an appropriately conservative rainfall event on which to base the flood protection designs. Further, the staff considers that the selection of a design flood event should not be based on the extrapolation of limited historical flood data, due to the unknown level of accuracy associated with such an extrapolation. DOE utilized a PMP computed by deterministic methods (rather than statistical methods) and based on site-specific hydrometeorological characteristics. The PMP has been defined as the most severe reasonably possible rainfall event that could occur as a result of a combination of the most severe meteorological conditions occurring over a watershed. No recurrence interval is normally assigned to the PMP; however, the staff has concluded that the probability of such an event being equaled or exceeded during the 1000-year stability period is very low. Accordingly, the PMP is considered by the NRC staff to provide an acceptable design basis.

Prior to determining the runoff from the drainage basin, the flooding analysis requires the determination of PMP amounts for the specific site location. Techniques for determining the PMP have been developed for the United States by Federal agencies in the form of hydrometeorological reports for specific regions. These techniques are widely used and provide straightforward procedures with minimal variability. The staff, therefore, concludes that use of these reports to derive PMP estimates is acceptable.

PMP values were estimated by DOE using Hydrometeorological Report No. 49 (HMR-49). A 1-hour PMP of 8.2 inches was used by DOE as a basis for estimating PMFs for the small areas at the site such as the top and side slopes. These procedures for estimating PMP values were reviewed, and it was concluded that the PMP amounts are acceptable for the small drainage areas at the site.

4.3.2 Infiltration Losses

The determination of the peak runoff rate is also dependent on the amount of precipitation that infiltrates into the ground during its occurrence. If the ground is saturated from previous rains, very little of the rainfall will infiltrate and most of it will become surface runoff. The loss rate is highly variable, depending on the vegetation and soil characteristics of the watershed. Typically, all runoff models incorporate a variable runoff coefficient or variable runoff rates. Commonly-used models such as the U.S. Bureau of Reclamation (USBR) Rational Formula (USBR, 1977) incorporate a runoff coefficient (C); a C value of 1 represents 100% runoff and no infiltration. Other models such as the U.S. Army Corps of Engineers Flood Hydrograph Package HEC-1 (COE, 1988) separately compute infiltration losses within a certain period of time to arrive at a runoff amount during that time period.

In computing the peak flow rate for the small drainage areas at the site, DOE used the Rational Formula (USBR, 1977). In this formula, the runoff coefficient was assumed to be 1.0; that is, DOE assumed that no infiltration would occur. Based on its conservatism, the staff concludes that this is an acceptable assumption.

4.3.3 Times of Concentration

The time of concentration (t_c) is the amount of time required for runoff to reach the outlet of a drainage basin from the most remote point in that basin. The peak runoff for a given drainage basin is inversely proportional to the time of concentration. If the time of concentration is assumed to be smaller, the peak discharge will be larger. Times of concentration and/or lag times are typically computed using empirical relationships such as those developed by Federal agencies. Velocity-based approaches are also used when accurate estimates are needed.

Such approaches rely on estimates of actual flow velocities to determine the time of concentration of a drainage basin.

Times of concentration for the riprap design were estimated by DOE using an average of several methods, including the Kirpich Method (USBR, 1977). These methods are generally accepted in engineering practice and are considered by the staff to be appropriate for estimating times of concentration at this site. Based on a review of the calculations provided, the staff concludes that the t_c values used by DOE were acceptably derived.

4.3.4 Rainfall Distributions and Intensities

After the PMP is determined, it is necessary to determine the rainfall intensities corresponding to shorter rainfall durations and times of concentration. A typical PMP value is derived for periods of about one hour. If the time of concentration is less than one hour, it is necessary to extrapolate the data presented in the various hydrometeorological reports to shorter time periods.

To determine peak flood flows for the cell, DOE developed a rainfall depth-duration curve using guidelines in NUREG-1623 and calculated the rainfall intensities for the small drainage areas at the site to be about 28-54 inches per hour. Based on a review of this aspect of the flooding determination, the staff concludes that the computed peak rainfall intensities are acceptable.

4.3.5 Computation of PMF Discharges

To estimate PMF peak discharges for the top and side slopes, DOE used the Rational Method (Chow, 1959). This method is a simple procedure for estimating flood discharges that is recommended in NUREG-1623 (Johnson, 2002). In using the Rational Method, DOE assumed a runoff coefficient equal to 1.0 and a flow concentration factor of 3. For a maximum top slope length of about 1300 feet (with a slope of 0.02) and a side slope length of about 180 feet (with a slope of 0.2), DOE estimated the peak flow rates to be about 1.28 cubic feet per second per foot of width (cfs/ft) for the top slope and 1.33 cfs/ft for the side slope. PMF flow rates for the downstream aprons were estimated by DOE and are similar to the flow rates for the side slopes.

PMF flow rates for the channels were calculated by DOE and represent an accumulation of flows down the side slopes and offsite runoff. For the various channels and drainage structures, DOE used the SCS unit hydrograph method (USBR, 1987) to calculate peak PMF flows. Based on a review of the calculations, including the time of concentration, rainfall intensity, and runoff, the staff concludes that DOE's estimated flow rates are acceptable.

4.4 Erosion Protection

The ability of a riprap layer to resist the velocities and shear forces associated with surface flows over the layer is related to the size and weight of the stones which make up the layer. Typically, riprap layers consist of a mass of well-graded rocks which vary in size. Because of the variation in rock sizes, design criteria are generally expressed in terms of the median stone size, D_{50}, where the numerical subscript denotes the percentage of the graded material that contains stones of less weight. For example, a rock layer with a minimum D_{50} of 4 inches could contain rocks ranging in size from 0.75 inches to 6 inches; however, at least 50% of the weight of the layer will be provided by rocks that are 4 inches or larger. Depending on the rock source, variations occur in the sizes of rock available for production and placement, and it is therefore necessary to ensure that these variations in rock sizes are not extreme. Design criteria for developing acceptable gradations are provided by various sources (e.g., Simons and Li, 1982), and examples of acceptable gradations may also be found in NUREG-1623.

4.4.1 Sizing of Erosion Protection

Riprap layers of various sizes and thicknesses are proposed for use at this site, and the design of each layer is dependent on its location and purpose. To reduce the number of gradations that need to be produced, DOE will place larger rock in some areas than is required. For ease of construction and to minimize the number of gradations, DOE has purposely over-designed several areas by providing larger rock than needed in many areas of the slopes and channels.

4.4.1.1 Top Slopes, Side Slopes, and Aprons

The portion of the top slope that drains to the south will be protected by a 6-inch thick layer of rock with a minimum D_{50} of about 1.8 inches. The area of the top slope draining to the north will be protected by a 6-inch layer of rock with a minimum D_{50} of 1.2 inches. Based on a review of the proposed gradation specifications, the minimum D_{50} that will be provided is about 2 inches, which is conservative.

For the north side slope of the cell, DOE proposes to use an 8-inch layer of rock with a minimum D_{50} of about 4 inches. The south side slope will be covered with a 12-inch layer of rock with a D_{50} of about 6 inches. The east and west side slopes will be protected by 6-inch layers of rock with a minimum D_{50} of 2 inches. Methods suggested in NUREG-1623 were used to determine the required rock sizes.

To protect the toe of the disposal cell and to dissipate the energy as the side slopes transition to natural ground, DOE will construct aprons along the toe of the side slopes. The area along the base of the south side slope will be protected by a rock toe/apron with a minimum D_{50} of 12 inches, while the toe of the north side slope will be protected by rock with a minimum D_{50} of 8 inches. The volume of rock was computed using a minimum depth of 3 times the D_{50} size and an apron width of 15 times the D_{50} size, or 10 feet, whichever is greater. The design criteria suggested in NUREG-1623 were used to determine rock sizes and rock volumes for the toe aprons.

Based on staff review of DOE's analyses and the acceptability of using design methods recommended by the NRC staff, the staff concludes that the proposed rock sizes for the top slopes, side slopes, and aprons are adequate.

4.4.1.2 Diversion Channels

DOE proposes to construct diversion channels at various locations in the area of the disposal cell. DOE developed peak PMF flows, rock sizes, and scour depths in accordance with methods recommended in NUREG-1623. Based on a check of the computations, the staff concludes that the peak flows, rock sizes, and scour depths are acceptable.

4.4.1.3 Channel Outlets

The diversion channels will extend several hundred feet past the edge of the disposal cell to prevent flows from directly impacting the cell side slopes. The channels will convey flows to the east and west sides of the cell and then will turn southward. At the end of the channels, the channels will be widened (termed flow "spreaders" by DOE). At the downstream end of the flow spreaders, additional rock will be provided to prevent gully headcutting into the spreaders. To reduce rock sizes to manageable levels, DOE intends to construct a pre-formed slope of 1V on 10H, and this slope will be extended to the expected scour depth. Staff review of the design of the riprap for the channel outlets indicates that the rock is large enough and extends to a sufficient depth to resist gully intrusion.

4.4.1.4 Sediment Considerations

The north side of the disposal cell would normally receive runoff directly from the area between Book Cliffs and the cell. This area will be protected by constructing a barrier using a very large quantity of excess excavated material (the "wedge"), which will act as a diversion berm to re-direct runoff away from the disposal cell. An access road between the cell and the wedge will be left in place. Runoff from the south side of the wedge will flow to the east and west in a ditch along the north side of the road, and runoff from the disposal cell will flow east and west along the south side of the road. See Figure 6-7 of the RAS.

The wedge will provide protection for the disposal cell by reducing the amount of runoff that is carried in the diversion channels to the north of the cell. Also, the wedge will reduce the amount of sediment entering the diversion channels. DOE performed sediment analyses to show that the wedge will accumulate sediment on its north side, but will be capable of re-directing flows away from the disposal cell.

DOE's analyses indicate that sediment will be produced on the south slope of the wedge and that sediment from the wedge will fill and overtop the unlined channel north of the access road. This excess sediment will be deposited in the rock-lined channel south of the road. DOE provided analyses to show that the riprap sizes are large enough to resist the increased velocities associated with a reduction in channel capacity and an increase in discharges associated with overtopping of the unlined channel.

4.4.2 Riprap Gradations

Riprap gradations for each of the different rock sizes and layers were selected by DOE using basic gradation criteria Based on review of the gradations provided, each layer thickness, gradation, and minimum rock size is acceptable.

4.4.3 Rock Durability

The previous sections of this TER examined the ability of the proposed erosion protection design to withstand flooding events reasonably expected to occur in a 1000- year period. In this section, rock durability is evaluated to determine if there is reasonable assurance that the rock itself is durable and will survive and remain effective for 1000 years. Rock durability is defined as the ability of the rock to withstand the forces of weathering. Therefore, rock durability is a key factor in evaluating the long-term stability of the rock cover. For rock to remain effective to control erosion, the rock size selected should not be reduced by weathering processes. Therefore, if the rock size used for the cover does not diminish over the 1000-year compliance period, its ability to control future erosion will be sustained. However, uncertainties exist with estimating future rock durability for 1000 years. As a result, NRC guidance identifies three evaluations of rock durability to provide multiple and complimentary lines of evidence and greater confidence in the sustained durability of the rock source selected. These evaluations are: 1) rock durability testing and scoring; 2) absence of adverse minerals and heterogeneities; and 3) evidence of resistance to weathering. Information for each of these evaluations was provided by DOE and the staff's review is described below.

4.4.3.1 Selection and Description of Rock Type and Source

Description of the rock types and deposit that is proposed for the rock source is important to understanding the variability of the deposit or formation containing the proposed rock source (e.g. percentage of each rock type), and the variability within the proposed rock source (e.g. different fabrics that could affect rock durability and resistance to weathering). Understanding the variability of the deposit/formation and each rock type are important to obtaining representative samples for durability tests and developing rock production procedures that may be needed to mitigate adverse rock types in the deposit/formation.

DOE has selected a basalt as a rock source from a site approximately four miles east of Fremont Junction, Utah, which is approximately 95 miles west of the Crescent Junction site. NRC approved DOE's use of this rock source in 1988 for its use in the erosion cover for the Green River UMTRA disposal cell in Green River, Utah. The Fremont Junction site consists of 400 acres of property owned by the State of Utah School of Institutional Trust Lands Administration that has been permitted for the purpose of mining ordinary sand and gravel. The basalt-bearing deposit at the Fremont Junction site is a Quaternary pediment-mantling alluvial deposit of Quaternary age.

DOE's selection of the Fremont Junction basalt is based on the combined results of the 1988 evaluations of the basalt for the Green River disposal cell and the recent studies in 2007 and 2008 for the Crescent Junction site. The 1988 evaluations consisted of field observations at two test pits, durability tests, petrographic analyses, and x-ray diffraction analyses. The 2007 and 2008 evaluations include field observations at eight test pits, durability tests, observations of the basalt on the Green River disposal cell, and natural analogue studies that provide evidence of long-term resistance to weathering. The basalt used at Green River was excavated from the same alluvial deposit about one mile northeast of the areas that would be excavated for the Crescent Junction site. Therefore, the 1988 petrographic analyses and x-ray diffraction analyses were used and not repeated in 2008.

The Fremont Junction deposit includes an overburden layer at the surface that is approximately eight feet thick that consists of clayey sand and clayey silt with a small percent of basalt clasts with caliche crusts, a reddish relic soil layer, and in places a white calcified zone. Beneath the overburden layer is the alluvial deposit that is at least 20 feet thick and consists of 15-45 % subrounded cobbles and boulders of basalt and other rock types such as tan sandstone, limestone, chert, and quartzite. Matrix material supports the cobbles and boulders and consists of sand and gravel up to three inches. DOE's rock production procedures discussed in Section 4.4.4, include screening to separate the matrix material from the cobbles and boulders of basalt and non-basalt that would then be crushed to the sizes specified for use as cover material.

Based on the estimates of rock types and alluvial deposit thickness, DOE estimates that the volume of useable rock should be at least twice the volume required by the design of the erosion cover.

DOE estimates that the cobble and boulder portion of the alluvial deposit includes about 95% dark gray basalt and 2-3% red basalt. These two types of basalt were likely derived from two different sources that are 15 to 20 miles southwest and south-southwest of the site. The remaining non-basalt lithologies in the alluvial deposit make up about 2-3%. The tan sandstone and limestone cobbles and boulders are soft and nondurable, whereas the chert and quartzite cobbles appeared to be at least as hard and durable as the basalt. The estimates of the non-basalt lithologies and their respective rock durability scores are important to conclusions about how much of this material is acceptable and unacceptable for use. The rock production procedures in Section 4.4.4 discuss how the unacceptable material, such as the tan sandstone, would be removed from the deposit either by crushing, which would reduce its percentage further, or removal of the boulders before crushing.

4.4.3.2 Rock Durability Testing and Scoring

Rock durability testing and scoring following the procedures in NRC's guidance in NUREG-1623 is one of the evaluations DOE used for determining the acceptability of the Fremont Junction rock source for its Crescent Junction erosion protection cover. This evaluation procedure provides a consistent and quantitative way to evaluate rock sources at NRC regulated sites using ASTM tests for parameters that are good indicators of rock durability (i.e., specific gravity, absorption, sodium sulfate soundness, and L/A abrasion).

DOE provided durability test data of samples from the Fremont Junction area collected in 1988 and 1989 for the Green River disposal cell and in 2007 and 2008 for the Crescent Junction site. Tests were conducted on samples from the gray and red basalts. Results from specific gravity, absorption, sodium sulfate soundness, and L/A abrasion tests were provided and then used to develop rock scores following NRC's guidance in NUREG-1623.

The scores of the 1988 samples for the Green River disposal cell ranged from 66.7% to 79.4%. The sample that scored 66.7% was described in the 1988 report as severely weathered. However, DOE's 2008 evaluation concludes that these samples were likely the vesicular red basalt. DOE's 1988-1989 quality control testing and scoring of four samples collected during the placement of the basalt cover at the Green River disposal cell resulted in additional and higher scores for the Fremont Junction basalt. Scores for the Type A rip rap ranged from 78 to 90% with an average of 85%. Scores for the Type B rip rap ranges from 80 to 90 % with an average of 83%.

DOE's scores from the 2007 and 2008 samples provided additional results. The gray basalt, which makes up approximately 95% of the alluvial deposit, had scores of 82.9 and 83.3. These scores exceed the 80% score that indicates a high quality rock that can be used for most applications according to NRC's guidance. The red basalt that makes up approximately 2-3% of the basalt had a score of 63.7 which is similar to the 1988 initial score. Although the 63.7% score is lower than the gray basalt, it is in the range for rock that would be acceptable for use in non critical areas. DOE noted that the sample of the red basalt was softer than the gray basalt; possibly because it was vesicular. During the June 25, 2008 site visit, field observations of cobbles and boulders of dense non-vesicular red basalt appeared to both DOE and NRC staff to be more competent than the vesicular red basalt that had a low score.

4.4.3.3 Absence of Adverse Minerals and Heterogeneities

DOE used information from field observations and the 1988 petrographic and x-ray diffraction analyses to identify if adverse heterogeneities or adverse minerals were present that could be vulnerable to weathering. Field observations were used to identify large scale adverse heterogeneities such as the undesirable overburden layer and fine grained matrix sediments supporting the cobbles and boulders in the overall deposit. As discussed in Section 4.4.1, DOE proposes to remove the overburden layer before excavation of the basalt alluvial deposit. DOE also proposes to screen out the finer matrix material from the basalt cobbles and bounders.

The petrographic and x-ray diffraction analyses were used to identify if adverse minerals that could be susceptible to weathering, such as olivine and clay, are present and if so in what amounts. DOE's 1988 petrographic analyses concluded that the samples lacked significant amounts of adverse minerals such as calcite, clays, olivine, and feldsphathoids. X-ray diffraction analyses determined that the basalt samples contained only 1% olivine.

The field observations and petrographic analyses also identified the non-basalt lithologies in the deposit and those lithologies that might be unacceptable and excluded by rock processing procedures. The non-basalt lithologies making up about 2-3% of the cobbles and boulders, consist of tan sandstone, limestone, chert, and quartzite. The sandstone appeared to be friable in field observations. The petrographic analysis of the sandstone indicated surface weathering is moderate and consists of pitting due to leaching of carbonate grains that penetrated one quarter of an inch. The 6% calcite occurred as recrystalized limestone grains and the 5% clay occurred as rock fragments. Although this undesirable sandstone makes up a very small part of the cobbles and boulders, as discussed in Section 4.4.1, DOE proposes to minimize this lithology by crushing and screening as well as removal of large boulders, if necessary.

4.4.3.4 Evidence of Resistance to Weathering

Evidence of resistance to weathering can be both direct and indirect. DOE's 2007 and 2008 field observations of the eight test pits did not show evidence of significant weathering of the basalt such as weathering rinds. To confirm these observations and to resolve the 1988 report of an upper weathered zone and weathering rinds on the red basalt, DOE also observed the crushed basalt used on the cover of the Green River disposal cell and the subrounded basalt boulders in the Green River channel. This basalt from the same deposit at Fremont Junction provided a large "exposure" of the basalt that was clean and free of the fine material and dust that limited observations in the test pits at Freemont Junction. DOE did not observe any weathering rinds on either the dark gray or red basalt. DOE concluded that the descriptions of weathering rinds from the 1988 investigation possibly were interpreted to be the thick caliche crusts on some basalt clasts. Thus, more recent DOE investigations, as well as NRC observations during a site visit, confirm the absence of weathering zones or weathering rinds on the Fremont Junction basalt.

The only evidence of basalt weathering was the leaching of olivine crystals by chemical weathering on the surface of a sample observed in the 1988 petrographic analyses. This analysis also noted that the olivine crystals observed in the interior of the sample had not been weathered. As mention above, the x-ray diffraction analysis indicated that olivine only made up 1% of the sample analyzed.

Because of the absence of quantitative weathering rate studies for basalt as well as other rock types, NRC's guidance in NUREG-1757 notes that indirect evidence of resistance to weathering can add confidence in the durability and slow weathering of rock types selected for long-term erosion protection. DOE identified the following geologic analogues to show that the Fremont Junction basalt has remained resistant to weathering for thousands of years and well beyond the 1000-year regulatory period required.

- Basalt boulders may have resisted weathering for 500,000 years based on the estimated age of the alluvial deposit, using a published steam downcutting rate for this part of the Colorado Plateau.
- Basalt boulders have resisted weathering for possibly 8,000 to 10,000 years based on the estimated age of wind-fluted surfaces on exposed basalt boulders caused by wind driven sand.
- Rock varnish on exposed basalt boulders may have been formed several thousand years ago.
- Lichen cover on exposed basalt boulders may have been in place for hundreds of years.
- Basalt boulders buried at depths of three to six feet in the overburden commonly have white calcium carbonate crusts, which can take tens of thousands of years to form, indicating these boulders have been in place for many thousands of years without noticeable weathering effects.

4.4.3.5 Conclusions

Based on the review of DOE's evaluations, the staff concludes that: 1) durability test results and scores demonstrate acceptable physical properties of the Fremont Junction basalt; 2) adverse minerals such as olivine and clay are present in very small amounts (1%) and adverse heterogeneities, such as friable sandstone and matrix sand and gravel, can be identified and avoided when rock is excavated or screened and crushed in processing: 3) there is direct evidence from the Fremont Junction deposit and Green River disposal cell cover of the absence of weathering such as weathering rinds; and 4) indirect evidence from natural basalt analogues add confidence that basalt weathering rates are slow and the basalt has resisted weathering for thousands of years at the Fremont Junction area. Based on these evaluations, the staff concludes that the Fremont Junction basalt is durable and should resist weathering and associated size reduction for at least the 1000 year compliance period. Therefore, the staff considers that the Fremont Junction basalt is acceptable for use in the erosion controls at the Crescent Junction site. This conclusion is consistent with NRC's previous approval of the basalt for use at the Green River disposal cell.

4.4.4 Testing and Inspection of Erosion Protection

DOE provided information regarding testing, inspection, and quality control procedures to be used for the erosion protection materials.

4.4.4.1 Rock Selection During Production

As discussed above, DOE has selected the Fremont Junction basalt as it rock source. Based on information provided by DOE in Sections 6.6 and 6.7 of the RAP and as discussed above in Section 4.4.3.1, it appears that the rock in the proposed quarry could be somewhat variable, depending on the location where rock will be produced within the quarry. DOE provided information to document the quality assurance and quality control (QA/QC) procedures that will be implemented during rock production to address this variability and to assure that rock of acceptable quality will consistently be produced.

The overall goal of the rock selection procedure is to minimize the potential that unsuitable rock is produced. To accomplish this, DOE intends to strip overburden from the alluvial deposits and to stockpile this material in a manner where it is separated from the basalt cobbles and boulders. Rock materials will be excavated, crushed, and screened into stockpiles of various sizes. The rock will then be crushed and further screened, as necessary, to produce the required rock sizes. These primary and secondary sorting processes should assure that rock will be relatively homogeneous and that visible portions of the stockpiles will be representative of the entire stockpile. Crushing and screening will also remove significant amounts of weak, friable materials (i.e., tan sandstone and limestone), resulting in a product that contains only limited amounts of poor-quality materials. In the unlikely event that a stockpile contains significant unacceptable rock, the lower quality material (i.e., tan friable sandstone and limestone) would be extracted to assure that no more than 10% by volume is present in the final product.

On June 26, 2008, the staff directly observed the Fremont Junction site. Based on observations during that site visit and information provided by DOE in Sections 6.6 and 6.7 of the RAP, the staff concludes that the proposed program for rock production is acceptable.

4.4.4.2 Durability Testing

DOE proposes that rock durability testing will be performed a minimum of four times and/or at a frequency of one test for every 10,000 cubic yards of material produced. This testing frequency is recommended in NUREG-1623 and is equivalent to others approved by the staff and have been implemented at other reclaimed sites during construction.

DOE's proposed rock durability testing program will include the following tests, shown with their American Society of Testing and Materials (ASTM) designation:

1. Bulk Specific Gravity - ASTM C 127
2. Absorption - ASTM C 127
3. Sodium Sulfate Soundness - ASTM C 88
4. L.A. Abrasion at 100 cycles - ASTM C 131 or ASTM C 535
5. Schmidt Rebound Hardness - ISRM Method

Based on a review of the proposed procedures, the staff concludes that an acceptable durability testing program has been provided to ensure that rock of acceptable quality will be provided. The testing program was developed using suggested staff guidance in NUREG-1623 and is equivalent to several which were approved by the staff and have been implemented at other reclaimed sites during construction.

4.4.4.3 Gradation Testing

DOE proposes that rock gradation testing for each gradation will be performed a minimum of four times and/or at a frequency of one test for every 10,000 cubic yards of material placed. This testing frequency is recommended in NUREG-1623 and is equivalent to others approved by the staff and have been implemented at other reclaimed sites during construction.

4.4.4.4 Riprap Placement

DOE indicates that riprap will be placed using a computerized placement method where the equipment is calibrated to assure that proper thicknesses of rock are placed. In addition, DOE provided specifications for placement of the rock that will confirm that the riprap layers will be placed to the depths and grades shown on the drawings and that riprap will be placed in a manner to ensure that areas of segregation do not exist. Based on a review of the information provided by DOE, the staff concludes that the proposed procedures are sufficient to ensure acceptable placement of the riprap.

4.5 Conclusions

Based on review of the information submitted by DOE and on independent calculations, the NRC staff concludes that sufficient information has been provided to justify that the erosion protection design is adequate to provide reasonable assurance of protection for 1000 years, as required by 40 CFR 192.

5.0 WATER RESOURCES PROTECTION

5.1 Introduction

Water resources protection was reviewed in accordance to the review procedures for contained in the Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites under Title I of the Uranium Mill Tailings Radiation Control Act (SRP), Section 4.3. The review procedures outlined in the SRP serve as review guidelines for determining if the site investigations were adequate enough in scope and technique to provide the necessary data for hydrologic characterization and disposal standards. Not all the review procedures in the SRP apply to this site as the uranium processing site is not at this location.

5.2 Site Characterization

5.2.1 Identification of Hydrogeologic Units

The proposed disposal cell location is overlain by a 20 to 25 foot thick layer of unconsolidated alluvial outwash material and colluvial material derived from the adjacent book cliffs. This alluvial/colluvial material does not contain measurable water and is not considered a hydrologic unit. This could be expected in an arid region where the evaporation rates are much higher than the rainfall and infiltration rates. Evaporation rates at the Crescent Junction site are approximately 60 inches per year while the site receives approximately 9.1 inches of rainfall per year. Hydrologic properties were not determined for the overlying alluvial/colluvial material since the material is dry, will be wholly excavated from the disposal cell and will be isolated from disposal cell leachate by the cell design.

Below the mantle of alluvial/colluvial material is the Mancos Shale, which is a 4000 foot massive shale unit, of which approximately 2400 feet lies beneath the site. The top 50 to 100 feet of the Mancos Shale that lies beneath the site is considered the “weathered Mancos Shale” and has hydraulic conductivities higher than the “unweathered Mancos Shale” that lies below. The weathered Mancos Shale is identified by DOE as having bedding plane fractures and high angle fractures that are not present in the unweathered Mancos Shale. The transition between the weathered and the unweathered Mancos Shale occurs between approximately 50 to 100 feet below the top of the Mancos Shale. The Mancos Shale contains localized pockets of water, but this water is not considered potable water as the water contains very high concentrations of dissolved solids. Further evidence that the Mancos Shale is not a potable source of water is the fact that the nearest water source to the site is the Big Thompson Spring that is located seven miles to the north east. This spring is located near the top of the Neslen Formation which is a part of the Cretaceous Mesaverde Group that is stratigraphically above the Mancos Shale. The nearest groundwater well to the site is approximately 15 miles to the south west at the Grand County Airport and uses water from 800 to 1200 feet below the airport.

The Dakota Sandstone lies below the Mancos Shale and is approximately 2400 feet below the surface of the site. The Dakota Sandstone is a source of potable water in the region and is therefore considered the uppermost aquifer for regulatory purposes outlined in 40 CFR 192. Hydraulic properties were not determined for the Dakota sandstone. This is based on the approximate 2400 foot depth to the Dakota sandstone and the determination that leachate is unlikely to reach the Dakota sandstone for at least 3,330 years, at a minimum (DOE, 2008, Attachment 3).

The Mancos and Dakota bedrock hydrologic units at the site are dipping to the northeast at approximately 10 degrees. DOE advanced 10 core holes through the overlying alluvial material and 300 feet into the Mancos Shale. No faults, slickensides or notable geologic structures were identified. There are no known faults or structural features found within the Mancos Shale underlying the site.

DOE has provided adequate stratigraphic and geologic information to adequately define the geologic units at the site. DOE has provided hydrogeologic information to identify hydrogeologic units, including the geometry, lateral extent, and thickness of all potentially affected aquifers and confining units at the disposal site. DOE has provided a hydrologic conceptual model of the units found at the proposed disposal cell site. Identification of hydrologic units is from a combination of on and off site geologic mapping, published literature, core holes, and monitoring wells advanced up to 300 feet into the Mancos Shale. The Mancos Shale is considered Class IV, saline ground water, by the State of Utah. Total dissolved solids concentrations in groundwater from seven on site wells ranged from 23,000 mg/L to 42,000 mg/L, levels that are considered very saline to briny. Since the Mancos Shale does not contain potable water, DOE has identified the uppermost aquifer as the Dakota Sandstone, the only aquifer and potential potable source of groundwater at the site. NRC staff agrees with this determination. There are no known water users of the Dakota Sandstone in the immediate vicinity of the site. DOE has provided climatic data, geologic data, and surface water data that are integrated into the hydrologic characterization where applicable.

5.2.2 Hydraulic and Transport Properties

Hydraulic and transport properties have been estimated by field testing of the weathered Mancos Shale. Hydraulic conductivity was estimated for the weathered Mancos Shale using the air-entry permeameter test. The methodology used for the air-entry test is discussed in detail in the RAP, Attachment 3, Appendix A (DOE, 2008). The geometric mean of the weathered Mancos Shale using this test was estimated at 1.2×10^{-4} cm/sec and is reported in the RAP, Attachment 3, Appendix A.

Field permeability “bail” testing was also used to estimate the hydraulic conductivity of the unweathered Mancos Shale. This was done by removing water in several monitoring wells and monitoring well recovery data. The assumption was made that the unweathered Mancos Shale would have a low hydraulic conductivity that would allow for this type of test. The methodology used for the field permeability “bail” test is discussed in detail in the RAP, Attachment 3, Appendix B. The geometric mean was estimated to be between 2.5×10^{-6} to 3.1×10^{-7} cm/sec and is reported in the RAP, Attachment 3, Appendix B.

Both the weathered and unweathered Mancos Shale were tested for hydraulic conductivity using field-permeability packer tests. The methodology used for the field permeability “bail” test is discussed in detail in the RAP, Attachment 3, Appendix C. This series of tests estimated hydraulic conductivities in the range of 10^{-3} cm/sec for the weathered and 10^{-7} cm/sec for the unweathered Mancos Shale. This data is reported in the RAP, Attachment 3, Appendix C.

DOE also performed systematic pumping tests on the 300 foot core holes and monitoring wells to determine if water contained within the Mancos Shale was interconnected or occurred in isolated pockets. The methodology used for the systematic pumping tests is discussed in detail in the RAP, Attachment 3, Appendix D. Results from the study were mixed as only five of the ten core holes contained sufficient water to conduct the tests. Of the five tested, only one core hole showed a decreased volume of water indicating that water may be in an isolated pocket and is becoming depleted. The other four wells yielded constant volumes of water that DOE believes indicate that connate water may be held in much larger compartments and additional pumping would be required to deplete the water. DOE has indicated that since five of the holes are dry and one showed depletion, this lends credence that the other four contain larger compartments of water. This theory is speculative and may or may not be the case; however, NRC staff has determined that this is not a major concern as geochemical testing has shown that all the water within the site is extremely saline and not potable.

Hydraulic properties were not determined for the overlying alluvial/colluvial material as all of this material will be excavated from the disposal cell and will be isolated by cell design from cell leachate.

The vertical transport time of constituents potentially seeping from the tailing impoundment and affecting the uppermost aquifer, the Dakota sandstone, was also estimated. The methodology used for approximating the vertical transport time from the tailings impoundment to the uppermost aquifer is discussed in detail in the RAP, Attachment 3, Appendix E. DOE did not field determine an effective porosity, but instead used an effective porosity range of .5 to 5 percent, which is more conservative than that of 10 percent as suggested in the Section 4.3.1.3.2 of the NRC SRP. The calculated vertical travel time between the Mancos Shale and the Dakota Sandstone ranged between 3,330 and 33,300 years, which is much greater than the 1000 year design standard. While this is a large range, NRC staff agrees with the DOE that uncertainties of the variable used in the calculation, hydraulic gradient, hydraulic conductivity, and effective porosity, lead to a large range of values and that even the lowest range calculated is a conservative estimate.

DOE has also performed calculations to estimate the potential for mounding below the tailings cell and resultant lateral leachate spreading. These calculations are reported in Attachment 3, Appendix G. DOE used a set of conservative assumptions in the calculations to determine if leachate mounding would occur below the tailing cell. Additionally, DOE calculations estimated how far leachate would spread laterally at the interface between the weathered and unweathered Mancos Shale which is located approximately 50 feet below the base of the tailings cell. The calculations were performed using both the upper-bounding and lower-bounding geometric mean hydraulic conductivities that were obtained from field tests in the weathered Mancos Shale. The calculations showed a potential mounded surface of approximately 16 feet above the interface of the weathered and unweathered Mancos Shale and a lateral spread of approximately 3340 feet at 1000 years when using an upper-bounding hydraulic conductivity of 2059 ft/yr. A second calculation showed a potential mounded surface of approximately 33 feet above the interface and a lateral spread of approximately 1200 feet at 1000 years when using a lower-bounding hydraulic conductivity of 124 ft/yr. These values reflect that if water moves faster within shale, water will not mound as much but will spread farther laterally because the leachate moves faster. Conversely, if water were to move much slower, leachate will mound much higher and spread laterally at a much slower rate. The higher-bounding hydraulic conductivity with greater lateral spreading is the most conservative estimate presented, and in effect, shows a worst-case scenario. DOE has produced a cross section and map view of possible lateral spreading at the site using the conservative calculation with the upper–bounding hydraulic conductivity of 2059 ft/yr. NRC staff has determined that the calculation presented is indeed conservative as it relies on a set of conservative assumptions that are presented in the Appendix.

DOE has also indicated (in Appendix G) that using realistic assumptions, they expect the mounding and lateral spreading to be less than under either scenario using hydraulic conductivities of 2059 ft/yr or 124 ft/yr. Using the realistic assumptions, DOE doesn't anticipate any mounding or lateral spreading of cell fluid during long-term steady state conditions. While this may be the case, NRC staff has determined there is some uncertainty of how the cell will perform over time. However, this is an area where groundwater monitoring for expected performance of the tailings cell and the behavior of leachate within the Mancos Shale, if any, can easily be measured at the site.

DOE has proposed to monitor groundwater for the presence of leachate by converting coreholes 0202, 0203, 0205, and 0210 into monitoring wells that will be screened through the weathered Mancos Shale and into the unweathered Mancos Shale. These wells are located in all four compass directions around the proposed tailing cell. DOE proposes to monitor these wells for three years following initial placement of tailings into the tailings cell, and every three years thereafter. NRC staff agrees that this is sufficient monitoring over the long-term to determine that no leachate is migrating from the tailings cell into the Mancos Shale, or if leachate is migrating, it is migrating within the bounds established by DOE in their conservative calculations (DOE, 2008, Remedial Action Selection Report).

DOE has performed an adequate analysis of the hydraulic and transport properties of the site. Details on the ground water flow characterization have considered the hydraulic properties and geologic features of the primary geologic unit at the site, the Mancos Shale, that may affect the rate and direction of ground water advection. The Dakota sandstone is approximately 2400 feet below the surface of the site underlies the Mancos Shale. The Dakota sandstone has been identified by DOE as the uppermost aquifer and NRC staff agrees with this determination based on the evidence provided. The characterization has included onsite testing and analysis of the hydraulic conductivity of the weathered and unweathered Mancos Shale using air-entry permeameter tests, permeability "bail" testing, and field-permeability packer tests. DOE also conducted pumping tests in an attempt to show that water in the Mancos Shale was isolated and contained in pockets. While this test was not conclusive, it is unlikely to have a great bearing on the site suitability. The groundwater within the Mancos Shale has been shown to be extremely saline. As discussed in the next section of the TER, the DOE has literature and personal communications from technical experts that have studied the Mancos Shale. These experts believe the water within the shale is connate water that has been present since the formation was deposited and the NRC staff has no reason to doubt the validity of this theory. The disposal cell has been designed with four locations for standpipes along the down gradient interior boundary of the cell to monitor the presence or absence of cell fluids. DOE will also monitor the long-term performance of the cell using four monitoring well that are located in all four compass directions around the tailings impoundment.

5.2.3 Geochemical Conditions

DOE sampled water from several monitoring wells developed within the Mancos Shale. Water was sampled for a range of constituents normally found in leachate from uranium mill tailings cells. These values are reported in Attachment 5, Appendix H. DOE has shown that water contained within the Mancos Shale is extremely saline to briny and not potable. The total dissolved solids for the shale from on site monitoring wells ranges from 23,000 mg/L to 42,000 mg/L, which is unfit for human or livestock consumption. This water is classified as *Class IV, Saline Ground Water* by the State of Utah. Since these levels are greater than 10,000 mg/L, this water is also meets the definition of limited use ground water as defined in 40 CFR 192.11. DOE also has suggested that water in the Mancos Shale is likely connate water. Connate water refers to the liquids that were trapped in the pores of sedimentary rocks as they were deposited. This interpretation is supported by published literature and personal communication from technical experts that have studied the Mancos Shale (DOE, 2008, Attachment 5).

DOE tested the theory that the water is very old water trapped in compartments within the Mancos Shale, possibly even connate water. This determination was inconclusive. DOE also used radiocarbon dating techniques to determine a relative age of the water. DOE assumed that if the water is very old, or possibly connate, the water would be devoid of any carbon. Samples devoid of carbon would indicate the water was older than 40,000 years before present (BP), based on the half-life of carbon, which is the detection limit for the test. While a date range for the water was undetermined by the test, the water was found to be greater than 40,000 years BP, the detection limit of the test, in 5 of 6 samples. One sample was found to be in the range of 38,650 years BP, and is thought to have likely been contaminated by modern-day atmospheric carbon that may have been introduced into the sample. In any event, the radiocarbon dates do show that the water is very old. The radiocarbon test is not conclusive as to whether the water is connate water, but does show the water is very old, and much older than the performance requirement for the tailings cell of 1000 years.

DOE has performed geochemical attenuation and performance assessment modeling to help evaluate the attenuation of contaminants in groundwater that may migrate from the tailing cell. Samples of the Mancos Shale were taken from 10 core samples distributed throughout the site. Results of the laboratory investigation provided information about the Mancos Shale including abundance and mineralogy of water-soluble minerals, mineralogy of water-insoluble minerals, including clays, cation exchange capacity, surface area, and chemical distribution ratios. These data were used to develop a one-dimensional reaction-transport model of the tailings water transport throughout the Mancos Shale. Horizontal flow through the upper Mancos Shale and vertical flow through the deeper Mancos Shale were modeled using the PHREEQC code. Results indicated that NH_4 migration is retarded by several pore volumes while uranium is retarded by about one pore volume if calcium is released from gypsum dissolution (DOE, 2008, Attachment 4).

DOE expects that geochemical processes at the site are likely to attenuate concentrations of ammonia and uranium which might leach from the disposal cell over time. Chemical retardation of ammonia is expected to occur primarily through ion exchange with sodium, potassium, calcium, and magnesium. Uranium attenuation is expected to occur from geochemically reducing conditions that are expected to exist at increasing depth within the carbonaceous Mancos Shale. DOE uses the natural occurrence of natural gas pockets that were encountered during the project and that have been reported in the area in the past as evidence for geochemical reducing conditions at depth. DOE expects the Mancos Shale beneath the site to naturally attenuate any dissolved chemical species that may leach from the site by a factor of one to three.

While DOE has taken several samples that can be used for background conditions, no specific hazardous constituents of concern were identified. DOE has designed the cell that will allow leaching into the underlying Mancos Shale. DOE has estimated that constituents leaching from the tailings impoundment will be hydraulically isolated from the uppermost aquifer because of the hydrogeologic characteristics of the Crescent Junction Site and the cell design.

DOE has taken several samples that can be used to determine background water quality of water contained within the primary hydrologic unit at the site, the Mancos Shale. The water quality of the uppermost aquifer, the Dakota sandstone, was not determined due to the extreme depth below the site. NRC staff agrees that water quality for the Dakota sandstone is unnecessary for this site due to the depth of the formation. DOE has adequately determined the geochemistry and hydraulic properties of the Mancos Shale. Water within the Mancos Shale is extremely saline to briny and is not used for human or livestock consumption. DOE has postulated that water within the Mancos Shale is connate water and is trapped in isolated pockets. NRC staff is reluctant to accept this theory based on the information provided, but DOE has been able to show through radiocarbon dating that the water is extremely old and likely greater than 40,000 years old. Based on the regulatory performance period of 1000 years, it is irrelevant if the water is connate water or not, or if the water is isolated in pockets or not. NRC staff does agree that the water in the Mancos is very old, is geochemically very saline to briny, and is not potable for human or livestock consumption. NRC staff expects that natural attenuation will occur within the Mancos Shale due to the wide range of chemical species within the shale and the likely reducing conditions which should increase the time that it would take for contaminants potentially leaching from the cell, to reach the uppermost aquifer. Fluid migration is estimated to take between 3,330 and 33,300 years to reach the uppermost aquifer, and additional chemical retardation will act to delay the arrival of contaminants. This is further evidence to provide reasonable assurance that the 1000 year disposal standard will be met as required under 40 CFR 192.

5.2.4 Water Use

The nearest groundwater well to the site is 15 miles south of the site at the Grand County Airport. Groundwater is pumped from wells ranging from 800 to 1200 feet below the Grand County Airport. The nearest potable water is from Big Thompson Spring, 7 miles to the northeast of the site. Depth to the uppermost aquifer, the Dakota sandstone, is over 2400 feet below the site. There are no perennial streams or rivers located near the site. On site geotechnical borings have shown that the approximately 25 feet of alluvial/colluvial material that overlies the Mancos Shale is dry. Groundwater monitoring wells constructed in the Mancos Shale and resulting samples indicate that water within the Mancos Shale is unfit for human consumption and is very old, likely greater than 40,000 years old. Ten monitoring wells were developed 300 feet into the Mancos Shale. Of those, three were dry.

DOE's compliance strategy is hydraulic isolation from nearby water users. Based on the evidence provided by DOE, NRC staff agrees that water at the site is hydraulically isolated from nearby water users. DOE has adequately demonstrated that the site is isolated and that there are no water users within the boundaries of the site and will likely not be any users near the site. There are no perennial rivers or steams in the area and DOE has adequately shown that contaminants will likely be contained within the Mancos Shale and not manifest at or near the site as seeps or discharges in dry swales or creek beds.

5.3 Conceptual Design Features

DOE has designed the cell cover to limit infiltration into the cell. Above the contaminated RRM, DOE will construct an interim cover of fine grained material to protect the RRM prior to construction of the rest of the cover. A radon barrier of low permeability pulverized Mancos Shale will be constructed above the interim cover. Above the radon barrier, DOE will construct a 6-inch layer of sandy gravel to provide drainage of surface water seeping through the layers above it. The top layers of the cover provide frost protection for the radon barrier and erosion protection for the cell. A more complete description of the cover can be found in Section 3.6 of this TER.

DOE has designed the cell without an engineered liner. 40 CFR 192.20 requires that new depository sites for tailings should use a liner or equivalent to protect groundwater. As the uppermost aquifer is 2400 feet below the surface, the 2400 feet of Mancos Shale between the cell and the aquifer is considered to be more than the equivalent of a liner for the tailings cell.

DOE has also engineered the cell to minimize the potential for water to bathtub in the base of the cell. The hydraulic conductivity of water infiltrating through the cell's engineered cover is expected to be much lower than the hydraulic conductivity of the weathered Mancos Shale beneath the cell. Some water may seep into the weathered Mancos Shale since the cell base will not have an engineered clay barrier. Because the hydraulic conductivity of the weathered Mancos Shale at the base of the cell is higher than the cell cover, leachate "bathtubbing" is not expected to occur.

The cell will be designed to ensure water will not flow into the alluvial/colluvial material that lies over the weathered Mancos Shale. NRC staff has previously raised this as a possible issue since the alluvial/colluvial material likely has a much higher hydraulic conductivity than the weathered Mancos Shale and there was concern that seepage could occur at the alluvial/colluvial and Mancos Shale interface. DOE has adequately addressed this issue by modification to the cell design by keying the base of the cell into the Mancos Shale as shown in Figures 7.3 and 7.4 of the RAP (DOE, 2008). DOE will also use four standpipes to monitor the cell performance for accumulations of leachate at the cell base and for leachate removal. The cell will be designed to shed water off the top of the cell and not infiltrate. The average rainfall is 9.1 inches and the evaporation rate in the arid climate is several times the precipitation rate. These factors should alleviate the possibility of seepage along the alluvial/colluvial and Mancos Shale interface. Additionally, modeling shows that seepage, if it occurs, will be contained in the weathered Mancos Shale and, to a lesser extent, the unweathered Mancos Shale. Additional design features to limit infiltration and protect the cell form erosion are discussed in Section 3.6 and 3.8 of the TER.

5.4 Disposal Standards

DOE is using the compliance strategy of hydraulic isolation of the uppermost aquifer at the Crescent Junction disposal cell to demonstrate compliance with the disposal standards of 40 CFR 192. DOE has stated that no groundwater protection standards need to be established or constituents of concern need to be identified because of the hydraulic isolation of the site. The point of compliance is defined in the SRP as a vertical surface within the uppermost aquifer at the hydraulically down-gradient limit of the waste management area. Since the uppermost aquifer is the Dakota sandstone, approximately 2400 feet below the surface of the site, DOE has not proposed monitoring in the uppermost aquifer and consequently, DOE has not proposed point of compliance monitoring wells.

DOE has demonstrated hydraulic isolation of the uppermost aquifer by thoroughly characterizing the site and locating current and potential water users in the site vicinity. The nearest water users are from a spring 7 miles away and the nearest groundwater users are 15 miles away. DOE has shown the water quality of the Mancos Shale is extremely saline with total dissolved solid concentrations in the range of 30,000 to 40,000 mg/l in 9 of 10 samples taken from the Mancos Shale. Not only is water quality poor, but water quantity is very limited in the Mancos Shale. There is no use of groundwater at the site or surrounding the site and groundwater in the Mancos Shale has been shown to be extremely briny, saline, and unusable.

DOE has provided a thorough assessment to show that the Crescent Junction disposal site is hydraulically isolated from the uppermost aquifer and NRC staff agrees with this assessment. DOE has not proposed groundwater protection standards or point of compliance wells for the site. NRC staff agrees that point of compliance wells are not required for this site as a point of compliance wells would have to be developed within the Dakota sandstone approximately 2400 feet beneath the site. DOE has estimated that travel times from cell leachate would take between 3330 to 33,300 years to reach the Dakota sandstone, under conservative estimates, and NRC staff does not dispute this assessment. Since the compliance period for this site is 1000 years, there is no basis for requiring point of compliance wells in the Dakota sandstone. DOE has estimated the performance of the cell and the possible resulting spread of leachate from the base of the cell using both conservative and realistic assumptions. Under conservative assumptions, leachate may spread a short distance from the cell, but under realistic assumptions, no leachate is expected to be released from the cell. NRC staff agrees that monitoring within the cell for the presence or absence of leachate will be a good measure of cell performance. Additionally, DOE intends to monitor the disposal cell performance by converting four coreholes to monitoring wells surrounding the cell to monitor for the presence or absence of leachate.

6.0 RADON ATTENUATION AND SITE CLEANUP

6.1 Introduction

This section of the TER documents the staff's evaluation of the radon attenuation design and soil cleanup for the planned remediation action at the Moab, Utah UMTRA Project. The RAP was reviewed against the EPA requirements presented in 40 CFR Part 192, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings using Section 5.0 of the Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites Under Title I of the Uranium Mill Tailings Radiation Control Act (NRC, 1993). The results of this review consist primarily of evaluations of the proposed remedial actions to assure compliance with the applicable EPA standards.

6.2 Radon Attenuation

The uranium mill tailings and contaminated materials in the tailings pile (residual radioactive material, RRM) at the Moab Processing Site will be relocated to the Crescent Junction, Utah, disposal site and placed in an engineered disposal cell. The disposal cell will have a radon barrier that has been designed to limit the release of radon to less than 20 picoCuries per meter^2 per second to meet the EPA radon flux standard. The staff's review of the disposal cell design for radon attenuation included evaluation of the pertinent design parameters for both RRM and the radon barrier soils, and the calculation of the radon barrier thickness.

The Moab UMTRA Project cover design is described as consisting of an interim cover of clean native alluvial materials of one-foot minimum thickness, a compacted clay radon barrier of conditioned on-site weathered Mancos Shale, a 0.5-foot thick sandy gravel infiltration and bio-intrusion barrier, and a 3.5-foot thick frost protection layer that includes a 0.5-foot thick rock mulch erosion protection layer. The cover design includes erosion protection, frost protection and drain layers that were not included in the calculation of the radon barrier layer thickness due to the high permeability of these materials. The side slopes of the cover design will be much thicker than the required cover and will be adequate to provide the necessary radon attenuation to meet the EPA standard. The side slopes were evaluated by DOE solely for erosion protection. The radon barrier depends on the thickness of the interim cover since both layers reduce the radon emission. The thickness of the required Mancos Shale radon barrier for the disposal cell is four feet for a one-foot thick interim cover.

The design parameters of the contaminated and cover materials that were evaluated for acceptability include the following: long-term moisture content, radon diffusion, radon emanation, density, porosity, material layer thickness, average radium-226 activity, and ambient radon concentration. These parameters were used in calculating the radon barrier thickness using the RADON computer code (NRC, 1989).

6.2.1 Evaluation of Parameters

The required thickness of the barrier depends on the properties of the radon barrier and the contaminated materials. NRC staff reviewed the validity of the physical and radiological parameters of the contaminated materials and the radon barrier material thickness used for input in the RADON computer code (NRC, 1989).

Physical properties for the disposal cell layers were determined from laboratory testing of representative samples. The dry density, specific gravity and porosity were determined from standard compaction tests. The average specific gravity of the tailings is 2.8 based on five samples used to calculate an average porosity of 0.44. The average specific gravity of the alluvial material interim cover is 2.67 based on seven samples used to calculate an average porosity of 0.38. The Mancos Shale radon barrier average specific gravity is 2.65 based on two samples used to calculate an average porosity of 0.33.

DOE selected a mean long-term moisture content of 15 percent for tailings, which is in the typical range for tailings. The mean long-term moisture content for the interim cover is 9 percent based on the mean of 20 measured 15-bar moisture content analyses as determined by ATM Method D3152. The mean long-term moisture content of the Mancos Shale radon barrier is 12 percent based on the mean of 12 measured 15-bar moisture content analyses as determined by ASTM D3152. DOE indicates that the Mancos Shale long-term moisture content is better represented by the calculated and measured 15-bar moisture content test than by the in situ moisture content of Mancos Shale.

DOE noted that the radon diffusion coefficient used in the RADON computer code may be calculated by the code, based on a relationship with degree of saturation and porosity, or values can be entered manually using values determined by laboratory tests. The radon diffusion coefficient used was based on equation 9 from a paper by Rogers and Nielson (1991). This 1991 paper is based on updated studies conducted since the 1984 work by Rogers and Nielson referenced in Regulatory Guide-3.64. For the tailings, DOE used a calculated radon diffusion coefficient of 0.01037 cm^2/sec based on a long-term moisture content of 15 percent by weight and a porosity of 0.44. The calculated radon diffusion coefficient for the interim cover was 0.01636 cm^2/sec based on a long-term moisture content of nine percent and a porosity of 0.38. The radon diffusion coefficient for the Mancos Shale radon barrier was calculated as 0.004636 cm^2/sec based on a long-term moisture content of 12 percent and porosity of 0.33.

The RADON computer code default radon-emanation coefficient of 0.35 was used for all of the tailings, random fill and cover materials inputs. DOE noted that the default value agrees well with the Grand Junction Disposal Site radon-emanation coefficient of 0.36.

DOE used an ambient radon concentration of zero (0) pCi/L in the RADON computer code because this parameter has little influence on the model results. The actual radon concentrations at background locations ranged from 0.5 to 1.2 pCi/L.

DOE determined the radium-226 radioactivity in the tailings pile by analyses of 104 samples using gamma spectroscopy. The samples included tailings sands, slime, transitional tailings, and other contaminated materials. The average radium-226 activity was 707 pCi/g. DOE estimates that the overall volume-weighted average is 565 pCi/g of radium-226, and the modeled volume-weighted average is 1245 pCi/g. DOE indicates that the radium-226 activity will be carefully monitored for the upper seven feet of the disposal cell to ensure that the average activity does not exceed 707 pCi/g.

The radium-226 activity for the interim cover and clean fill perimeter dikes is based on five samples of materials from the Crescent Junction Site. The radium-226 activity ranged from 1.4 to 2.3 pCi/g and had a mean activity of 1.9 pCi/g. The radium-226 activity for the radon barrier is based on two samples of weathered Mancos Shale from the Crescent Junction Site. The radium-226 activity of the Mancos Shale ranged from 1.6 to 3.0 pCi/g, and had a mean activity of 2.3 pCi/g.

DOE evaluated the disposal cell side slope thickness by modeling a RRM layer and interim cover layer and determined that an 11 foot thickness will provide adequate radon attenuation to meet the EPA radon flux standard.

DOE used a 500 cm tailings thickness for all RADON computer code runs. Regulatory Guide 3.64 indicates that a 500 cm tailings thickness may be considered to be an infinitely thick source for radon. The actual design thickness for the cell is 43 feet. The tailings consist of two layers, a lower layer of 36 feet and an upper layer of seven feet. DOE chose this configuration to allow higher activity materials to be placed in the lower layer provided that the radium-226 activity in the upper layer is 707 pCi/g or less.

6.2.2 Evaluation of Radon Attenuation Model

DOE used the RADON computer code (NRC, 1989) to estimate the required radon barrier thickness for the Moab UMTRA Project disposal cell. DOE performed three runs of the RADON computer code to determine the sensitivity of the calculated radon barrier as certain variables were changed. The DOE analyses resulted in a required radon barrier thickness of four feet using the parameters discussed above.

The NRC staff also used the RADON computer code (NRC, 1989) to estimate the required radon barrier thickness for the Moab UMTRA Project disposal cell using the parameters selected by DOE. NRC also ran the RADON computer code using a mean long-term moisture content of five-percent for the radon barrier. The NRC analysis indicated that the proposed radon barrier thickness of four feet is adequate to meet the EPA radon flux standard.

6.2.3 Conclusions

The NRC staff, having reviewed the parameters of the contaminated materials discussed above, concluded that the physical and radiological properties are representative of the configuration proposed and acceptable methodology was used to determine the activities and emanation fraction of the contaminated materials at the site. NRC noted that DOE choice of mean long-term moisture content of the radon barrier is based on calculated and measured 15-bar moisture content rather than the in situ moisture content of the Mancos Shale. NRC ran the RADON compute code using an additional value for mean long-term moisture content of five-percent and the radon barrier thickness was sufficient to meet the EPA radon flux standard.

6.3 Site Cleanup

6.3.1 Extent of Cleanup Needed

DOE identified the RRM volume to be disposed as a number of separate quantities: the tailings pile, remediated off-site soils, remediated vicinity property materials and the subpile soils or contaminated soil below the pile that resulted from leaching and infiltration. No demolition or remediation of buildings or structures are necessary since onsite buildings have already been demolished and placed in the tailings pile.

DOE estimated the RRM volume by field sampling and radiological surveys of the Moab Processing Site as approximately 9.9 million cubic yards of contaminated materials in the tailings pile covering 130 acres. The subpile volumes were estimated by advancing boreholes through the tailings pile into underlying alluvial soils. A limited number of borings were made because of the expense and to minimize contamination to the substrate. As a result of limited data, DOE has added two extra feet of materials to the design volume based on lessons learned from remediation of other UMTRA Project sites. Subsequently, the design volume of the Moab UMTRA Project disposal cell is 12.0 million cubic yards.

DOE also estimated that 0.70 million cubic yards of additional contaminated material (off-pile RRM) is spread over 439-acres within the DOE property boundary. The depth of contaminated materials for the off-pile RRM ranges from 6-inches to 20-feet below grade. Concentrations of radioactive contaminants in the tailings pile ranged up to 1283 pCi/g for radium-226, up to 1154 pCi/g for total uranium, and up to 779 pCi/g for thorium-230.

DOE indicates that there is little evidence of tailings leaving the Moab Processing Site and contaminating vicinity properties in the City of Moab. Properties adjacent to the processing site are being assessed for extent of contamination. An estimate of 0.12 million cubic yards is being used for the volume of cleanup of vicinity properties and in the City of Moab.

6.3.2 Soil Cleanup Standards

DOE has committed to remediate the contaminated areas to meet the 5 pCi/g (surface) and 15 pCi/g (subsurface) EPA radium-226 standards in 40 CFR 192, and to place the contaminated materials in an engineered disposal cell.

DOE indicates that when remediation of contaminated material is not practical or feasible, application of supplemental standards may be considered according to 40 CFR 192.21. Supplemental standards will be applied in areas where excessive environmental harm or worker risk outweighs the benefits of attaining the EPA soils cleanup standards. DOE has indicated that several potential uses of supplemental standards will be applied in those areas under asphalt of the state and federal highways, areas around high-pressure gas lines and near high-voltage electrical lines, areas on steep hillsides, areas around the Union Pacific tracks, areas below the water surface of the Colorado River, and areas around significant archaeological features. DOE indicates that proposed supplemental standards must be approved by NRC.

DOE indicates that if thorium-230 is detected in significant soil concentrations after radium-226 has been removed then a supplemental standard under criterion (f) of 40 CFR 192.21 will be imposed. DOE has provided Table 9-2, Authorized Limits for Soils, Including Background, which defines the acceptable combinations of radium-226 and thorium-230 soil concentrations for surface and subsurface soils that will meet the EPA cleanup criteria. NRC agrees that the proposed radium-226 and thorium-230 soil concentrations will meet the EPA 40 CFR 192 criteria.

6.3.3 Verification of Soil Cleanup Standards

DOE plans to develop engineered design drawings to depict the depth of contamination and requirements for soil remediation. Gamma surveys and soil samples will be taken to guide the depth and extent of excavation to prevent under excavation or over excavation.

Final verification surveys will be taken to ensure that the radiological cleanup efforts are complete and that the remediated areas comply with the EPA standards. After completion of excavation, a verification measurement will ensure that the average residual radium-226 concentration in each 100-m^2 satisfies the EPA standard.

DOE intends to use a global-positioning-system/gamma scan (GPS/GS) methodology (Whicker & Little, 2005) and complementary soil sampling in the verification survey process. The GPS/GS system will be used to do 100% scans of every 100-m^2 grid. A correlation between the gamma scan reading and radium-226 soil concentrations will be established so areas that exceed the radium-226 soil standard can be identified based principally on gamma scan results. A minimum of five percent of the soil grids will be randomly selected and composite soil samples will be taken to confirm the validity of the assumed correlation of gamma scan readings to radium-226 soil concentrations.

Independent radiological surveillances and health and safety audits will be conducted by DOE and its Technical Assistance Contractor to ensure that all activities meet federal, state, local and UMTRA project standards.

6.3.4 Conclusions

NRC staff concludes that the radon barrier design of the proposed engineered disposal cell will reduce the radon flux rate to EPA standards.

NRC also concludes that the process described in the Moab UMTRA Project Final Remedial Action Plan should ensure that the remediated site is adequate to comply with EPA standards.

DOE plans to remediate the Moab processing site to EPA standards in 40 CFR 192. DOE will implement supplemental standards in accordance with 40 CFR 192 for (1) thorium-230 in significant concentrations after the radium-226 is remediated, and (2) for areas where excessive environmental harm or risks to worker safety outweighs the benefits of meeting the soil cleanup standard. NRC staff concludes that this approach is consistent with 40 CFR 192 and finds that the DOE approach is acceptable. Also, NRC staff concludes that the proposed radium-226 and thorium-230 soil concentrations for surface and subsurface soils will meet the EPA 40 CFR 192 criteria.

DOE will conduct final verification surveys to assure that the EPA standards in 40 CFR 192 are achieved. DOE has elected to use a GPS/GS methodology (Whicker & Little, 2005) for final verification surveys. NRC staff concludes that the final verification survey methodology is adequate to ensure that the EPA 40 CFR 192 standards are achieved.

7.0 REFERENCES

10 CFR Part 40, Appendix A, U.S. Nuclear Regulatory Commission (NRC), Code of Federal Regulations.

10 CFR Part 100, Appendix A., U.S. Nuclear Regulatory Commission (NRC), "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Code of Federal Regulations.

40 CFR Part 192, U.S. Environmental Protection Agency, "Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," Code of Federal Regulations.

American Society for Testing and Materials, "1995 Annual Book of ASTM Standards," Philadelphia, PA, 1995.

Campbell, K. W., and Y. Bozorgnia, "Updated Near-Source Ground Motion (Attenuation) Relationships for the Horizontal and Vertical Components of Peak ground acceleration and Acceleration Response Spectra," Bulletin of Seismological Society of America, 93, pp.314-331, February 2003.

Chow, V.T., *Open Channel Hydraulics*, McGraw-Hill Book Co., New York, 1959.

Day, R.W., *Geotechnical and Foundation Engineering, Design, and Construction*, McGraw-Hill Book Co., New York, 1999.

DOE (U.S. Department of Energy), "Remedial Action Plan and Final Design for Stabilization of the Inactive Uranium Mill tailings at Green River, Utah," 1991a.

DOE (U.S. Department of Energy), "Remedial Action Plan and Final Design for Stabilization of the Inactive Uranium Mill tailings at Grand Junction, Colorado," 1991b.

DOE (U.S. Department of Energy), "Final Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah, Disposal Site," July 2008.

Johnson, Terry L., "Design of Erosion Protection Covers for Long-Term Stabilization," NUREG-1623, U. S. Nuclear Regulatory Commission, 2002.

National Oceanic and Atmospheric Administration,"Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages," U. S. Department of Commerce, Hydrometeorological Report (HMR) No. 49, 1977.

NRC (U.S. Nuclear Regulatory Commission), "Calculation of Radon Flux Attenuation by Earthen Mill Tailing Covers," Regulatory Guide 3.64, June 1989.

NRC (U.S. Nuclear Regulatory Commission) "Final Standard Review Plan for the Review and Remedial Action of Inactive Mill Tailings Sites under Title I of the Uranium Mill Tailings Radiation Control Act," Revision 1, 1993.

NRC (U.S. Nuclear Regulatory Commission), "Final Technical Evaluation Report for the Proposed Revised Reclamation Plan for Atlas Corporation Moab Mill," NUREG-1532, March

1997.

Rogers, V.C., and K. K.Nielson, “Correlations for Predicting Air Permeabilities and ^{222}Rn Diffusion Coefficients In Soils”, Health Physics, 61(2), pp. 225 – 230, 1991.

Simons, D.B. and R.K. Li, "Surface Mining Diversions Design Manual," Office of Surface Mining, United States Department of the Interior, OSM/TR-52/2, September 1982.

Stevens, M.A., D.B. Simons, and G.L. Lewis, "Safety Factors for Riprap Protection," American Society of Civil Engineers, Journal of the Hydraulics Division, v. 102, No. HY5, 1976.

U.S. Bureau of Reclamation, *Design of Small Dams* (3rd Ed), U.S. Department of the Interior, 1987.

Whicker, Randy and Little, Craig, Memorandum to Toby Wright and Bob Hopping, “Correlation of Ra-226 in Soil with Gamma Exposure Rate at the Moab Site”, May 19, 2005.

Wong, I.G. and J. R. Humphrey, “Contemporary Seismicity, Faulting, Faulting and State of stress in the Colorado plateau,” Bulletin of Geological Society of America, V 101, pp. 1127-1146, 1989.