FINAL
TECHNICAL EVALUATION REPORT

FOR THE

REMEDIAL ACTION

AT THE

SLICK ROCK, COLORADO
URANIUM MILL TAILINGS
PROCESSING AND DISPOSAL SITES

SEPTEMBER 1996

DIVISION OF WASTE MANAGEMENT
U.S. NUCLEAR REGULATORY COMMISSION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The Slick Rock Site was designated as one of 24 abandoned uranium mill tailings piles to be remediated by the U.S. Department of Energy (DOE) under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). UMTRCA requires, in part, that the U.S. Nuclear Regulatory Commission 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 Technical Evaluation Report (TER) documents the NRC staff's review of the DOE Final Remedial Action Plan and Site Design (RAP) and associated documents (DOE, 1995 and 1996).

1.1 EPA Standards

As required by UMTRCA, remedial action at the Slick Rock site must comply with regulations established by the 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 (RRM) 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 provide reasonable assurance that releases of radon-222 from RRM to the atmosphere will not exceed 20 picocuries/square meter/second, or increase the annual average concentration of radon-222 in air at any location outside of the disposal site by more than 0.5 picocurie/liter [40 CFR 192.02(b)].

3. 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 15-centimeter-thick layers of soil more than 15 centimeters below the land surface [40 CFR 192.12(a)].

On January 11, 1995, EPA published a final rule for groundwater standards for remedial actions at inactive uranium processing sites (40 CFR 192, Subparts A through C). The standards consist of two parts; a first part, governing the control of any future groundwater contamination that may occur from tailings piles after remedial action, and a second part, governing the cleanup of contamination that occurred before the remedial action of the tailings. In accordance with UMTRCA Section 108(a)(3), the remedial action shall comply with the EPA standards.

1.2 Site History and Proposed Action

The Slick Rock uranium mill tailings sites are located near the small town of Slick Rock in San Miguel County, Colorado (Figure 1.1). There are two designated Uranium Mill Tailings Remedial Action (UMTRA) Project sites at

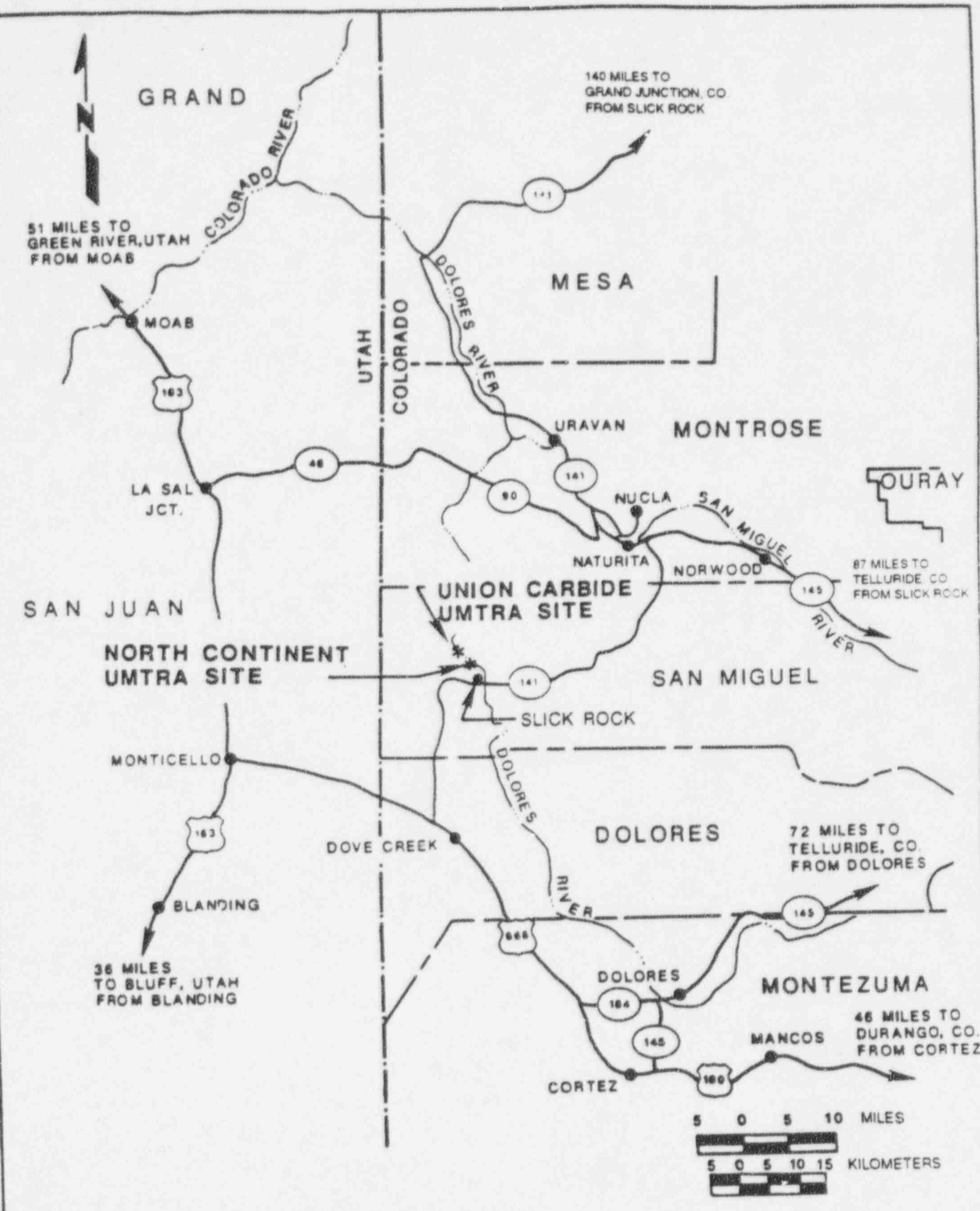

FIGURE 1.1
LOCATIONS OF THE UNION CARBIDE AND NORTH CONTINENT UMTRA SITES NEAR SLICK ROCK, COLORADO

Slick Rock; the Union Carbide (UC) site which began operating in 1957 and the North Continent (NC) site which dates to 1931. Both sites are owned by Union Carbide Corporation and are adjacent to the Dolores River. The UC site is approximately 1 mile (mi) (2 kilometers [km]) downstream of the NC site. Contaminated materials cover an estimated 55 acres (ac) (22 hectares [ha]) at the UC site and 12 ac (4.9 ha) at the NC site. All mill buildings have been removed from both sites. The sites contain concrete foundations, tailings piles, demolition debris, and areas contaminated by windblown and waterborne radioactive materials. The total estimated volume of contaminated materials is approximately 620,000 cubic yards (yds^3) (470,000 cubic meters [m^3]). In addition to the contamination at the two processing site areas, four vicinity properties were contaminated. Contamination associated with the UC and NC sites has leached into groundwater.

Figure 1.2 shows the general features of the UC site and Figure 1.3 shows the general features of the NC site.

The remedial action proposed by DOE consists of the following major activities:

1. Transport of all contaminated materials from both former mill sites to the proposed Burro Canyon disposal site located approximately 2.5 mi (4 km) east of the mill sites. Figure 1.4 shows the location of the Burro Canyon disposal site and Figure 1.5 shows the general features of the disposal site.

2. The contaminated materials will be transported over a 6 mi (10 km) haul route with portions of the route on state and county maintained roads. Some portions of the haul route will require upgrading.

3. Contaminated material will be placed and stabilized in a 12 ac (9 ha) engineered cell partially below grade. The disposal cell will be situated to utilize the saddle and mesa topography at the Burro Canyon site. The cell will be shaped to minimize any detrimental effects of surface water drainage and potential geomorphic change.

4. The disposal cell will hold approximately 620,000 yd^3 (470,000 m^3) of contaminated material and cover an area approximately 610 ft (190 m) wide and 900 ft (280 m) long. The cell will range from 30 ft (9 m) to 50 ft (20 m) above the existing ground surface.

5. All contaminated material will be covered with a 2-ft (0.6 m)-thick layer of fine-grained materials that will constitute a radon barrier to prevent release of radon into the atmosphere. A 2-ft (0.6 m)-thick frost protection layer of fine-grained material will be placed over the radon barrier. The frost protection layer will be overlain by a 6-in (0.2 m) sand and gravel bedding layer. The top of the cover will consist of riprap ranging in depth from 8 to 12 in (0.2 to 0.3 m). The completed cell will have a 2- to 4-percent top slope and 25-percent side slopes, occupy an area of 12 ac (4.9 ha), and have a buffer area of 31 ac (13 ha) for a total site of 43 ac (17 ha). After completion of

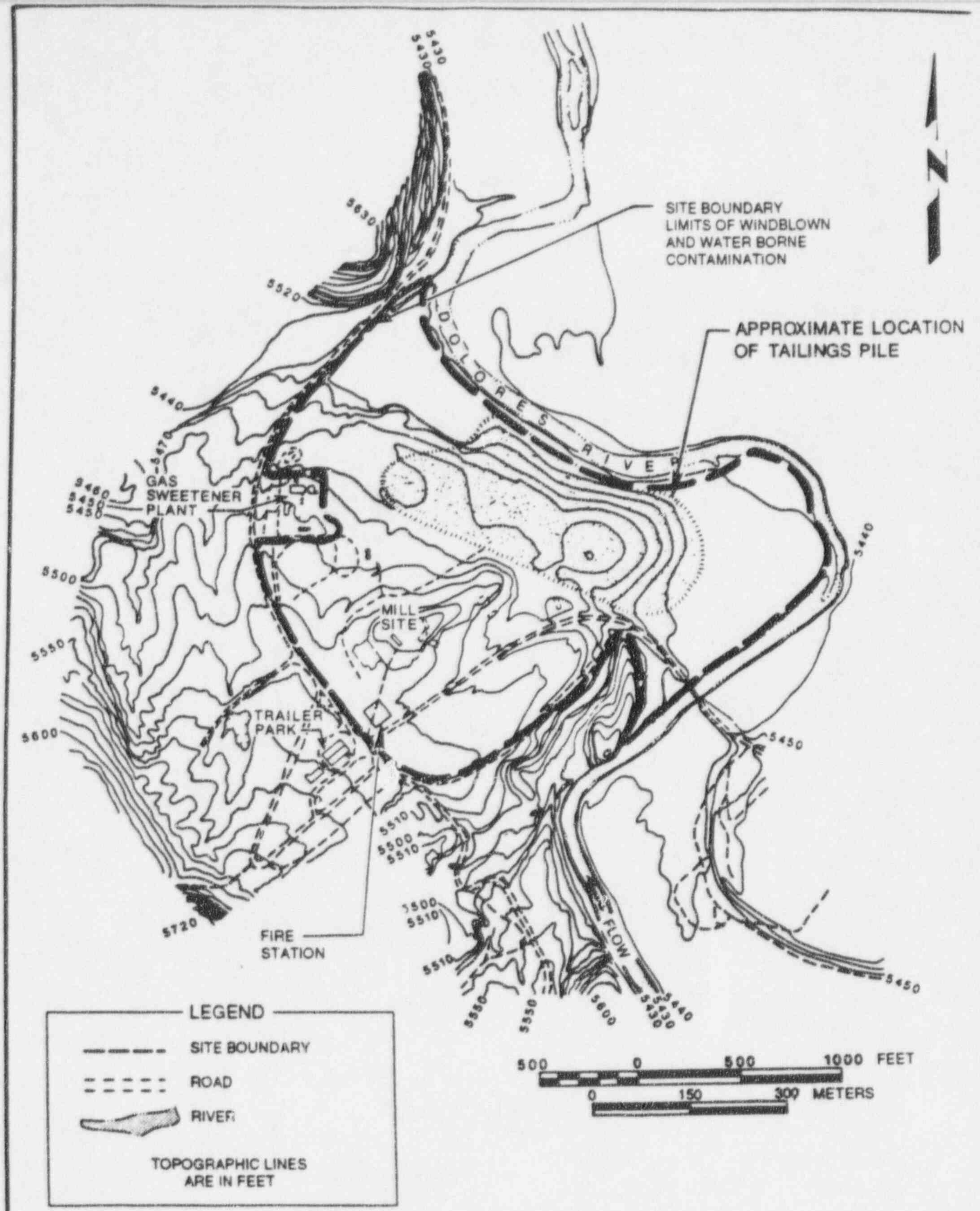

FIGURE 1.2
LOCATION OF THE UNION CARBIDE
UMTRA SITE NEAR SLICK ROCK, COLORADO

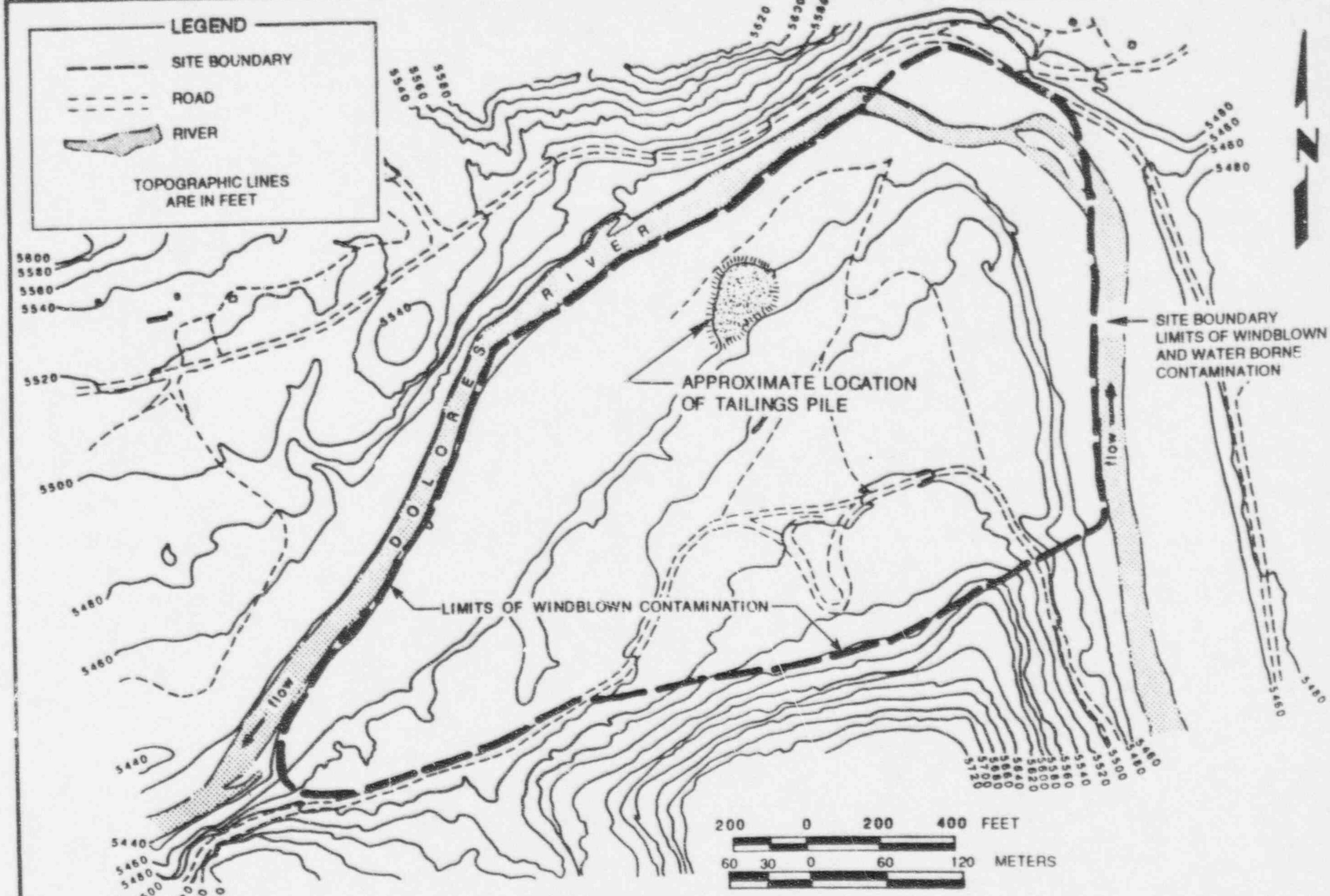

FIGURE 1.3
LOCATION OF THE NORTH CONTINENT UMTRA SITE NEAR SLICK ROCK, COLORADO

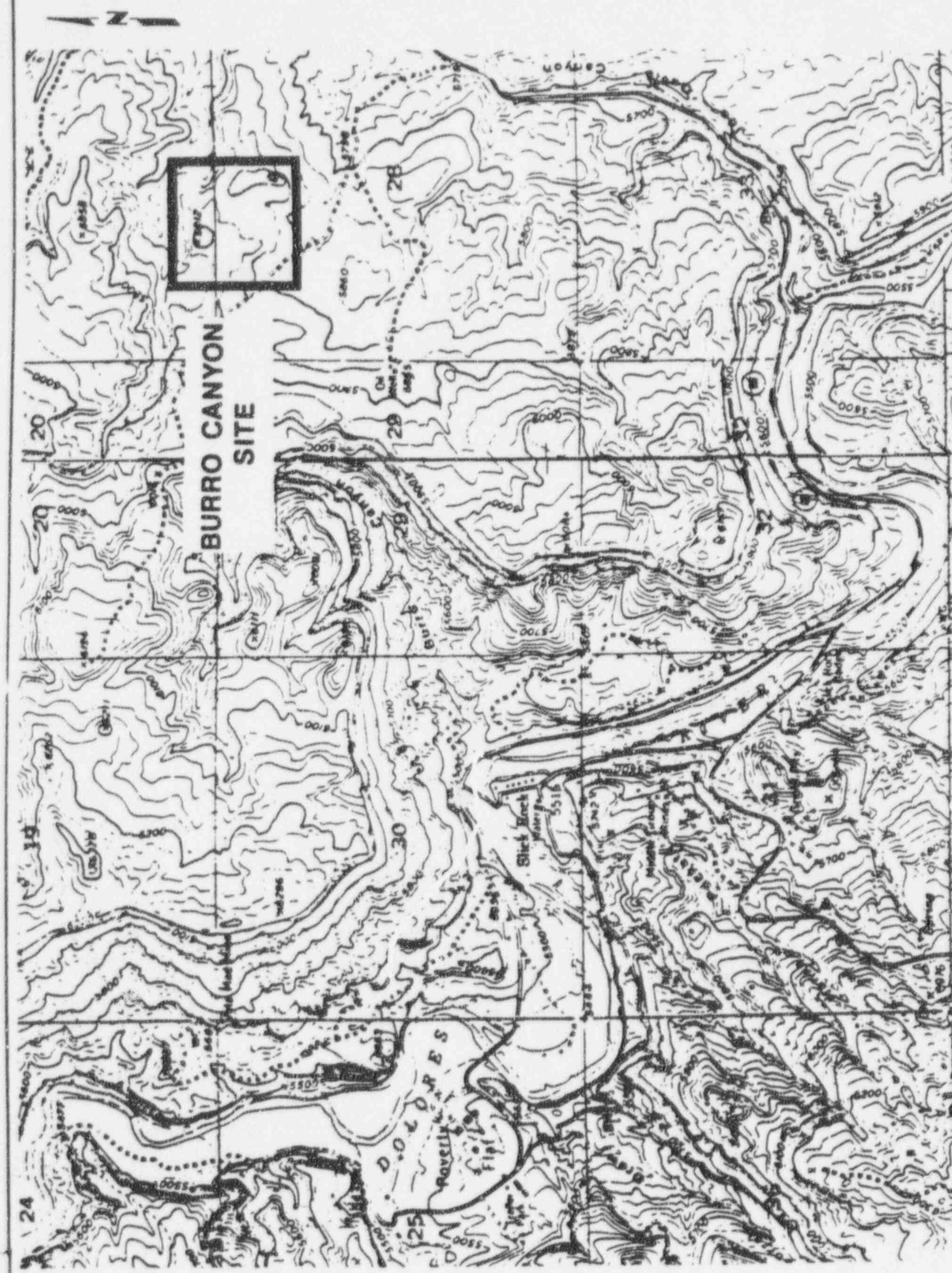

FIGURE 1.4
BURRO CANYON SITE LOCATION

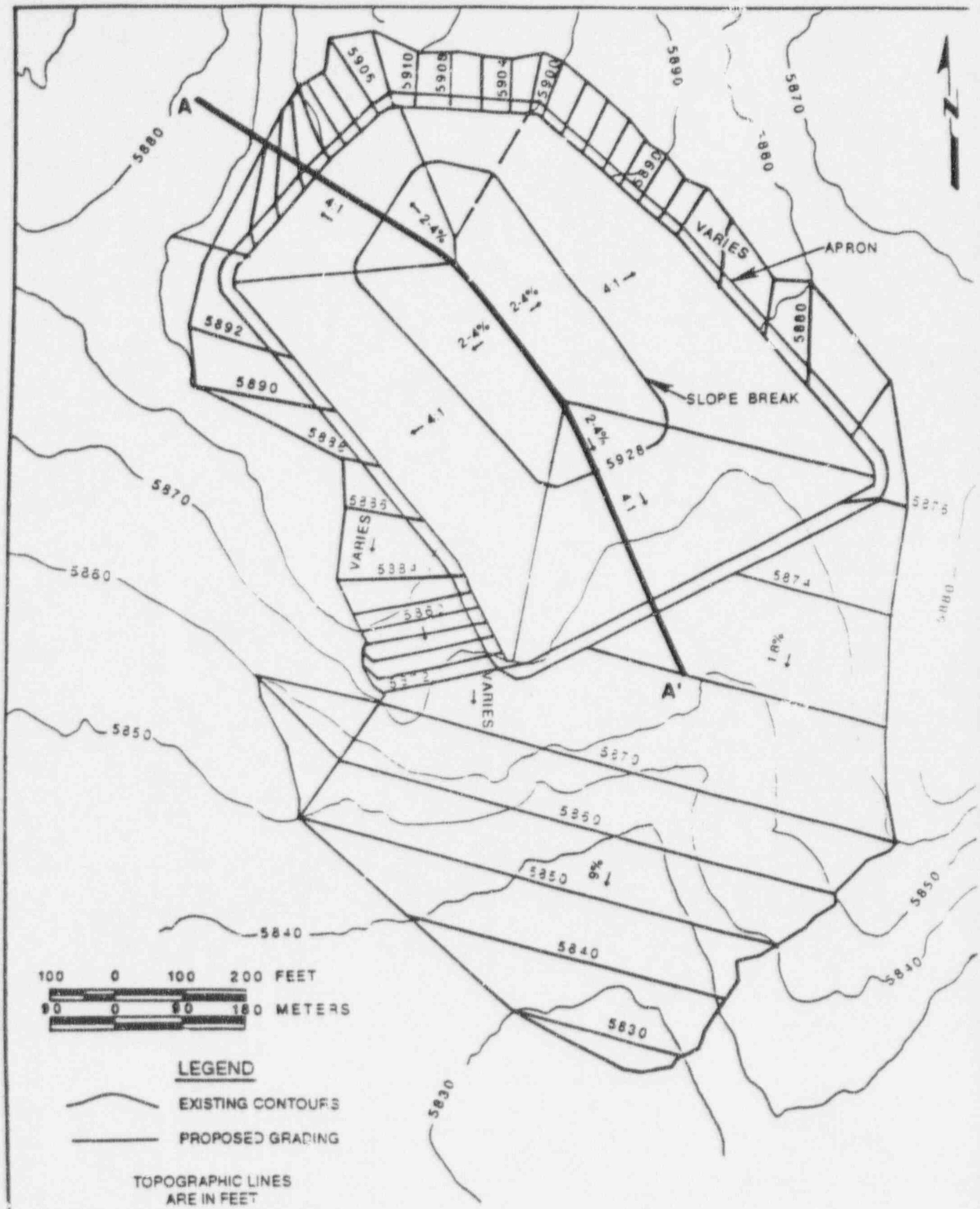

FIGURE 1.5
DISPOSAL CELL FOR THE SLICK ROCK TAILINGS
SLICK ROCK, COLORADO

remedial action, the processing sites will be restored with uncontaminated fill, and revegetated or mulched for erosion protection. Following completion of remedial action, the processing sites will eventually be released for use consistent with existing land use controls.

1.3 Review Process

The NRC staff review was performed in accordance with the Standard Review Plan for UMTRCA Title I Mill Tailings Remedial Action Plans (SRP; NRC, 1993) and consisted of comprehensive assessments of DOE's site design and remedial action plan. The review is discussed in further detail in Sections 2 through 6 of this TER.

The remedial action information assessed by the NRC staff during this review was provided primarily in the following documents:

- Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Sites at Slick Rock, Colorado, Remedial Action Selection Report, (with Attachments 1 - 5), September 1995.

- Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Sites at Slick Rock, Colorado, May 1996.

- Uranium Mill Tailings Remedial Action Project (UMTRAP), Slick Rock, Colorado, Calculations, Final Design for Review, Volumes I - VI, March 1994.

- Uranium Mill Tailings Remedial Action Project (UMTRAP), Slick Rock, Colorado, Information for Bidders, Volumes I -VII, March 1994.

- Uranium Mill Tailings Remedial Action Project (UMTRAP), Slick Rock, Colorado, Information for Reviewers, March 1994.

- MK Ferguson Company, Remedial Action Inspection Plan, Revision 0, Review D, January 1995.

1.4 TER Organization

The purpose of this TER is to document the NRC staff's review of DOE's Final Remedial Action Plan and Site Design for the Slick Rock sites and the designated disposal site at Burro Canyon. The sections of this report have been organized by technical discipline relative to the EPA standards in 40 CFR Part 192, Subparts A-C. Sections 2, 3, and 4 provide the technical basis for the NRC staff's conclusions with respect to the long-term stability standard in 40 CFR 192.02(a). Section 5, Water Resources Protection, summarizes the NRC staff's conclusions with regards to the adequacy of DOE's compliance demonstration with EPA's groundwater protection requirements in 40 CFR Part 192. Section 6, Radon Attenuation and Site Cleanup, provides the basis for

the staff conclusions with respect to the radon control standards in 40 CFR 192.02(b) and soil cleanup in 40 CFR 192.12(a).

1.5 Summary of Open Issues

In its review of the preliminary final RAP for the Slick Rock processing and disposal sites, the NRC staff identified 24 open issues. Those issues have been satisfactorily addressed by DOE in the Final RAP (See Table 1.1 of this TER) with the exception of groundwater cleanup which has been deferred until a later phase of the Uranium Mill Tailings Remedial Action (UMTRA) Project.

TABLE 1.1 SUMMARY OF OPEN ISSUES		
OPEN ISSUE	TER SECTION	STATUS
1. DOE should update the earthquake database (at least through 1993) and use more recent techniques in the determination of horizontal acceleration.	2.3.5 2.4.3	CLOSED
2. DOE should provide support for the demonstration of the absence of Quaternary faulting and demonstrate (through existing references) a definitive age (years before present) of Pleistocene and\or Holocene for the Quaternary deposits not offset by the underlying non-tectonic faults.	2.3.5 2.4.3	CLOSED
3. DOE should clarify the manner of assignment of different magnitudes (5.7 for the Burro Canyon site and 7.0 for the Naturita site) for the same structure (Big Gypsum valley) and the determination as to which ME should be used. DOE should provide a technical basis for the statement that the 6.2 earthquake is the threshold magnitude at which ground rupture occurs. DOE should discuss the methodology used to describe how the maximum earthquake values in Figure 2-7 were drawn.	2.3.5 2.4.3	CLOSED
4. DOE should discuss and provide figures, as appropriate, regarding the RAP statement that hydrocarbon exploration has occurred adjacent to the site. The potential for hydrocarbon production in the site area and the effect of such production on the integrity of the disposal cell should be addressed, including the potential for collapse of the strata overlying the production horizon(s). DOE should provide an oil/gas well location map and text to include both exploration and exploitation wells, as well as seismic surveys within a 9.3 mi (15 km) radius of the site.	2.3.6 2.4.1	CLOSED
5. DOE should adopt those natural resource portions (potash, natural brines) of the Naturita RAP (DOE, 1993) that are equally applicable to the Burro Canyon site.	2.3.6 2.4.1	CLOSED

TABLE 1.1 SUMMARY OF OPEN ISSUES		
OPEN ISSUE	**TER SECTION**	**STATUS**
6. DOE should include the planned additional consolidation testing.	3.2.4 3.3.2	CLOSED
7. Paragraph three of Section 3.3.3 in the Remedial Action Selection Report is confusing and should be re-written to more clearly address long-term differential settlement gradients.	3.3.2	CLOSED
8. In section 02200 of the Specifications (DOE, 1994), the following revisions are suggested: 1) 2.2.B.1.b - Maximum particle size should not exceed 1/2 the compacted lift thickness. As written, the specification allows particle sizes as thick as the compacted lift. This specification is not conducive to achieving compaction. 2) 2.2.B.2.b - The paragraph would permit the placement of radon barrier material that has only 30 percent fines. DOE needs to provide additional assurance that radon barrier soils will meet or exceed the quality of those in the radon attenuation model. 3) 3.5.C.6 - If the "routing of hauling and spreading units" is insufficient to achieve proper compaction, additional mechanical compaction with alternate equipment will be necessary. 4) 3.5.C.7.b - References to 90% and 95% compaction should refer to "assumed" or "equivalent" compaction since the actual value cannot be determined. 5) 3.7.A - Areas excavated to bedrock or to cobbles/gravel should not require subgrade preparation provided that they are judged to be free of loose, compressible, or otherwise unsatisfactory materials. Additional language should be added to require confirmation of the integrity of bedrock and cobble/gravel subgrades.	3.4.2	CLOSED

TABLE 1.1
SUMMARY OF OPEN ISSUES

OPEN ISSUE	TER SECTION	STATUS
9. DOE needs to provide the Remedial Action Inspection Plan for NRC review and concurrence.	3.5 4.4.3	CLOSED
10. DOE must demonstrate compliance with EPA's final groundwater clean-up standards in 40 CFR 192, Subparts B and C.	5.1	DEFERRED, SEE TER SECTION 5.5
11. DOE has indicated that additional laboratory experiments (batch and/or column leaching tests) are needed to evaluate adsorption reactions in soils beneath the disposal cell. This is an open issue, pending the reporting of these test results.	5.2.3	CLOSED
12. DOE must provide information on the current source(s) of municipal and domestic water supply for the town of Slick Rock and the vicinity surrounding the processing sites. This information should be in the form of a text description of the municipal water supply and a map showing the locations of the identified private wells within a 2-mile radius of the sites. DOE must also provide an evaluation of the future projected water use in the vicinity of the processing sites.	5.2.4	CLOSED
13. DOE must provide evidence through water-quality measurements or potentiometric measurements in the vicinity of the NC site to support the assumption that the Dolores River provides a hydraulic barrier between the tailings site and the identified private wells on the opposite side of the river.	5.2.4	CLOSED
14. DOE should reference documentation, such as State or Dolores County studies on population projections, that support the statement in Attachment 3 of the RAP that "Groundwater development in the vicinity of the disposal site should not increase over the next 50 years."	5.2.4	CLOSED

TABLE 1.1 SUMMARY OF OPEN ISSUES		
OPEN ISSUE	**TER SECTION**	**STATUS**
15. DOE should recalculate the seepage flux analysis in Calculation No. SRK-11-93-12-06-00, using a realistic and conservative estimate for the bottom seepage rate. The analysis does not mention how the $1x10^{-6}$ cm/s value was deemed representative. It appears that the value was selected as the median of packer test permeabilities. Borehole packer tests are designed to measure the horizontal component of permeability. The analysis presented utilizes the vertical permeability component. Layered earth materials commonly exhibit a distinct anisotropy between the horizontal (Kh) and vertical (Kv) permeability components, with horizontal component generally being the larger. The anisotropy ratio Kh/Kv can be 10:1 in some materials, and as high as 100:1 in others. A reevaluation of this calculation must also address any impacts to long-term moisture accumulation scenario and potential adverse impacts to seepage through the sandstone layers exposed in the excavation sidewalls.	5.3	CLOSED
16. DOE should provide the stated numerical simulation (Attachment 3, page 3-51) of the upper sandstone as a calculation set in the RAP, and reference it as the demonstration that the uppermost aquifer at the disposal site cannot provide a sustained yield of 150 gpd.	5.4.1	CLOSED

TABLE 1.1 SUMMARY OF OPEN ISSUES		
OPEN ISSUE	**TER SECTION**	**STATUS**
17. NRC staff considers that visual inspections of potential seeps is inadequate to demonstrate that the cell is performing as designed. Visual inspection of potential seeps at a distance of potentially 100 meters or more from the disposal cell does not provide the earliest practicable verification of cell performance. DOE should develop a monitoring plan that demonstrates cell performance in a more direct manner. An approach, such as monitoring the saturation level in the tailings through standpipes, would provide the earliest verification of cell performance.	5.4.3	CLOSED
18. DOE must provide minus 15 bar capillary suction measurements of the UC off-pile and sub-pile material to confirm that a conservative long-term moisture value has been chosen for the model.	6.2.1 A	CLOSED
19. DOE must commit to providing additional radon diffusion coefficient measurements on the UC off-pile and sub-pile material for the final RAECOM analysis (radon flux estimation).	6.2.1 A	CLOSED
20. DOE must commit to using a measured or conservative (default) value for the UC subpile material radon emanation fraction in the final RAECOM analysis.	6.2.1 A	CLOSED
21. DOE must provide Ra-226 concentration data for the radon barrier soil.	6.2.1 B	CLOSED
22. DOE must revise the specifications or the Remedial Action Selection Report (Section 6) concerning the placement compaction of the radon barrier soil to be consistent.	6.2.1.B	CLOSED
23. DOE must provide additional characterization data for Th-230 in the areas of boreholes 214 and 226, and at grid point 58550N 63400E or plan verification sampling for Th-230 in these areas.	6.3.1	CLOSED

TABLE 1.1
SUMMARY OF OPEN ISSUES

OPEN ISSUE	TER SECTION	STATUS
24. DOE must provide additional characterization of this property for the supplemental standards application.	6.3.2	CLOSED

2.0 GEOLOGIC STABILITY

2.1 Introduction

This section of the TER documents the staff's review of regional geologic and seismologic information for the proposed remedial action at the UC and NC uranium mill processing sites and disposal of the mill tailings at the Burro Canyon site, approximately 2.5 miles (mi) (4.0 km) east of these processing sites. The emphasis in this section is on the geologic and seismologic information relative to the permanent disposal of the uranium mill tailings from the two processing sites at the Burro Canyon site. Background information for this TER is derived from DOE's RAP (DOE, 1996), supplementary information provided during the review process, staff site visits, and independent sources as cited.

The EPA standards (40 CFR 192) do not include generic or site-specific requirements for characterization of geologic and seismologic conditions at UMTRA Project sites. Rather, 40 CFR 192.02(a) requires that control mechanisms be designed to be effective for up to 1,000 years, to the extent achievable, and in any case for at least 200 years. NRC staff has interpreted this standard t mean that certain geologic and seismologic conditions must be met in order to have reasonable assurance that the long-term performance objectives will be achieved. Guidance regarding these conditions is specified in the SRP (NRC, 1993).

2.2 Location

The UC and NC uranium mill processing sites are located in southwestern Colorado, approximately 1 mi (1.61 km) northwest of Slick Rock, San Miguel County. The Burro Canyon disposal site is located approximately 6 road mi (9.7 km) east of the UC and NC processing sites. A more detailed description and map location for the three sites is provided in Section 1.0 of this TER.

2.3 Geology

DOE characterized the regional and site-specific geology by referring to published and unpublished geologic literature, interpretation of maps and images of various kinds, including LANDSAT, low-sun-angle, and conventional aerial photographs. Subsurface geologic data, including logs of exploratory boreholes drilled on the site were reviewed and field investigations were conducted as recommended in SRP Sections 1.3.2 through 1.3.5. A summary of DOE's geologic characterization is presented below.

2.3.1 Physiographic Setting

The site region lies in the Paradox Basin within the Canyon Lands section of the Colorado Plateau physiographic province. The Canyon Lands are characterized by large-scale folds, unwarped plateaus, lava-capped mesas, deep and narrow river canyons, and laccolith mountains (Hunt, 1974) with elevations ranging from 5,000 to approximately 7,000 ft (1,524 to 2,134 m) above mean sea level. The Burro Canyon disposal site lies on a small mesa isolated from upland runoff in the folded and faulted belt of the Paradox Basin,

approximately 30 mi (48.3 km) southwest of the Uncompahgre Uplift. The surface topography of the Burro Canyon disposal site is formed by a resistant outcrop of the Dakota Sandstone near the axis of the Disappointment syncline.

2.3.2 Stratigraphic Setting

DOE characterized stratigraphy by: referring to published and unpublished geologic literature and maps; reviewing site-specific subsurface geologic data, including logs of exploratory boreholes drilled on the site; and conducting field investigations as recommended in SRP Section 1.3.2.

Bedrock in the Burro Canyon site region consists of a Precambrian igneous and metamorphic basement complex overlain by a thick sequence of marine and continental rocks of Cambrian to Cretaceous age. In some areas, the sedimentary deposits are overlain by Tertiary igneous rocks and unconsolidated Quaternary deposits. The combined thickness of sedimentary rocks in the region is about 13,000 ft (4000 m) (Shawe and others, 1968; see RAP Figure 2.3, p. 2-11). The sedimentary units are folded into broad, parallel, northwest-trending anticlines and synclines. Evaporites (the Pennsylvanian Paradox Formation) have intruded the axial parts of the anticlines. Based on subsurface investigations (bore holes and monitoring wells) in the designated disposal cell area at the Burro Canyon site, soil cover ranges from one to five feet (0.3 to 1.5 m) thick with the underlying shales and thin sandstones of the Dakota Sandstone (Lower and Upper Cretaceous) ranging from 8 to 41 ft (2.4 to 4.6 m) in thickness. The Dakota Sandstone is underlain by mudstone/claystone of the Lower Cretaceous Burro Canyon Formation. At borehole 515 (see Volume III, Final Design for Review, Information for Bidders, DOE, 1995) the Burro Canyon Formation is 380 ft (131.2 m) thick. The drill terminated at a depth of 431.7 ft (131.2 m) after penetrating 27 ft (8.2 m) of the underlying sandstones and mudstones of the Brushy Basin member of the Jurassic Morrison Formation.

The NRC staff finds reasonable assurance that the subsurface conditions at the Burro Canyon disposal site will not affect the site's ability to meet the remedial action standards.

2.3.3 Structural Setting

DOE characterized the region's structural setting by referring to published regional geologic maps, aerial reconnaissance (conventional and LANDSAT), field observations, and mapping of features critical to assuring the long-term stability of the remedial action. These studies were recommended in SRP Section 1.3.3. A summary of DOE's structural characterization is presented below.

The two major regional structural and tectonic features of direct relevance to the Burro Canyon disposal cell site are the Uncompahgre Uplift [nearest approach 24 mi (38 km)] and the salt anticline region of the Paradox Basin. Both are northwest-trending structural provinces within the Colorado Plateau. The Burro Canyon disposal cell is located within the salt anticline region of the Paradox Basin. The Uncompahgre Uplift, which is located to the northeast of the disposal cell, is a large, northwest-trending, asymmetrical block

composed of a complex Precambrian igneous and metamorphic core overlain by Mesozoic sedimentary units and bounded on the northeastern and southwestern flanks by abrupt, locally faulted monoclines. Faulting may have been initiated in the late Tertiary (Miocene or Pliocene) and may have persisted well into the Pleistocene (Cater, 1966; Lohman, 1981; Sinnock, 1981; Kirkham and Rogers, 1981). These tectonic uplift-bounding faults are considered potentially active by Kirkham and Rogers (1981).

As indicated above, the Burro Canyon disposal site is located in the Colorado Plateau and is near the axis of the Disappointment syncline within the Paradox Basin. The Paradox Basin is approximately 40 mi (65 km) wide with the Burro Canyon site located approximately 9.3 mi (15 km) from the southern province boundary and 30 mi (48.3 km) from the northern province boundary. The northern boundary is coincident with the southwestern flank of the Uncompahgre Uplift. Sedimentary rocks in the Paradox Basin are folded in a series of broad, northwest-trending anticlines and synclines generally parallel to the southwestern edge of the Uncompahgre Uplift (Kirkham and Rogers, 1981; also see RAP Figures 2.4 and 2.5a). These anticlines were produced by compressional folding that occurred in the Late Cretaceous-Early Tertiary Laramide orogeny and by the diapiric intrusion of salt into the overlying strata from the deeply underlying thick evaporite beds (salts of the Paradox Member of the Pennsylvanian Hermosa Group). As compressional forces relaxed, graben faulting developed on the crests of the salt anticlines causing their collapse. A second phase of collapse was caused by dissolution of the salt due to the deep incision of the drainage with flowage of the salt towards the rivers (Cater, 1970). These collapse-induced faults are considered non-tectonic since they result from down-dropping sedimentary rocks which overlie areas of salt removed by flow and dissolution.

The bedrock beneath the disposal cell (Dakota Sandstone, Burro Canyon, and Morrison Formations) is not faulted, but it dips gently toward the northeast at about 2 degrees.

The NRC staff finds that the RAP adequately characterizes the regional and site-specific structural setting of the Burro Canyon disposal site.

2.3.4 Geomorphic Setting

DOE characterized the regional geomorphology by referring to published literature and topographic maps, as recommended in SRP Section 1.3.4. Site geomorphic conditions were characterized by field observations. A summary of DOE's geomorphic characterization is provided below.

The Burro Canyon disposal site is located on a small mesa, isolated from upland runoff, along the axis of the Disappointment syncline. The mesa is capped by the Dakota Sandstone and is underlain by the Burro Canyon Formation, the top of which consists of a highly resistant bed of silicified claystone. The average slope across the site is approximately 0.033 ft/ft (0.001 m/m). The site drainage exits the mesa on the south slope where the channel slope is 0.10 ft/ft (0.03 m/m). The rate of erosion in the sandstone bedrock channel is low, with no active gullies. A sandstone veneer forms a natural armor on the slopes, particularly at the head of minor gullies. The silicified upper

portion of the Burro Canyon Formation is resistant to gully formation. This silicification imparts the mudstone of the Burro Canyon Formation with a resistance to erosion that is significantly greater than that of similar claystone-mudstone units (e.g., the Dakota Sandstone and the Morrison Formation) exposed in the area (Shawe and others, 1968). The location of the disposal site atop the mesa limits the drainage area, thus limiting the erosion rate. Although no site-specific studies were conducted, investigations elsewhere in the Paradox Basin (Woodward-Clyde, 1982) yield historic surface denudation rates ranging from 0.3 to 3.1 ft (0.09 to 0.94m)/1,000 years for lithologic units similar to those at the Burro Canyon site. Furthermore, little bedrock incision appears to have occurred during the last 8,000 to 10,000 years (Woodward-Clyde, 1982). Estimates of rates of scarp retreat in bedrock units in the site region range from 0.8 to 1.8 ft (0.2 to 0.55 m)/1,000 years in formations similar to those at the Burro Canyon site (Woodward-Clyde, 1982).

The NRC staff finds that the RAP adequately characterizes the regional and site geomorphology for the Burro Canyon site.

2.3.5 Seismicity

The Burro Canyon disposal cell is located in the Paradox Basin within the Colorado Plateau physiographic province. DOE's discussion of historical seismicity within the site region is largely based on information in the National Geophysical Data Center/National Oceanographic and Atmospheric Administration earthquake database (NGDC/NOAA, 1994). Characterization of the regional seismicity is also based on analysis of the geologic and seismotectonic setting, Cenozoic geologic history, and geomorphic evidence of Late Tertiary and Quaternary fault movements. Where appropriate, maximum earthquake magnitudes are derived by applying fault length-magnitude relationships.

The largest earthquake recorded in the Colorado Plateau is magnitude 5.5, and based on the seismotectonic characteristics of the province, the largest ever expected is 6.5 (see RAP, Table 2.2, p. 2-28). This 6.5 estimate includes all expected events on known tectonic features, as well as floating earthquakes. Plate 2.1 in the RAP shows all mapped faults within 40 mi (65 km) of the Burro Canyon site, as well as all historic seismic events within this radius. As of 1994, the largest earthquake recorded by the National Geophysical Data Center within the 40 mi (65 km) site region was a magnitude 4.1 event that occurred within the Paradox Basin in 1984 (NGDC/NOAA, 1994). As indicated in Table 2.4 and on page 2-34 of the RAP, this event was located 34 mi (54 km) south of the site on trend with the Abajo Mountain and Verdure Graben fault system. A microearthquake monitoring program conducted within the Paradox Basin from 1979 to 1982 recorded 316 microearthquakes of magnitude (M_L) zero to 2.4 (Wong, 1984). Most of these events are believed to result from mine blasting or Colorado River-induced seismicity. In addition, the Paradox Basin has non-tectonic sources of seismic activity related to salt flow near deep potash mines in the Moab, Utah, area (Wong and others, 1987). The maximum magnitude observed from this seismic source is 3.0 (Wong and others, 1987). Kirkham and Rogers (1981) state that salt-tectonic faults are not likely to generate

earthquakes larger than magnitude 4.0 or 5.0; this is a very conservative upper bound for salt-tectonic earthquake magnitudes.

Commonly, faults in the Paradox Basin with surface expression are considered non-tectonic, since they result from the collapse of sedimentary rocks overlying areas of salt which is removed by flowage and dissolution. Although movement along these non-tectonic faults continues, it proceeds more as a gradual creep than sudden slip. Due to the unusual, non-tectonic nature of these faults, they are not considered to be capable (see descriptions in RAP Table 4.1). Pages 4-8 through 4-11 in the RAP present extensive evidence from a variety of sources supporting the conclusion that several fault systems in the site region result from salt tectonics, and hence normal fault length-magnitude relationships do not apply. Included in this category are faults within the Lisbon Valley, Big Gypsum Valley, and Paradox Valley.

Little is known regarding the nature of subsurface faults in the bedrock beneath the deformed, ductile Paradox strata. Several studies listed on page 4-8 of the RAP have examined possible links between salt tectonic features on the surface and underlying basement faults, and the preponderance of evidence suggests that the surface faults are rooted in the Paradox Formation rather than linking with tectonic basement faults. The cross section in RAP Figure 2-5c, modified from Woodward-Clyde (1982), illustrates the conceptualized disconnect between surface and basement faults.

Several bedrock fault segments up to 3 mi (5 km) long occur within 4 mi (6 km) of the site, and they appear to be non-tectonic segments related to collapse of the Lisbon Valley salt-cored anticline. Based on low-sun-angle aerial reconnaissance and ground inspection, these segments do not appear to have Quaternary offset. Nonetheless, for conservatism, they are considered to be active and capable of a magnitude 3.5 event. Likewise, segments in Big Gypsum Valley lie 4 mi (6 km) from the site and are assumed capable of magnitude 3.5, although no evidence of Quaternary slip exists.

The floating earthquake (FE) is defined as an earthquake which is not associated with a known tectonic structure. The maximum magnitude for a FE can be considered as the threshold magnitude above which ground rupture will occur. This value is generally specific to a tectonic province, and based in part on the seismic history of the province. The maximum FE considered for the Burro Canyon site is magnitude 6.2, which is an appropriate value for sites in the Colorado Plateau interior. Detailed justification for this magnitude is provided on pages 1-3 and 1-4 of the RAP, under the definition of the floating earthquake. Magnitude 6.2 is consistent with the figure used for other UMTRCA Title I sites within the Colorado Plateau, such as Naturita and Mexican Hat.

The staff finds the RAP to adequately characterize the historical seismicity of the site region, as well as conservatively estimate magnitudes of future seismic events.

2.3.6 Natural Resources

DOE characterized the regional and site-specific natural resources by an analysis of regional and local publications, regional geologic maps, topographic maps, and field observations. A summary of DOE's characterization of the natural resources is as follows.

Known economic resources in the disposal site region consist of uranium and vanadium ores, gas and oil, potash and mineral-laden natural brines and minor amounts of coal. The most abundant resources developed in the region have been uranium and vanadium. Although the uranium-vanadium mines are no longer operating because of economic constraints, economically significant ore bodies are still present in the area and most likely underlie the site at an estimated depth of 910 ft (277.4 m).

Extensive oil and gas resources have been developed in the salt anticline region surrounding the Slick Rock site with exploration having occurred adjacent to the site. Although the locations of exploration for oil and gas are poorly known because of its proprietary nature, DOE has identified four exploratory wells within 9.3 mi (15 km) of the site, including one dry, abandoned exploratory oil/gas well located approximately 700 ft. (213.4 m) southwest of the site. The RAP does not identify any producing oil/gas wells within at least 9.3 mi (15 km) of the site. Since the potential production zones for future hydrocarbon production would be a considerable depth below the site, well exceeding the depths considered [910 ft (277.4 m)] for potential uranium/vanadium mining, the potential for subsidence or collapse associated with the extraction of hydrocarbons would be negligible.

Seismic exploration for hydrocarbons has been conducted in the region, possibly near the site itself. Specific locations of any seismic data that may have been collected in the site area are not identified in the RAP. NRC agrees with DOE's conclusion that locations of seismic lines are probably unimportant, as the data are most likely proprietary and hence unavailable to DOE.

Potash and brine mineral deposits occur within the site area and a large portion of the Paradox Basin (see RAP Figure 2.5). Although neither potash nor brine deposits have been identified directly beneath the site, potash exploration has occurred on the flanks of Big Gypsum Valley, a diapiric collapse salt anticline structure (Woodward-Clyde, 1983) approximately 3 mi (4.8 km) northeast of the site. The RAP considers Big Gypsum Valley to be the nearest potential location for the extraction of potash and brine mineral deposits. The only known production of potash and minerals in the Paradox Basin associated with natural brines is in the Moab, Utah, area approximately 50 mi (80.4 km) northwest of the site. Most natural brine occurrences in the Paradox Basin are too small for economic development. Since only 1,000 ft (304.8 m) of Paradox Salt deposits (the source of both the potash and brine deposits) reportedly underlie the site compared with the 10,000 ft (3048 m) deposits in nearby Gypsum Valley, the economic development of this resource beneath the site is unlikely. Furthermore, since any potential economic deposits of potash and mineral brines are well below the uranium/vanadium ore

assumed to underlie the site at 910 ft (277.4 m), the effect on the cell from any subsidence or collapse from the extraction of these deposits would be negligible.

Thin coal seams are present in the Dakota Sandstone, but they are discontinuous and do not underlie the site. The coal deposits are impure and do not contain economically important coal reserves. Likewise, there is no known potential for the development of geothermal heat in the disposal area.

The NRC staff finds that the RAP adequately describes the occurrence and development potential of natural resources near the Burro Canyon disposal site.

2.4 Geologic Stability

Geologic conditions and processes are characterized to determine the site's ability to meet standards in 40 CFR 192.02(a). In general, site lithologic, stratigraphic, and structural conditions are considered for their suitability as a disposal foundation and their potential interaction with tailings leachate and groundwater. Geomorphic processes are considered for their potential impact upon long-term tailings stabilization and isolation. Potential geologic hazards, including seismic shaking, liquefaction, on-site fault rupture, ground collapse resulting from the extraction of natural resources underlying the site, and volcanism are identified for the purpose of assuring the long-term stability of the disposal cell and success of the remedial action design.

2.4.1 Geomorphic Stability

The site will be protected from geomorphic processes by its position atop the mesa which is isolated from upland runoff and attendant erosion. The silicified claystone of the Burro Canyon Formation, outcropping along the perimeter of the mesa, coupled with the resistant Dakota Sandstone forming the channel way of the drainage of the site to the south, attests to the present and projected future stability of the disposal site. Elsewhere in the site region, scarp retreat rate is minimal in bedrock units similar to those at the Burro Canyon site.

Based on the information provided in the RAP, the NRC staff has reasonable assurance that geomorphic conditions of the site have been adequately characterized, and that the remedial action will not be adversely affected by geomorphic processes.

2.4.2 Seismotectonic Stability

Studies by DOE to analyze seismic hazards included: (1) determination of design-basis seismic sources, (2) selection of a design earthquake, (3) calculation of the peak horizontal ground acceleration, (4) determination of the potential of on-site fault rupture, and (5) recognition of potential earthquake-induced geologic failures at the site.

The characterization of the seismotectonic setting and seismic activity for the site region includes identification of both tectonic and salt-tectonic structures considered as potential seismic sources. Table 4.1 in the RAP lists all faults within 40 mi (65 km) of the site, the estimated maximum earthquakes based on the length-magnitude relationship of Bonilla and others (1984), and the estimated, 84th percentile, on-site peak ground accelerations using attenuation relationships of Campbell (1981) and Campbell and Bozorgnia (1994). All salt-tectonic faults are assigned a maximum magnitude of 3.5, a conservative estimate following the Wong and others (1987) estimates of salt-tectonic earthquake magnitudes. Faults in the Verdure and Shay grabens, approximately 22 mi (35 km) southwest of the site, are predicted to yield the largest on-site accelerations (0.18-0.20 g) of any identified structures in the site area.

The magnitude 6.2 FE is assumed to occur at a radial distance of 9.3 mi (15 km) from the site, resulting in a free-field, non-amplified, peak horizontal ground acceleration of 0.21 g (Campbell, 1981) at the disposal site. By the more recent Campbell and Bozorgnia (1994) attenuation model, the peak acceleration from the FE is 0.23 g. Therefore, the FE yields the maximum seismic acceleration, so it is appropriately chosen as the design earthquake for the Burro Canyon site.

The staff finds that the seismotectonic stability of the site has been adequately characterized.

2.4.3 Bedrock Stability

DOE's evaluation of the site region is described in the RAP with the staff's evaluation presented in TER Section 2.3. Based on the RAP the staff's evaluation indicates (1) no evidence of tectonic faulting assumed to be capable within at least 30 mi (48 km) of the disposal site, and (2) no potential geologic hazards attributable to either seismic shaking or on-site fault rupture.

The staff finds that the RAP adequately characterizes the bedrock stability of the Burro Canyon site.

2.4.4 Volcanic Stability

As indicated in the RAP (see p. 5-3), volcanism poses no hazard to the stability of the site since there are no Quaternary volcanic rocks in the site area, and the youngest igneous intrusive rocks are located in the Abajo and La Sal Mountains in eastern Utah some 35 mi (59.1 km) northwest of the site.

The NRC staff has reviewed the details of volcanism as provided in the RAP and concludes that the Burro Canyon site has been adequately characterized with regard to volcanic stability.

2.5 Conclusions

Based upon review of the RAP and additional material, the staff finds that the geology and geologic stability of the Burro Canyon site have been adequately characterized. The geomorphic stability has been characterized adequately to meet 40 CFR Part 192.

3.0 GEOTECHNICAL STABILITY

3.1 Introduction

This section of the TER presents the NRC staff review of the geotechnical engineering aspects of the proposed remedial actions at the Slick Rock, Colorado UMTRAP site, as detailed in DOE's Final Remedial Action Plan (DOE, 1996). The Remedial Action Inspection Plan (RAIP), Rev D, dated January 9, 1995, was also reviewed. The NRC staff's review consisted primarily of evaluations of the site characterization and geotechnical stability aspects of the stabilized tailings embankment and the cover design. The staff review of related geologic aspects such as stratigraphic, structural, geomorphic, and seismic characterizations of the site is presented in Section 2.0 of this report. The staff review of the groundwater conditions and protection strategy for the site is presented in Section 5.0 of this report.

3.2 Site and Material Characterization

3.2.1 Processing Site Description

The uranium mill tailings at Slick Rock were located at two processing sites: the UC and NC sites. Both sites are adjacent to the Dolores River. The processing sites contain former mill building concrete foundations, tailings piles, demolition debris, and windblown and waterborne radioactive materials. The total estimated volume of contaminated materials is approximately 620,000 cubic yards (yd^3; 470,000 cubic meters [m^3]). In addition to the contamination at the two processing site areas, four vicinity properties were contaminated.

Both the UC and NC tailings sites are located in San Miguel County, Colorado. The tailings sites are surrounded by steep, juniper-covered hillsides and cliffs of the Dolores River Canyon. The tailings sites are 5500 feet above mean sea level; the surrounding hillsides reach 6500 feet. The UC tailings site is approximately one mile downstream of the NC tailings site.

3.2.2 Disposal Site Description

The Burro Canyon site is in the northeastern part of the Colorado Plateau physiographic province near its boundary with the southern Rocky Mountain province. This portion of the Colorado Plateau is characterized by large-scale folds, plateaus, and deep, narrow river canyons. The entrenched meanders of the Paradox Basin are the principal features of the region.

Bedrock in the site region includes exposures of complete stratigraphic sequences of Mesozoic deposits. Most Upper Cretaceous and all Tertiary deposits have been removed by erosion. Paleozoic rocks underlie the region, but are rarely exposed.

3.2.3 Geotechnical Investigation

Geotechnical investigations and site characterization programs were performed at both processing sites and the disposal and borrow sites. The data obtained

during the site characterization programs were presented in Attachment 1, Information for Bidders, Volumes I, II, III, and IV (March 1994); and Appendix B to Attachment 3, RAP (September 1995). The geotechnical investigations included excavating test pits and augering boreholes.

3.2.3.1 Processing Sites

Two characterization programs were conducted at the processing sites, including one each at the UC and NC locations. Prior to 1987, DOE excavated three test pits at the NC pile and 19 test pits at the UC pile. The DOE conducted additional subsurface investigations at the UC pile by augering 51 boreholes and performing 12 piezocone soundings. Another 26 boreholes were advanced at the NC site. Bulk samples that required larger quantities of material were taken for laboratory analyses.

Additional data were collected at the Slick Rock processing sites during investigations performed in 1987 and 1989. DOE drilled another 13 boreholes at the UC site in 1989. The DOE also collected and analyzed soil samples from an additional 20 boreholes and 21 test pits at the UC site, and two boreholes and 12 test pits at the NC site.

3.2.3.2 Disposal Site

The DOE performed the disposal area subsurface investigations, obtaining geotechnical data from 20 test pits excavated with a backhoe. The test pits were advanced to depths of 3 to 10 feet. Additional geotechnical data were obtained during 1990 and 1993. Sixteen well boreholes and six coreholes were advanced in 1990. The coreholes were drilled to depths ranging from 80 to 430 feet. Seven coreholes and seven test pits were advanced during November, 1993. The coreholes were drilled to depths up to 37 feet, and the test pits were advanced to depths of 10 feet.

Disturbed and undisturbed soil samples were obtained from the boreholes using standard sampling and penetration techniques. Only disturbed samples of material were obtained from test pits.

3.2.3.3 Borrow Areas

The DOE conducted numerous investigations in borrow areas. A total of 27 test pits were excavated and logged to characterize the soil at the Disappointment Valley borrow site. Soil from the Disappointment Valley borrow site will be used to construct the radon barrier. All test pits were excavated using a backhoe. Bulk samples were collected for laboratory determination of moisture content and the geotechnical characteristics of remolded samples. Samples of the erosion protection rock, ranging from gravel to cobble-sized material, were obtained from 23 test pits excavated in the Dolores River borrow sites located between the UC and NC piles. Two of the 23 test pits are located at the Troy Rose gravel pit. An additional rock borrow source is located about 0.2 miles south of the UC mill site on the western bank of the Dolores River. Rock samples from this site were obtained from three deep test pits and three boreholes.

The staff has reviewed the details of the test pits and borings as well as the scope of the overall geotechnical exploration program discussed in Section 3.2.3 above. The staff concludes that the geotechnical investigations conducted at the UC and NC mill sites, and the Burro Canyon disposal site, adequately establish the stratigraphy and the soil conditions at the respective locations, that the explorations are in general conformance with applicable provisions of Chapter 2 of the NRC SRP, and that they are adequate to support the assessment of the geotechnical stability of the stabilized tailings and contaminated material in the disposal cell.

3.2.4 Testing Program

The staff has reviewed the geotechnical engineering testing program for materials from the UC and NC processing sites, and the Burro Canyon disposal site. The testing program included specific gravity, Atterberg limits, particle size distribution, moisture/ density relationships, saturated hydraulic conductivity, direct and triaxial shear strength tests, consolidation, percolation and water pressure tests, and capillary moisture analysis on samples of tailings and contaminated materials and soils from the disposal site. In response to NRC questions regarding potential consolidation settlement of the off-pile and subpile contaminated materials, the staff was informed by DOE that these materials were not subject to consolidation-type settlement, thus additional consolidation testing is not required. Based on this response, the testing program is judged to be satisfactory to define the material properties and in general agreement with applicable provisions of the NRC SRP.

3.3 <u>Geotechnical Engineering Evaluation</u>

3.3.1 Stability Evaluation

The staff has reviewed the exploration data, test results, critical slope characteristics, and methods of analyses pertinent to the slope stability aspects of the remedial action plan for the Slick Rock UMTRA project disposal embankment. The analyzed strength parameters and embankment cross section with the 4 horizontal to 1 vertical slope have been compared to the exploration records and the design details. The staff finds that the most critical slope section has been considered for the stability analysis.

Soil parameters for the various materials in the stabilized embankment slope have been adequately established by appropriate testing of representative material. Values of parameters for other earthen materials have been assigned on the basis of data obtained from geotechnical explorations at the site and data published in the literature. The staff also finds that appropriate methods of stability analysis (the modified Janbu and infinite slope methods) have been employed and have addressed the likely adverse conditions to which the disposal cell slope may be subjected. Furthermore, appropriate methods of stability analysis have also been employed for the excavation cell side slopes.

Factors of safety against failure of the disposal cell slope for seismic and static loading conditions have been evaluated for both the short-term (end-of-

construction) and long-term states. The values of the seismic coefficients used by DOE in the pseudo-static analysis are 0.14 for the long-term condition and 0.11 for the short-term condition. These values were derived from a 0.21g peak horizontal bedrock acceleration (see Section 2.4.2) in accordance with the recommended methods in the NRC SRP and are acceptable to the staff. As indicated in Section 2.4.2, the current attenuation model (Campbell and Bozorgnia, 1994) would yield a peak horizontal bedrock acceleration of 0.23g. The staff finds that the use of the pseudo-static method of analysis for seismic stability of the disposal cell slopes is acceptable considering the flatness of the slopes and the conservatism in the soil parameter values. The minimum factors of safety against failure of the disposal cell slope were 2.67 and 1.85 for the short-term static and pseudo-static conditions, respectively, compared to required minimums of 1.3 and 1.0. It is apparent that, if the current Campbell and Bozorgnia model had been used, the calculated factors of safety would still exceed the minimum required values. For this reason, DOE's analysis is considered to be satisfactory.

For the excavation slope, only short-term stability analyses apply. Factors of safety of 1.3 (short-term) and 1.5 (long-term) were derived. These values meet required design minimums.

3.3.2 Settlement and Cover Cracking

The staff has reviewed the analysis of total and differential settlement of the disposal cell and foundation materials and the resulting potential for cracking of the radon barrier. Soil parameters for the radon barrier and compacted tailings were determined from appropriate testing of representative material. Select fill and foundation materials were assigned soil strength parameter values on the basis of data obtained from geotechnical investigations and published data.

Multilayered analyses using conventional consolidation theory were used to evaluate the amount of primary and secondary settlement and the time rates of primary settlement that will occur. Comparison was made of the secondary consolidation at different locations to determine long-term differential settlement gradients. Based on the results of DOE's analysis, it was concluded that the cover will not experience significant cracking, nor will water collect on the top of the embankment.

The staff agrees that an appropriate number of sections have been chosen to assess the likely range of differential settlement. Calculated settlements along the profile varied from 1.0 inches to 5.7 inches, with a resulting maximum horizontal strain of 0.00055. The calculated tensile failure strain for the proposed radon barrier material (PI=16) was 0.00098.

DOE has concluded that total and differential settlement of the materials comprising the proposed disposal cell will not have an adverse effect on the ability of the cell to meet the stability standards. Based on available information, the staff agrees that settlement will generally be small due to the compaction of the materials in the cell and the granular nature of much of the material. Differential settlement should not cause ponding concerns due to the sloping configuration of the cell. Cracking of the cover due to

settlement should not occur, since the resulting maximum strain is well below the calculated tensile failure strain.

3.3.3 Liquefaction

The staff has reviewed the information presented on the potential for liquefaction at the disposal site based on the results of geotechnical investigations, including boring and test pit logs, test data, soil profiles, and other information. The medium-dense to dense foundation material is not susceptible to liquefaction. The compacted dry density of the stabilized tailings and contaminated materials will be equal to a minimum of 90 percent of maximum dry density as determined by the ASTM D-698 test, and the tailings pile embankment design provides for the tailings materials to be mostly in an unsaturated condition.

For liquefaction to occur, a soil must be saturated, loose, and cohesionless. Since neither the foundation nor embankment materials meet these criteria, the stabilized embankment will not be susceptible to liquefaction. The staff concludes that the stability of the disposal cell will not be adversely affected by seismically-induced liquefaction.

3.3.4 Cover Design

The proposed cover design for the Burro Canyon disposal cell employs a multi-layered system of earthen materials with differing layers on the top slopes and the side slopes. On the top, in descending order from the surface, are: (1) an 8-inch-thick Type A riprap layer; (2) a 6-inch-thick sand/gravel bedding layer; (3) a 2-foot-thick frost protection layer; and (4) a 2-foot-thick radon/ infiltration barrier. On the side slopes, in descending order are: (1) a one-foot-thick Type B riprap layer; (2) a 6-inch-thick sand/gravel bedding layer; (3) a 2-foot-thick frost protection layer; and (4) a 2-foot-thick radon/infiltration barrier. This system provides a total of 54 to 62 inches of cover over the contaminated material, and collectively is designed to limit infiltration of precipitation, protect the pile from erosion, and control the release of radon from the cell. Details of the staff review of the cover's performance related to erosion protection features is presented in Section 4.0 of this TER; the review of the cover's performance related to limiting infiltration are addressed in Section 5.0; and the review of the radon attenuation aspects of the cover is presented in Section 6.0. However, there are certain other aspects of the cover (frost protection, gradation/filter design, etc.) that are addressed herein.

The cover design includes a 2-foot-thick layer constructed solely for the purpose of protecting the radon barrier from frost damage. A computer analysis modelling the depth of frost penetration, using Slick Rock, Colorado, weather data, indicates that the combined thickness of the various layers of material and the radon barrier will provide adequate frost protection. Although DOE's design is based on a 200-year design life, the staff concurs that no additional frost protection is necessary.

Based on the geotechnical review of the disposal cell cover design, the staff concludes that the cover design of the disposal cell will perform adequately with respect to infiltration and frost protection.

3.4 Geotechnical Construction Details

3.4.1 Construction Methods and Features

The staff has reviewed and evaluated the geotechnical construction criteria provided in Attachment 1 to the RAP (DOE, 1995). Based on a review of RAP Attachment 1 and Calculations, Volumes I through VI, the staff concludes that the plans and drawings clearly convey the proposed remedial action design features. In addition, the excavation and placement methods and specifications represent accepted standard practice.

3.4.2 Testing and Inspection

The staff has reviewed and evaluated the testing and inspection quality control requirements provided in the project specifications and the RAIP. In general, the RAIP is found to provide a program for testing and inspection that is consistent with the Staff Technical Position on Testing and Inspection (NRC, 1989a).

3.5 Conclusions

Based on the review of the geotechnical engineering aspects of the design of the Slick Rock, Colorado proposed remedial action, the NRC staff has reasonable assurance that the long-term stability aspects of the EPA standards (40 CFR Part 192.02(a)) will be met by the design selected by DOE.

4.0 SURFACE WATER HYDROLOGY AND EROSION PROTECTION

4.1 Hydrologic Description and Site Conceptual Design

The Burro Canyon disposal site is located in southwest Colorado, approximately 2.5 miles east of the two processing sites. The average elevation of the disposal site is approximately 5875 ft above mean sea level (ft msl). The site is located on a small mesa and receives no offsite drainage. Runoff currently drains toward a gully located on the mesa's south side that cuts into the rim of the canyon.

In order to comply with EPA standards, which require stability of the tailings for 1000 years to the extent reasonably achievable and, in any case, for at least 200 years, DOE proposes to stabilize the contaminated materials in an engineered embankment to protect them from flooding and erosion. The design basis events for design of the erosion protection included the Probable Maximum Precipitation (PMP) and the Probable Maximum Flood (PMF), both of which are considered to have low probabilities of occurrence during the 1000-year stabilization period.

As proposed by DOE, the tailings from the two processing sites will be consolidated into a single pile, and will be protected by a rock cover. The rock cover will have a top slope of 2-4% and a side slope of 25%. The disposal cell will be surrounded by aprons which will safely convey flood runoff away from the cell and prevent gully intrusion into the contaminated materials. Because the site receives no offsite drainage, diversion ditches are not necessary.

4.2 Flooding Determinations

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

4.2.1 Selection of Design Rainfall Event

One of the most disruptive phenomena affecting long-term stability is surface water erosion. DOE has recognized the importance of selecting an appropriately conservative rainfall event on which to base the flood protection designs. DOE has concluded, and the NRC staff concurs, (NRC, 1990) 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 extrapolations. Rather, DOE utilized the PMP, which is computed by deterministic methods (rather than statistical methods), and is 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, DOE and the NRC staff have concluded that the probability of such an event being equalled or exceeded during the 1000-year stability period is small. Therefore, 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 entire United States primarily by the National Oceanographic and Atmospheric Administration (NOAA) 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.

A PMP rainfall depth of approximately 8.1 inches in 1 hour was used by DOE to compute the PMF for the small drainage areas at the disposal site. This rainfall estimate was developed by DOE using Hydrometeorological Report (HMR) 49 (NOAA, 1977). The staff performed an independent check of the PMP value, based on the procedures given in HMR 49. Based on this check of the rainfall computations, the staff concludes that the PMP was acceptably derived for this site.

4.2.2 Infiltration Losses

Determination of the peak runoff rate is dependent on the amount of precipitation that infiltrates into the ground during the occurrence of the rainfall. 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 Rational Formula (USBR, 1977), incorporate a runoff coefficient (C) where 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 (ACE, 1970), 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 design of the rock riprap erosion protection at the proposed disposal site, DOE used the Rational Formula (USBR, 1977). In this formula, the runoff coefficient was assumed by DOE to be unity; that is, DOE assumed that no infiltration would occur. Based on a review of the computations, the staff concludes that this is a very conservative assumption and is, therefore, acceptable.

4.2.3 Times of Concentration

The time of concentration 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 computed to be small, the

peak discharge will be conservatively large. Times of concentration and/or lag times are typically computed using empirical relationships such as those developed by Federal agencies (USBR, 1977). 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.

Various times of concentration for the riprap design were estimated by DOE using velocities computed using the Manning's Equation (Chow, 1959). Such velocity-based methods are considered by the staff to be appropriate for estimating times of concentration. Based on the precision and conservatism associated with such methods, the staff concludes that the times of concentration have been acceptably derived. The staff further concludes that the procedures used for computing time of concentration are representative of the small steep drainage areas present at the site.

4.2.4 Rainfall Distributions

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 1 hour. If the time of concentration is less than 1 hour, it is necessary to extrapolate the data presented in the various hydrometeorological reports to shorter time periods. DOE utilized a procedure recommended in HMR 49 and by the NRC staff (NRC, 1990). This procedure involves the determination of rainfall amounts as a percentage of the 1-hour PMP, and computes rainfall amounts and intensities for very short periods of time. DOE and the NRC staff have concluded that this procedure is conservative.

In the determination of peak flood flows, approximate PMP rainfall intensities were derived by DOE as follows:

Rainfall Duration (minutes)	Rainfall Intensity (inches/hr)
2.5	53
5	43
10	31
60	8.1

The staff checked the rainfall intensities for the short durations associated with small drainage basins. Based on a review of this aspect of the flooding determination, the staff concludes that the computed peak rainfall intensities are conservative.

4.2.5 Computation of PMF

4.2.5.1 Top and Side Slopes

The PMF was estimated for the top and side slopes using the Rational Formula, which provides a standard method for estimating flood discharges for small drainage areas. For the top slope and the side slope, DOE estimated the peak

flow rates to be about 0.16 cubic feet per second per foot of width (cfs/ft) and 0.39 cfs/ft, respectively. Based on staff review of the calculations, these estimates are considered to be conservative.

4.2.5.2 Apron/Toe

A PMF flow rate of 0.4 cfs/ft for the apron was computed similarly to the design flow rate for the top and side slopes. As discussed above, the flow rate is considered to be conservative.

4.3 Water Surface Profiles and Channel Velocities

Following the determination of the peak flood discharge, it is necessary to determine the resulting water levels, velocities, and shear stresses associated with that discharge. These parameters then provide the basis for the determination of the required riprap size and layer thickness needed to assure stability during the occurrence of the design event.

4.3.1 Top and Side Slopes

In determining riprap requirements for the top and side slopes, DOE utilized the Safety Factors Method (Stevens and others, 1976) and the Stephenson Method (Stephenson, 1979), respectively. The Safety Factors Method is used for relatively flat slopes of less than 10 percent; the Stephenson Method is used for slopes greater than 10 percent. The validity of these design approaches has been verified by the NRC staff through the use of flume tests at Colorado State University. It was determined that the selection of an appropriate design procedure depends on the magnitude of the slope (Abt and others, 1987).

The staff, therefore, concludes that the procedures and design approaches used by DOE are acceptable and reflect state-of-the-art methods for designing riprap erosion protection.

4.3.2 Apron/Toe

The design of the apron at the toe of the disposal cell is based on the following considerations:

1. provide riprap of adequate size to be stable against the design storm (PMP);

2. provide uniform and/or gentle grades along the apron and the adjacent ground surface such that runoff from the cell is distributed uniformly at a relatively low velocity, minimizing the potential for flow concentration and erosion; and

3. provide an adequate apron thickness to prevent undercutting of the disposal cell by (a) local scour that could result from the PMP, or (b) potential gully encroachment that could occur due to gradual headcutting over a long period of time.

The key elements which DOE evaluated in the design of riprap protection for the apron/toe are:

1. the lower part of the 25% side slope immediately upstream of the grade break formed when the side slope meets the apron;

2. the toe, which is the relatively flat lower slope (2%) immediately downstream of the grade break;

3. the downstream portion of the apron, which is assumed to have collapsed due to scour or long-term erosion; and

4. the ground surface adjacent to the apron.

DOE used several analytical methods for designing the riprap for the apron/toe. Additional detailed discussion of the riprap design of various components of the apron/toe can be found in Section 4.4.1.2, below.

4.4 Erosion Protection

4.4.1 Sizing of Erosion Protection

Riprap layers of various sizes and thicknesses are proposed for use at the site. The design of each layer is dependent on its location and purpose. The average rock sizes (D_{50}s) discussed below reflect a 15% allowance for oversizing due to the need to meet rock durability criteria (See Section 4.4.2).

4.4.1.1 Top Slopes and Side Slopes

The riprap on the top slope has been sized to withstand the erosive velocities resulting from an on-cell PMP, as discussed above. DOE proposes to use an 8-inch-thick layer of rock with a minimum D_{50} of 1.7 inches (Type A). The riprap will be placed on a 6-inch-thick bedding layer. The Safety Factors Method was used to determine the rock size.

The rock layer on the side slopes is also designed for an occurrence of the local PMP. DOE proposes to use a 1-foot-thick layer of rock with a minimum D_{50} of approximately 4 inches (Type B). The rock layer will be placed on a 0.5-foot-thick bedding layer. Stephenson's Method was used to determine the required rock size. Conservative values were used for the specific gravity of the rock, the rock angle of internal friction, and porosity.

Based on staff review of the DOE analyses and the acceptability of using design methods recommended by the NRC staff, as discussed in Section 4.3 of this report, the staff concludes that the proposed rock sizes are adequate.

4.4.1.2 Apron/Toe

DOE evaluated the design of the apron/toe in four separate segments, as discussed in Section 4.3.2, above. Following is the staff evaluation of each of the segments.

4.4.1.2.1 Lower Side Slope

For the lower portion (last 10 feet) of the side slopes (upstream portion of the apron), DOE proposes to use a layer of rock with a minimum D_{50} size of about 5.8 inches (Type C). Several methods were used to check the rock size required for the toe. DOE determined the shear forces associated with PMP flows down the side slope and assumed that turbulence would be created on the lower portion of the slope where it meets the toe. To account for this turbulence and energy dissipation, DOE increased the shear stress by 50%, in accordance with ACE recommendations. The required rock size was computed using the Safety Factors Method. Based on staff analysis of DOE's methods and assumptions, the Type C rock proposed for this portion of the slope is acceptable.

4.4.1.2.2 Toe

For the actual toe area, which will have a 20-foot length and a 2% slope, DOE used the Safety Factors Method to determine the required rock size. The flow rate was increased by a factor of 3 to account for flow concentrations near the downstream end of the apron. The D_{50} rock size calculated using this method was found to be smaller that the proposed D_{50} size of 5.8 inches. Based on our review of DOE's calculations, the rock size is acceptable.

4.4.1.2.3 Collapsed Slope

As part of the analysis of the toe area, DOE conservatively assumed that the natural ground downstream of the toe would be eroded due to cumulative local scour and/or erosion at its base, resulting in the collapse of the rock into the eroded area. DOE assumed that the collapsed slope of the rock would be 1 vertical (V) on 4 horizontal (H). A sufficient amount of rock will be provided in the toe to assure that the maximum slope after the assumed failure does not exceed the 1V on 4H slope. Using the Stephenson Method, the required rock size is calculated to less than the proposed size of 5.8 inches. This rock is considered to be acceptable.

4.4.1.2.4 Natural Ground

In order to determine the depth to which the toe must be placed, it is necessary to estimate the depth of scour which will occur at the natural ground slope just downstream of the toe. DOE assumed that a flow concentration factor of 3, corresponding to gully flows, would occur. Using the Lacey Regime Equation (Davis and Sorenson, 1969), the scour depth was estimated to be 2 feet. However, DOE proposes to place the toe to a depth of 5 feet, for conservatism. Staff review of the calculations indicates that the toe design is acceptable.

4.4.2 Rock Durability

The EPA standards require that control of RRM be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years. The previous sections of this report examined the ability of the erosion protection to withstand flooding events reasonably expected to occur

in 1000 years. In this section, rock durability is considered to determine if there is reasonable assurance that the rock itself will survive and remain effective for 1000 years.

Rock durability is defined as the ability of a material to withstand the forces of weathering. Factors that affect rock durability are: (1) chemical reactions with water; (2) saturation time; (3) water temperature; (4) sediment scour; (5) windblown scour; (6) wetting and drying; and (7) freezing and thawing.

DOE identified several potential sources of rock in the immediate site vicinity. The suitability of the rock as protective covers was then assessed by laboratory tests to determine its physical characteristics. DOE conducted the tests and used the results of the tests to classify the rock's quality and to assess the expected long-term performance of the rock. In accordance with past DOE rock-testing practice, the tests included:

1. Petrographic Examination (ASTM C295). Petrographic examination of rock is used to determine its physical and chemical properties. The examination establishes if the rock contains chemically unstable minerals or volumetrically unstable materials.

2. Bulk Specific Gravity (ASTM C127). The specific gravity of a rock is an indicator of its strength or durability. In general, the higher the specific gravity, the better the quality of the rock.

3. Absorption (ASTM C127). A low absorption is a desirable property and indicates slow disintegration of the rock by salt action and mineral hydration.

4. Sulfate Soundness (ASTM C88). In locations subject to freezing or exposure to salt water, a low percentage is desirable.

5. Schmidt Rebound Hammer. This test measures the hardness of a rock and can be used in either the field or the laboratory.

6. Los Angeles Abrasion (ASTM C131 or C535). This test is a measure of rock's resistance to abrasion.

7. Tensile Strength (ASTM D3967 or ISRM Method). This test is an indirect test of a rock's tensile strength.

DOE then used a step-by-step procedure for evaluating durability of the rock, in accordance with procedures recommended by the NRC staff (NRC, 1990), as follows:

Step 1. Test results from representative samples are scored on a scale of 0 to 10. Results of 8 to 10 are considered "good"; results of 5 to 8 are considered "fair"; and results of 0 to 5 are considered "poor".

Step 2. The score is multiplied by a weighing factor. The effect of the weighing factor is to focus the scoring on those tests that are the most applicable for the particular rock type being tested.

Step 3. The weighted scores are totaled, divided by the maximum possible score, and multiplied by 100 to determine the rating.

Step 4. The rock quality scores are then compared to the criteria which determines its acceptability, as defined in the NRC scoring procedures.

In accordance with the procedures suggested in the NRC Staff Technical Position (NRC, 1990), DOE conducted durability testing of several rock sources. Based on these tests, the rock quality score was determined. The rock scored from 67-85 (averaging 77), and DOE proposes to oversize the rock by a factor of about 15%, using NRC criteria (NRC, 1990). The staff concludes that the rock sources proposed meet the durability criteria suggested by the staff (NRC, 1990) and are of sufficient quality to meet EPA standards.

4.4.3 Testing and Inspection of Erosion Protection

DOE provided the testing and inspection quality control requirements for the erosion protection materials in the Remedial Action Inspection Plan (RAIP). This information was evaluated by the staff to determine the adequacy of the quality and placement of rock materials selected. Because the rock source may contain rocks of many different types, DOE intends to test each of the rock types to determine their durability and to determine the percentage of each type. These percentages will then be used to calculate the rock quality scores. Although some of the rocks may be sandstones, the procedures proposed by DOE will ensure a riprap layer consisting of uniformly high quality rock, given the mixed types available. Based on review of the information provided in the RAIP, the staff concludes that the design meets the requirements of 40 CFR 192.

4.5 Upstream Dam Failures

There are no impoundments near the site whose failure could potentially affect the site.

4.6 Conclusions

Based on review of the information submitted by DOE, the NRC staff concludes that the site design will meet EPA requirements as stated in 40 CFR 192 with regard to flood design measures and erosion protection.

5.0 WATER RESOURCES PROTECTION

5.1 Introduction

The NRC staff reviewed the Remedial Action Plan (DOE, 1995) and supporting documents for the Slick Rock, Colorado, UMTRA Project site for compliance with EPA's groundwater protection standards in 40 CFR Part 192, Subparts A through C (EPA, 1995). All field investigations, analyses, and conclusions presented in the RAP were performed by DOE, or its contractors. The staff reviewed the RAP in accordance with relevant portions of the SRP (NRC, 1993). All site descriptions and characterizations presented in this chapter are based on information and data provided by DOE. Specific analyses and conclusions made by staff, as a part of this review, are designated as such.

The staff, consistent with EPA's groundwater protection standards, distinguishes between the disposal of RRM at the disposal site and the clean-up of existing groundwater contamination at the processing sites. DOE proposes to defer clean-up of existing groundwater contamination at the processing sites until the UMTRA Ground Water Project. Deferring clean-up of existing groundwater contamination can be made only after demonstration that public health and safety will not be adversely impacted by the deferral.

DOE stated that the level of site characterization at the processing sites is sufficient to address only whether the remedial action will comply with the EPA groundwater protection standards. Additional groundwater characterization, including water quality, groundwater flow, and aquifer properties, may be conducted when the conceptual groundwater restoration strategy is developed.

DOE concluded that the proposed remedial action complies with the EPA groundwater protection standards at the disposal site, because the uppermost aquifer yields less than 150 gpd (568 Lpd) and meets the definition of limited use groundwater in 40 CFR 192.11(e). DOE proposes supplemental standards under 40 CFR 192.21(g) with no hazardous concentration limits and no groundwater monitoring at the point of compliance (POC).

5.2 Hydrogeologic Characterization

5.2.1 Identification of Hydrogeologic Units

A. Processing Sites

The Slick Rock processing sites encompass two separate locations along the western bank of the Dolores River, within approximately one mile of each other. These sites are identified as the UC and NC sites. The UC site is the larger of the two sites. Both sites are within the deeply entrenched Dolores River valley, along the gently sloping terrace surfaces dissected by small stream channels and gullies. The tailings piles at both sites are within the modern floodplain of the Dolores River.

The uppermost aquifer at both sites consists of Dolores River alluvium, the underlying Entrada Formation, and the underlying Navajo Sandstone. These three hydrostratigraphic units are unconfined to confined, show variable permeabilities, and may be hydraulically connected. The alluvium is composed of widespread unconsolidated clayey sands, sandy gravels, and cobbles. The Entrada Formation is composed the Slick Rock Member and the Dewey Bridge Member. The Slick Rock Member is absent at the UC site, but consists of light brown, fine-grained, poorly-cemented sand at the NC site. The Dewey Bridge Member directly underlies the alluvium at the UC site and underlies the Slick Rock Member at the NC site. At both sites, the Dewey Bridge consists of reddish-brown, clayey siltstone, very fine-grained sandstone, and shale. The Navajo Sandstone underlies the Entrada Formation throughout the Slick Rock area and is composed of light-brown to reddish-brown, fine-grained sandstone.

Site characterization activities conducted in September 1989 by DOE indicate the presence of paleochannels at the UC site. Lithologic data suggests that these paleochannels have eroded into the Entrada Formation and the Navajo Sandstone, contributing up to 50 ft (15 m) of highly permeable gravel. The Navajo Sandstone may be unconfined to semiconfined under portions of the UC site.

Thicknesses of the units that comprise the uppermost aquifer are variable. The alluvium ranges from 20 to 160 ft (6 to 49 m) in thickness; the Entrada Formation ranges in thickness from approximately 20 to 90 ft (6 to 27 m). The Navajo Sandstone thickness reportedly ranges from 0 to 420 ft (128 m) in the Slick Rock area. Borings drilled at the two sites have not fully penetrated the Navajo sandstone. The groundwater depth at both sites ranges from 10 to 20 ft (3 to 6 m) in wells screened in the alluvium.

Staff agrees with the conclusion that the Dolores River alluvium, the Entrada Formation and the Navajo Sandstone units comprise the uppermost aquifer at the UC and NC uranium processing sites.

B. Disposal Site

The Burro Canyon disposal site sits on the weathered pediment of Dakota Sandstone that overlies the interbedded mudstones, siltstones, and sandstones of the Burro Canyon Formation. The lowest unit of the Dakota Sandstone consists primarily of low-permeability carbonaceous shale and mudstone. Two thin sand layers ranging in thickness from 1 to 6 ft (0.3 to 3 m) are interbedded with the lower Dakota shales and mudstones. The Dakota Sandstone is unsaturated at the disposal site.

The thickness of the Burro Canyon Formation is relatively uniform in the vicinity of the site. Three water-bearing units are within the Burro Canyon beneath the site. These units are described as the Upper, Middle, and Lower sandstones, at depths of 100, 200 and 300 ft (31, 61, and 91 m), respectively. Thick interbedded claystones, mudstone, and siltstone sequences separate each of these sandstone units. Geochemistry and potentiometric head data collected from these three hydrogeologic units indicate a distinct hydraulic separation among these units. The claystone and mudstone units above the Upper sand and between the deeper sandstone units are effective aquitards which would inhibit

the potential vertical migration of contaminated fluids from the disposal cell. The Upper sandstone is designated as the uppermost aquifer at the disposal site, because of the hydraulic separation from the deeper units and the unsaturated condition of the shallow Dakota Sandstone unit.

Staff agrees with the conclusion that the Upper Sandstone unit of the Burro Canyon Formation comprises the uppermost aquifer at the disposal site.

5.2.2 Hydraulic and Transport Properties

DOE used eleven monitoring wells at the UC site and three wells at the NC site to characterize the hydraulic and transport properties at the processing sites. The NC wells are all screened in the Dolores River alluvium. None of the NC site wells are exclusively screened in the Entrada Formation. Only one well is screened in the Navajo Sandstone at the NC site. Of the 11 wells at the UC site, 5 wells are screened in the Dolores River alluvium, 3 wells are screened in the Entrada Formation, and 3 wells are screened in the Navajo Sandstone. DOE installed 14 monitoring wells, 4 boreholes, and 13 test pits to characterize lithology, groundwater elevations, and hydraulic properties at the disposal site.

Tables 5.1 and 5.2 summarize DOE's hydraulic conductivity and linear velocity calculations at the processing and disposal sites.

TABLE 5.1
MEAN HYDRAULIC CONDUCTIVITY ft/day (cm/s)

Unit	UC Site	NC Site	Burro Canyon
Dolores Alluvium	14 (4.9×10^{-3})*	23 (8.1×10^{-3})*	N/A
Entrada Formation	not measured	not measured	N/A
Navajo Sandstone	0.024 (8.5×10^{-6})*	not measured	N/A
Dakota Sandstone	N/A	N/A	0.4 (1×10^{-4})†
Dakota Mudstone	N/A	N/A	0.006 (2×10^{-6})†
Upper Sandstone	N/A	N/A	0.04 (1×10^{-5})‡
Middle Sandstone	N/A	N/A	0.09 (3×10^{-5})**
Lower Sandstone	N/A	N/A	0.05 (2×10^{-6})*

Notes:
* Measurements by slug tests
† Measurements by bore-hole packer tests (16 tests in 3 holes)
‡ Measurements by single-well pumping/bailed recovery tests
** Measurements by multiple-well pumping tests

TABLE 5.2 AVERAGE LINEAR GROUNDWATER VELOCITY			
Site	Gradient ft/ft or m/m	Effective Porosity*	Velocity ft/yr (m/yr)
UC (Alluvium)	0.008	0.25	150 (45.7)
NC (Alluvium)	0.003	0.25	100 (30.5)
UC/NC (Entrada)	not determined	not determined	not determined
UC (Navajo)	0.02	0.30	1 (0.3)
NC (Navajo)	not determined	not determined	not determined
Burro Canyon (Upper sandstone)	0.04	0.10	6 (1.8)
Burro Canyon (Middle sandstone)	0.02	0.20	2 (0.6)
Burro Canyon (Lower sandstone)	0.06	0.10	1 (0.3)
* Estimated from lithology types (Freeze and Cherry, 1979, p. 37)			

Potentiometric surface maps constructed for both processing sites show that groundwater flow is generally toward the Dolores River. The alluvial aquifer is recharged by seepage from the Dolores River upstream of the NC site. Groundwater discharges from the alluvium into the Dolores River downgradient of the UC site.

The staff defers comment on the hydrogeologic calculations for the Slick Rock processing sites, because DOE proposes to defer groundwater clean-up to the UMTRA Ground Water Project. DOE has agreed to evaluate groundwater quality, flow characteristics, and aquifer properties as part of developing the groundwater restoration strategy.

DOE performed six pumping and bailer recovery tests on four wells completed in the Upper sandstone. All tests consistently showed low yields for these wells. The maximum measured saturated thickness in this unit is about 19 ft (6 m), and the calculated transmissivities ranged from 0.022 to 1.58 ft^2/day (0.002 to 0.15 m^2/day) with an average of 0.16 ft^2/day (0.015 m^2/day). Staff has reviewed the aquifer properties tests performed by DOE and agrees with the conclusion that the Upper sandstone is a low yield aquifer.

5.2.3 Geochemical Conditions and Extent of Contamination

A. Processing Sites

Baseline water quality in the Dolores River alluvium is similar at both the UC and NC sites. Groundwater at both sites is predominately a sodium-sulfate

type, with the UC site also containing calcium-sulfate type groundwater. Total Dissolved Solids (TDS) in background wells ranges from 622 to 991 milligrams per liter (mg/L) at the NC site and 875 to 1180 mg/L at the UC site. The background pH ranges from 6.9 to 7.7 at the NC site, and 6.9 to 7.3 at the UC site. Molybdenum concentrations slightly exceed the Maximum Contaminant Limit (MCL) in the background wells at both sites.

Alluvial groundwater quality downgradient at both sites shows contamination related to uranium milling activities. Groundwater downgradient of the UC site contains cadmium, molybdenum, net gross alpha, nitrate, selenium, and uranium in excess of the statistical maximum[1] values derived from the baseline water quality. Downgradient groundwater at the NC site contains molybdenum, net gross alpha, selenium, and uranium in excess of the statistical maximum values derived from the background water quality.

Baseline water quality of the Entrada Formation was determined only for the UC site. Groundwater in the Entrada Formation is predominately a calcium-bicarbonate and magnesium-bicarbonate type. Background TDS in the Entrada ranges from 147 to 1990 mg/L, and pH ranges from 7.8 to 8.0. The statistical maximum for background selenium levels in the Entrada slightly exceeds the MCL. Downgradient groundwater at the UC site contains nitrate, selenium, and sulfide in excess of the statistical maximum values derived from the background water quality.

Background groundwater quality in the Navajo Sandstone is characterized as a calcium-bicarbonate type at both sites. TDS in the Navajo ranges from 492 to 1530 mg/L at the NC site and 229 to 1160 mg/L at the UC site. The pH ranges from 7.2 to 7.8 in wells at both sites. The statistical maximum for background radium levels in the Navajo slightly exceeds the MCL at the NC site. The statistical maximums for background radium and selenium levels exceed the MCL at the UC site. Downgradient water quality in the Navajo was measured only at the UC site. Three constituents, molybdenum, radium-226 and -228, and uranium infrequently equal or exceed the MCLs in the Navajo Sandstone downgradient from the UC site. Zinc exceeded the background statistical maximum value in each of the UC downgradient wells on one or more occasions.

The staff defers comment on the geochemistry assessment of the processing sites because DOE proposes to defer groundwater clean-up. DOE has agreed to evaluate groundwater quality, flow characteristics, and aquifer properties as part of developing the groundwater restoration strategy. Because of the dynamic nature of the contamination plumes, DOE must redefine the plumes at a later time when the remediation of the aquifer is to take place.

B. Disposal Site

Six background monitoring wells are screened in the uppermost aquifer (Upper sandstone) at the disposal site. Groundwater samples collected from this unit

---

[1] The statistical maximum is the upper limit of the 98-percent confidence interval for the true average concentration, assuming normal or log-normal distributions.

indicate sodium-sulfate and sodium-bicarbonate types. The TDS concentration ranges from 556 to 973 mg/L, and the pH ranges from 7.5 to 9.1. The activity of radium-226 and -288 occasionally equals or slightly exceeds the MCL in wells 518 and 529. Selenium concentrations in well 518 have consistently exceeded the MCL.

DOE indicates that geochemical conditions at the disposal site appear favorable for attenuating most hazardous constituents in the tailings pore fluids. This assessment is based on chemical analyses of drill cutting and core samples, groundwater quality analyses, petrographic examination of soils, and laboratory experiments. The calcium content in the shale beneath the disposal cell has been measured at 36 tons $CaCO_3$ per 1000 tons soil. The measured cation exchange capacity (CEC) of the mudstone is relatively high (15 to 16 milliequivalents [meq] per 100 grams [g] of soil), with the CEC of the Upper sandstone being somewhat lower (6.6 meq/100 g). These data suggest a significant exchange capacity exists in the units directly beneath the cell. Three-point-sorption batch experiments were performed using a surrogate leachate spiked with cadmium, molybdenum, selenium, and uranium on fine-grained material from the Burro Canyon formation. Partitioning coefficients (K_d), retardation velocities, and travel times were then calculated for the spiked constituents. Partitioning coefficients for more mobile constituents, including chloride, sulfate, and nitrate were also derived. The calculated K_d for cadmium (800 mL/g), molybdenum (0.7 mL/g), selenium (2 mL/g), and uranium (approximately 0.5 mL/g) indicate that attenuation will occur as tailings leachate migrates beneath the disposal cell.

Wells within the Upper sandstone did not yield sufficient quantities of water to allow measurement of Redox Potential (Eh) or related parameters. Generally, wells screened in the Lower sandstone have relatively high Eh values (400 millivolts [mV]), indicating oxidizing conditions. Eh values for wells in the Middle sandstone beneath the cell averaged 250 mV. These values do not indicate sufficient reducing conditions to convert sulfate to sulfide or U^{+6} to U^{+4}. The mudstone unit directly beneath the cell contains finely disseminated pyrite that may locally provide sufficiently reducing conditions to convert U^{+6} to U^{+4}.

The relatively high K_d values, in conjunction with at least 60 ft (18 m) of mudstone between the bottom of the disposal cell and the first water-bearing unit provide a reasonable assurance that leachate will not adversely impact the groundwater beneath the disposal cell.

5.2.4 Water Use

A. Processing Sites

DOE indicates 18 private wells are situated within a 2-mile (3.2 km) radius of the Slick Rock UC and NC processing sites. DOE states that no municipal water supply wells are located in the town of Slick Rock or the surrounding area. DOE indicates that three private wells are downgradient from the UC site, but are expected to be beyond the influence of the contaminant plume, based on water quality measurements from wells 684 and 685. Three private wells are on the opposite side of the Dolores River from the NC site.

Three private wells are on the opposite side of the Dolores River from the NC site. DOE states that the river is assumed to be a hydraulic barrier separating the NC contaminant plume from the private wells; however, additional characterization during the groundwater clean-up phase will be required to support this assumption. Of the three wells situated across the river from the NC site, only one well (672) is usable. DOE states that the water quality of this well was tested in February 1994; and the results showed that all potentially hazardous constituents (arsenic, barium, cadmium, chromium, lead, molybdenum, net gross alpha, nitrate, combined radium-226 and -228, selenium, and uranium) were below each respective MCL. Staff considers that this sampling information is reasonable assurance that well 672 has not been impacted by seepage from the NC site, and the likelihood of adverse impact from deferring groundwater clean-up is low.

DOE states that the Dolores River, which flows past the two processing sites, is a potential water source for construction activities at the two sites.

B. Disposal Site

No known registered wells or private wells are actively used within the Upper sandstone of the Burro Canyon Formation, within a 2-mile (3.2 km) radius of the disposal site. DOE has stated that groundwater development in the vicinity should not increase over the next 50 years. The first water-bearing zone has a low yield, and would not support the 150 gpd sustained yield needed for a domestic water supply. No development is planned adjacent to the proposed Burro Canyon disposal site.

DOE states that a 60 percent population growth is projected for San Miguel County from 1995 to 2020. There is no indication of where the growth will occur, but it is reasonable to assume that populations will increase around existing population centers such as Telluride. Most of the land surrounding the disposal site is administered by the Bureau of Land Management, primarily for grazing. Consequently, any substantial population increase near the disposal cell, and a corresponding increase in water use, is doubtful.

Staff agrees with the DOE's assessment of the hydraulic properties of the uppermost aquifer at the disposal site and the forecast of potential population growth and future groundwater demand in the vicinity of the disposal site.

5.3 Conceptual Design Features to Protect Water Resources

DOE proposes to relocate the tailings and contaminated materials from the Slick Rock processing sites for disposal in an engineered, partially below grade, disposal cell at the Burro Canyon site. The disposal cell will hold approximately 620,000 cubic yards (474,000 m^3) of contaminated material. The base of the cell will be excavated into the low-permeability claystones and mudstones of the Burro Canyon Formation. The excavated claystone/mudstone will provide a low-permeability layer from the base of the pit to approximately 7 to 39 ft (2 to 12 m) up the side wall to form a continuous saucer-shaped bottom and side liner.

The cover design components of the disposal cell are, in ascending order: (a) a 2-foot-thick (61 cm) sandy-clay radon barrier. The anticipated saturated hydraulic conductivity of this layer is $1x10^{-7}$ cm/s; (b) a 2-foot-thick (61 cm) layer of fine-grained soil with some sand, to provide frost protection for the deeper radon barrier; (c) a 6-inch-thick (15 cm) sand/gravel bedding layer to drain water laterally and prevent displacement of large diameter rock in the erosion protection layer; and (d) an 8- to 12-inch (20 to 30 cm) riprap layer for erosion protection. The anticipated saturated hydraulic conductivity of the cover is expected to be $1x10^{-7}$ cm/s.

A design consideration that must be addressed at the Slick Rock disposal cell is the potential for accumulating contaminated water within or beneath the disposal cell. Water can accumulate from the short-term redistribution of moisture in the tailings or from long-term infiltration through the cover components. The limiting factor in both scenarios is the seepage flux through the bottom and sides of the cell excavation in relation to the retention capacity of the excavation.

DOE conducted an analysis to address the concerns with short-term moisture accumulation in the disposal cell. DOE concluded that the disposal cell contained adequate capacity to hold all the anticipated water added during construction of the disposal cell. DOE also plans to only add water necessary for dust control during placement, since the tailings are primarily sand and would not require additional moisture for compaction.

For long-term concerns, DOE's designed hydraulic conductivity of the cover is only slightly lower than an estimated vertical hydraulic conductivity of the Burro Canyon mudstones. The potential impact to disposal cell performance is discussed in sections 5.4.2 and 5.4.3.

5.4 Disposal and Control of Residual Radioactive Materials

EPA's standards in Subparts A and C of 40 CFR Part 192 require DOE to demonstrate that the disposal of RRM complies with site-specific groundwater protection standards and closure performance standards in four areas: Water Resources Protection Standards for Disposal (TER Section 5.4.1), Performance Assessment (TER Section 5.4.2), Closure Performance Standards (TER Section 5.4.3), and Groundwater Monitoring and Corrective Action Program (TER Section 5.4.4).

5.4.1 Water Resources Protection Standards For Disposal

The site-specific groundwater protection standards for disposal contained in 40 CFR 192.02 consist of three elements for groundwater monitoring: (a) a list of hazardous constituents, (b) a corresponding list of concentration limits, and (c) a POC; or the supplemental standards established under 40 CFR 192.22.

DOE proposes to use supplemental standards for groundwater protection at the disposal site in accordance with the limited use groundwater provision of 40 CFR 192.21(g). DOE states that the quantity of water available in the uppermost aquifer is less than 150 gpd (568 Lpd) and meets the limited use definition 40 CFR 192.11(e)(3). DOE performed several site-specific aquifer

tests in the uppermost aquifer at the disposal site. All tests indicate that the aquifer is low yield.

In addition, DOE conducted a numerical analysis (Calculation NO. SRK-11-94-14-09-00) of the sustainable yield in the uppermost aquifer, based on the results from aquifer tests. The calculated drawdown for a hypothetical well operating at 150 gpd (568 Lpd) exceeds the maximum observed saturated thickness of 18.9 ft (5.8 m) in the uppermost aquifer. The result of this calculation supports the assertion that the uppermost aquifer cannot sustain the minimum well yield.

Supplemental standards shall, "come as close to meeting the otherwise applicable standards as is reasonable under the circumstances," as stated in 40 CFR 192.22(a). DOE's demonstration for meeting these elements under 40 CFR 192.22(a) is presented below in sections 5.4.1.1 through 5.4.1.3.

5.4.1.1 Hazardous Constituents

Hazardous constituents at the Burro Canyon disposal site were identified from chemical analysis of the tailings materials at the UC and NC processing sites and an evaluation of the uranium recovery process used at the sites. DOE stated that eight inorganic hazardous constituents with designated MCLs were detected in pore fluid samples from the UC and NC sites. These constituents are: arsenic, cadmium, lead, molybdenum, net gross alpha, nitrate, selenium, and uranium. In addition, six inorganic hazardous constituents without MCLs were also detected in pore fluid samples. These constituents are: antimony, copper, thallium, tin, vanadium, and zinc.

Both processing sites were screened for the presence of organic priority pollutant compounds. Toluene and di-n-butyl phthalate were detected in groundwater samples from one well. These compounds were also detected in one or more of the accompanying field blanks during that sampling round. DOE concluded that the presence of these compounds were likely the result of inadvertent contamination, since the compounds also occurred in the field blanks. No other organic compounds were detected in samples from the monitoring wells.

The staff reviewed DOE's assessments of the hazardous constituents given the following three criteria for selecting hazardous constituents: (1) the constituents are reasonably expected to be in or derived from the tailings, (2) they are listed in Appendix I of 40 CFR Part 192, and (3) they were detected in the tailings or groundwater at the site. The staff concurs with the list of hazardous constituents, based on an independent review of the information provided by DOE.

5.4.1.2 Concentration Limits

DOE proposes narrative supplemental standards rather than numeric limits for groundwater protection, in accordance with 40 CFR 192.21(g). DOE's evaluation is based on the following determinations of the site-specific conditions:

- There is no historical or existing beneficial use of the groundwater in the uppermost aquifer, due to limited yield.
- The proposed disposal cell foundation will be separated from the uppermost aquifer by 25 to 75 ft (7.6 to 23 m) of low-permeability mudstone, providing hydraulic isolation.
- Deeper aquifers beneath the uppermost aquifer are separated by thick low-permeability sediments, and exhibit an upward hydraulic gradient toward the uppermost aquifer.
- Field reconnaissance indicates that there is no evidence of groundwater discharge anywhere in the site vicinity, and consequently no point of exposure.

Consequently, DOE is not proposing groundwater monitoring for the Burro Canyon disposal cell. DOE states that the proposed remedial action comes as close to meeting the otherwise applicable standards (Subpart A) as is reasonable under the circumstances. NRC staff considers that given the site-specific conditions at the Burro Canyon disposal site, numeric concentration limits would not provide any added protection of public health or environment.

5.4.1.3 Point of Compliance

DOE has not identified a POC for the Burro Canyon disposal cell. DOE does not propose groundwater monitoring at the disposal site, as previously discussed in section 5.4.1.2.

5.4.2 Performance Assessment

DOE must demonstrate that the performance of the disposal unit will comply with EPA's groundwater protection standards in 40 CFR 192 Subparts A and C. DOE conducted aquifer tests of the uppermost aquifer (Upper sandstone) and concluded that the aquifer met the requirements for limited-use groundwater under 40 CFR 192.11(e)(3). Additionally, DOE's investigation showed that the disposal cell foundation will be separated from the uppermost aquifer by at least 25 ft (7.6 m) of low-permeability mudstone.

As discussed in section 5.3, DOE also performed an analysis to show that short-term redistribution of water used during construction would not cause seepage along the thin, unsaturated sandstone layers in the Dakota Sandstone which will be exposed in the side walls of the disposal cell excavation.

Moisture accumulation over the long-term was addressed by designing the disposal cell cover with an overall permeability lower than the anticipated hydraulic conductivity of the bottom materials. DOE states in the RAP that the average measured horizontal conductivity of the Burro Canyon mudstones is $2x10^{-6}$ cm/s. Staff considers this value representative of the side walls below the sandstone layer of the disposal excavation; however, the vertical hydraulic conductivity of the bottom of the disposal cell is likely less, perhaps by as much as 10 or 100 times. Staff performed a cursory water budget

calculation to compare the cover and bottom fluxes. The calculation indicates that incoming and outgoing fluxes are very nearly the same under a conservative assumption that only the side walls of the sub-grade contribute to the outgoing flux.

DOE states that the measured horizontal hydraulic condu vity of the sandstone layer exposed in the disposal cell side-wall is approximately $1x10^{-4}$ cm/s. Staff considers that the sandstone layer within the excavation side-walls should allow any potential water which could potentially accumulate over the long-term to move laterally from the disposal cell before the water level would rise to the ground surface elevation.

5.4.3 Closure Performance Demonstration

DOE must demonstrate that the proposed disposal design will (1) minimize and control groundwater contamination, (2) minimize the need for further maintenance, and (3) meet initial performance standards of the design, in accordance with the closure performance standards of 40 CFR 192.02.

DOE concludes that the disposal cell foundation will be separated from the uppermost aquifer by at least 25 ft (7.6 m) of low-permeability mudstone. Additionally, there is no historical or existing beneficial use of the groundwater in the uppermost aquifer, due to limited yield. Future maintenance of the disposal cell should be minimized, since DOE proposes to use natural, stable earth materials for cell construction.

5.4.4 Groundwater Monitoring and Corrective Action Plan

40 CFR 192.03 requires DOE to implement groundwater monitoring during the post-disposal period for the purpose of demonstrating that the disposal cell will perform in accordance with the design. 40 CFR 192.04 requires the implementation of a corrective action program if the monitoring shows an exceedance of concentration limits. The monitoring plan required under 40 CFR 192.03 should be designed to include verification of the site-specific assumptions used to project the disposal system performance. Prevention of groundwater contamination may assessed by indirect methods, such as measuring the moisture migration within various components of the cover, tailings, or beneath the tailings; as well as direct groundwater monitoring.

DOE does not propose groundwater monitoring at this site. Supplemental standards under 40 CFR 192.21(g) are applied in lieu of the groundwater protection standards of 40 CFR 192.02(c). DOE proposes to install four standpipes in the tailings at the toe of the disposal cell to drain away any accumulated moisture during remedial action (RAP Drawing No. SRK-DS-10-0339). DOE also plans to install at least one piezometer in the Dakota Sandstone near the toe of the disposal cell as a monitoring plan to meet 40 CFR 192.03. Details of monitoring plans will be provided in the long-term surveillance plan.

Staff considers combination of the standpipes and piezometer(s) as adequate to comply with 40 CFR 192.03. The standpipes should monitor any potential short-term water accumulation and provide a means for mitigating any excess water.

The advantageous location of the sandstone layer in the side wall and the piezometer(s) outside the disposal cell should allow adequate detection of any potential water seepage from long-term water accumulation.

The EPA standards require that if the groundwater protection standards are found or projected to be exceeded, a corrective action program to restore the disposal cell to design requirements shall be implemented as soon as practicable, and in no event later than 18 months after a finding of exceedance. DOE has committed to notify the NRC within one month if the standpipe and piezometer monitoring indicates that corrective action is necessary.

5.5 Clean-Up and Control of Existing Contamination

DOE must demonstrate compliance with the EPA standards listed in 40 CFR 192, Subparts B and C for clean-up and control of existing groundwater contamination. The staff considers that groundwater clean-up at UMTRA Project sites may be deferred, as provided in the UMTRCA amendment of 1982. However, in order to defer clean-up of groundwater at the Slick Rock processing sites, DOE must demonstrate that (1) clean-up of the processing sites will not be impacted by the disposal, and thus, is separable from the disposal actions, and (2) that public health and safety will be protected.

DOE proposes to defer the compliance demonstration for clean-up of existing contamination. By virtue of moving the tailings to the Burro Canyon site, DOE demonstrated that the disposal of the tailings will not impact groundwater clean-up of the Slick Rock processing sites. DOE's water-use inventory and analysis of existing water quality near the processing sites indicate that usable wells have not be adversely impacted by groundwater contamination from the two sites. Staff agrees that deferring groundwater clean-up should not compromise public health and safety; however, further characterization of the groundwater conditions near the processing sites is needed before groundwater clean-up commences.

5.6 Conclusions

The staff concludes that DOE's proposed remedial action for the Slick Rock sites has demonstrated compliance with the EPA groundwater standards, with the exception of the following open issue, which may be deferred, as provided by the UMTRCA amendment of 1982:

> DOE must demonstrate compliance with EPA's groundwater clean-up standards in 40 CFR 192, Subparts B and C.

6.0 RADON ATTENUATION AND SITE CLEANUP

6.1 Introduction

This section of the Technical Evaluation Report (TER) documents the staff evaluation of the radon attenuation design and processing site cleanup plan for proposed remedial action at the Slick Rock, Colorado, Uranium Mill Tailings Remedial Action (UMTRA) Project site. The material characterization, radon barrier design, proposed remedial action, and radiological verification plan are evaluated to ensure compliance with the applicable EPA standards. This review follows the NRC SRP (NRC, 1993).

6.2 Radon Attenuation

To meet the EPA standards for limiting release of radon (Rn-222) from RRM to the atmosphere, contaminated material will be relocated to the disposal site in Burro Canyon. A multi-layer cover will be placed on the disposal cell and will consist of the following layers: 18-inch-thick radon barrier, 24-inch-thick frost protection, 6-inch-thick bedding, and 8- to 12-inch-thick riprap.

NRC staff evaluated DOE's input values for the RAECOM computer code that was used to calculate the radon barrier thickness required to meet the radon flux limit. The staff's review addressed the adequacy of the parameter values (i.e., code inputs) and the overall radon flux model. This was done by evaluating the justification and assumptions made for each parameter value to confirm that each is representative of the material, or conservative, consistent with site construction specifications, and based on long-term conditions. NRC staff then performed an independent analysis of the design using the RADON code (NRC, 1989b).

Included in the NRC staff review was an evaluation of the pertinent aspects of the design that are related to the contaminated materials and radon barrier soil. For example, the staff evaluated the ability of the frost protection, bedding, and riprap layers of the cover to protect the radon barrier layer from drying the long-term effects of freeze-thaw damage and disruption by biointrusion.

In addition, the staff evaluated the barrier layer thickness and its ability to satisfy criteria for construction, settlement, cracking, and infiltration of surface water. These aspects of cell design are discussed in Section 3 of this report. Erosion protection aspects of the cover design are discussed in Section 4.

6.2.1 Evaluation of Parameters

The required thickness of the radon barrier depends on the characteristics of the radon barrier soil(s) and the underlying contaminated materials. NRC staff evaluated the physical and radiological data for these materials and any assumptions or justification for estimates associated with those parameters that were used to derive the input for the RAECOM and RADON computer codes.

NRC staff evaluated each input value to confirm that it was representative of the radon barrier and contaminated material, consistent with anticipated construction specifications, conservative, and based on long-term conditions.

The design parameters of the contaminated and radon barrier materials that were evaluated include: material layer thickness, layer sequence, bulk dry density, specific gravity, porosity, long-term moisture content, and radon diffusion coefficient. In addition, the radium (Ra-226) concentration and radon emanation coefficients of the contaminated materials were evaluated. The computer code parameter values utilized by DOE are summarized below.

TABLE 6.1 CODE INPUT SUMMARY

per Remedial Action Selection Report and calculation 11-340-02-00

LAYER/ MATERIAL	THICK (cm.)	POROS- ITY	DENS. (g/cm^2)	Ra-226 (pCi/g)	Rn EM.	MOIST.* % by wt.	DIF. COEF (cm^2/s)
NC material	762	0.44	1.51	345	0.42	8.5	0.019
# samples		(6sg)	(9)	(271)	(12)	(5)	(3)
UC Tailings	1067	0.46	1.46	135	.19	4.3	0.029
# samples		(10sg)	(7)	(212)	(14)	(7)	(2)
UC off & sub pile	853	0.39	1.64	35	0.31	9.4	0.019
# samples		(15sg)	(6)	(222)	(9)	(28)	(2)
Radon Barrier	45	0.39	1.64	0	n/a	9.5	0.015
# samples		(5sg)	(7)	(0)	(0)	(4)	(4)
Frost Barrier	61	0.466	1.56	0	n/a	6	0.039
# samples		(5sg)	(7)	(0)	(0)	(4)	(4)

NC = North Continent; UC = Union Carbide; T. = tailings; sg = specific gravity tests used in calculation of porosity; * = in-situ values

A. Contaminated Materials

Contaminated materials will be removed from two former processing sites near the town of Slick Rock; the North Continent (NC) and Union Carbide (UC) sites. The materials at both sites include tailings and offpile (debris, and wind and water borne), and subpile materials. The material thicknesses used in the analysis are based on the conceptual design of the remedial action plan and the available data.

The placement sequence of the various contaminated materials is delineated in the construction specifications and drawings, and in Table D-1 of the RAP, Information for Reviewers. The materials containing the highest concentration

of Ra-226, NC site contaminated materials and the material from Area "A" at the UC site, are to be placed at the bottom of the cell. Because the NC material will be covered by approximately 63 feet (1920 cm) of UC material on top and greater than 15 feet (457 cm) on the side slopes, its impact on the radon flux to the cover will be negligible. The UC tailings are intermediate in Ra-226 concentration and will be approximately 28 feet (853 cm) from the radon barrier on top and 15 feet (457 cm) from the radon barrier layer on the side slopes. The UC offpile and subpile material containing low levels of Ra-226 will be placed above the UC tailings. The radon barrier layer will cover the cell.

Characteristics of the contaminated materials were determined from laboratory testing of representative samples. DOE tested both the NC tailings and offpile material and calculated a volume-weighted average for each parameter. Because the contaminated materials will be relocated and mixed during placement, this method of calculating specific characteristics is considered acceptable. The same procedure was used to estimate the UC tailings, offpile and subpile material parameters.

The results from a series of maximum dry density tests (ASTM D-698) were averaged to determine a representative value. The specifications require the relocated contaminated materials to be compacted to 90 percent of the maximum Proctor dry density. DOE calculated the average placement dry density as 1.51 g/cc (94.2 pcf) for the NC material, 1.46 g/cc (91.1 pcf) for UC tailings, and 1.64 g/cc (102.3 pcf) for the UC offpile and subpile materials. Results from a series of specific gravity tests were used to determine average values of 2.70, 2.69, and 2.70, respectively. Porosity values of 0.44, 0.46, and 0.39, respectively, were then calculated.

DOE selected long-term moisture values for the contaminated materials based on in-situ moisture tests. DOE stated that these average test values for NC material, UC tailings, and UC offpile and subpile materials (8.5, 4.3, and 9.4 percent, respectively) are at, or near, typical residual moisture content values for similar materials. Since the materials closest to the surface have the greatest impact on the radon flux, NRC staff expressed concern about the long-term moisture value for the UC off and subpile materials. To address these concerns, DOE calculated the long-term moisture using empirical relationships and obtained a value of 9.4. In order to provide conservatism, DOE used a long-term moisture of 6.0 percent for the UC offpile and subpile materials in a radon flux sensitivity model. The modeling indicated that the lower moisture value would not significantly impact the radon flux. DOE has also committed to performing confirmatory testing during construction to justify the final radon flux calculations which will be presented in the Completion Report. Staff considers the commitment to perform confirmatory testing to be acceptable.

For the NC tailings, a radon diffusion coefficient of 0.019 cm^2/s (at the long-term moisture saturation) was determined by DOE based on tests on three samples at three to six different moisture levels. Values were plotted and a best fit was obtained using a least squares methodology. Two samples each of UC tailings and UC offpile or subpile material yielded values of 0.029 and 0.019, respectively. Staff considers that two samples are not adequate to

provide a representative input value. However, DOE has committed to performing confirmatory testing on the offpile/subpile material during construction to justify the final radon flux calculations which will be presented in the Completion Report. This approach is considered acceptable.

Testing conducted by DOE indicated that the radon emanation property of the material at the Slick Rock processing site is statistically independent of moisture content and Ra-226 concentration. Radon emanation fraction determinations on NC tailings averaged 0.42, UC tailings averaged 0.19, and UC offpile material averaged 0.45. For the model, DOE assumed that the UC subpile material radon emanation fraction would be 0.19. The volume-weighted average for the combined offpile and subpile material is 0.31. The NRC staff does not consider this assumption conservative, and used a emanation fraction of 0.35 (the code default value) in its verification of the radon flux estimate. To provide additional assurance that the estimated parameters are satisfactory, DOE has committed to performing confirmatory testing during construction to justify the final radon flux calculations which will be presented in the Completion Report.

The Ra-226 concentration of the contaminated materials was determined primarily by gamma spectroscopy. The Slick Rock characterization data indicates that 236 NC and 457 UC samples were analyzed for Ra-226. The presentation of these data in calculation 11-275-01-00 (DOE, 1994) indicates that DOE included values of 1 to 5 pCi/g in the average (35 pCi/g) for UC offpile and subpile areas. Because material with such low Ra-226 values would not be expected to be excavated and placed in the disposal cell, the code Ra-226 input value for this UC material is considered low (not conservative). NRC staff determined that the Ra-226 values used in the model are adequate for the preliminary design because of DOE's standard procedure for measurement of Ra-226 in the contaminated materials after placement in the disposal cell. Because this UC material has a wide range of Ra-226 values (range 1-475 pCi/g), more precise data on the material placed in the upper portion of the cell is needed to confirm the design. Following its standard procedures, DOE should analyze as-placed contaminated material for Ra-226 and model this material in 2 to 4-foot layers so that any layering effect due to variations in Ra-226 concentration will be accounted for in the final RAECOM analysis.

B. Radon Barrier Soil

The physical properties of the radon barrier soil were selected by DOE based on the results of laboratory testing of samples from the Burro Canyon borrow site. The construction specifications require the barrier soil to be compacted to 95 percent Standard Proctor density. The average specific gravity for the radon barrier soil was 2.67, and the 95 percent Standard Proctor density was 1.64 gm/cc (102.4 pcf). These values result in a calculated porosity of 0.385.

DOE performed capillary moisture and in-situ moisture tests to evaluate the radon barrier long-term moisture content. Ten capillary moisture saturation tests of radon barrier soil averaged 13.7 percent, and 19 in-situ moisture measurements averaged 9.1 percent. DOE chose the lowest of these two values to calculate an average long-term moisture content of 9.5 percent by weight.

The value chosen by DOE is acceptable to NRC staff based on the following considerations. The barrier material optimum moisture content for compaction averages 18.1 percent, and the construction specifications require that the material be placed between optimum moisture and three percent above optimum moisture. Also, DOE has quality control procedures to limit drying of the placed radon barrier material before it is covered.

The radon diffusion coefficient for the radon barrier material, based on five test results, was 0.011 cm^2/s. NRC staff agrees that this is a reasonable value for the clayey sand and clay (SC and CL soil classification) barrier soil.

The Ra-226 concentration of the radon barrier soil was modeled as zero. This would be acceptable if it were demonstrated that the borrow source had a Ra-226 concentration that approximated the disposal site background level. To demonstrate the Ra-226 concentrations are satisfactory, DOE has committed to perform confirmatory testing during construction to justify the final radon flux calculations which will be presented in the Completion Report.

C. Frost Protection Soil

The frost protection soil will be obtained from the same Burro Canyon borrow source as the radon barrier. Therefore, the physical properties of the frost protection soil will be similar to the radon barrier soil.

The construction specifications require the frost protection soil to be compacted to 90 percent Standard Proctor density. The average specific gravity for the radon barrier soil was 2.67, and the 90 percent Standard Proctor density was 1.55 gm/cc (97.0 pcf). These values result in a calculated porosity of 0.385. To account for frost damage, DOE increased the porosity by 11.5 percent to 0.466. While this approach is considered acceptable, DOE failed to decrease the dry density which corresponds to the increase in porosity. In the independent analysis, NRC staff used a dry density of 1.42 gm/cc.

As noted above, the long-term moisture content for the radon barrier soil in DOE's model was 9.5 percent. DOE indicated that the frost protection soils could be slightly sandier than the Burro Canyon soils used for the radon barrier and assumed a lower long-term moisture content of 6 percent for the frost protection soils. NRC staff considers this assumption to be conservative.

The radon diffusion coefficient for the frost protection material was estimated to be 0.039 cm^2/s, using empirical relationships. NRC staff considers this estimation to be conservative.

The Ra-226 concentration of the frost protection soil was modeled as zero. This would be acceptable if it were demonstrated that the borrow source had a Ra-226 concentration that approximated the disposal site background level. To demonstrate the Ra-226 concentrations, DOE has committed to perform confirmatory testing during construction to justify the final radon flux calculations which will be presented in the Completion Report.

D. Ambient Radon Concentration

The ambient air radon concentration is another required parameter value for the RAECOM model. It was measured in the Slick Rock area in 1977 and the average value was 1.5 pCi/l. Radon monitoring at the disposal site in 1990 and 1991 yielded an ambient radon concentration of 0.5 pCi/l. Although the latter value is more appropriate, the former number was used in the RAECOM analysis. DOE stated that the use of either radon concentration value results in equivalent radon barrier design thickness determinations. This was confirmed by NRC staff modeling.

E. Summary

NRC staff has reviewed the physical and radiological parameter values assigned to the contaminated materials by DOE and concludes that most are a reasonable representation of average conditions. However, UC offpile and subpile material values for radon emanation, radon diffusion coefficient, and Ra-226 concentration require substantiation during construction, as discussed above.

DOE has stated (Remedial Action Selection Report, page 6-2) that the final cover design will be based, in part, on additional measurements of the radon barrier material properties. This is acceptable to the NRC staff, because DOE will provide all relevant new data for both radon barrier soil (including Ra-226 measurements) and contaminated materials, and the revised RAECOM analysis incorporating these data, for NRC review in the Completion Report, or a RAP modification.

6.2.2 Evaluation of Radon Attenuation Model

DOE used the RAECOM computer code to evaluate the radon attenuation of the cover for compliance with the EPA long-term radon flux standard of 20 pCi/m^2/s. Several models with varying configurations of the contaminated materials were examined. A minimum radon barrier of 1.5 feet (45 cm) is required on the side slopes if UC tailings are 2.5 feet (76 cm) away from the radon barrier, because of the intervening low-level Ra-226 material. For conservatism, DOE proposes to place these tailings at least 15 feet (457 cm) from the radon barrier.

Based on average parameter values and the design layer configuration, DOE determined that a minimum radon barrier thickness of 9 inches (23 cm) is required to meet the flux limit at the top of the radon barrier. When DOE used the average values plus or minus (whichever was conservative) the standard error of the mean (SEM) for most RAECOM input values, the model indicated the minimum radon barrier thickness is 19 inches (47 cm). DOE proposed 18 inches (44 cm). Taking into account the compounded conservatism associated with an average plus or minus the SEM analysis, staff considers the design thickness of 18 inches to be adequate.

NRC staff used the RADON computer code to model the radon flux using more conservative values for the UC offpile/subpile layer in place of the DOE values. As noted above, staff questioned the appropriateness of using an average emanation fraction of 0.31 for the UC offpile/subpile layer. In

addition, staff decreased the dry density for the frost barrier layer to more accurately model the freeze-thaw damage. Based on its evaluation using average parameters, the staff estimated an average long-term radon flux of 17.2 pCi/m^2/s for the proposed cover design, which is considered acceptable.

DOE addressed the effects of frost penetration (freeze-thaw damage) on the cover (calculation 11-340-02-00) and concluded that a frost protection layer 2-feet thick is adequate. Without considering the protective effect of snow cover, the probable worst case (increased dry density of the bedding layer and decreased moisture in the frost protection layer) would result in frost penetration to 38.6 inches. Because the cover material above the radon barrier is 38 inches thick, there would be no significant effect on the radon attenuation ability of the barrier.

DOE did not specifically address biointrusion. Staff considers that biointrusion of the radon barrier will be restricted by the unfavorable environment of the rock layer in the cover. Although it is recognized that some volunteer plant growth will occur, staff concludes that the growth will most likely be shallow-rooted grasses (based on studies performed at other Title I sites nearby) whose roots should not exceed the minimum 38 inches of cover materials above the clay radon barrier layer. Animals indigenous to the area are not expected to select the reclaimed disposal area over native terrain for habitation. Staff also considered that the site will be transferred to the custodial agency which is required to perform long-term surveillance and maintenance. Any problems, such as extensive plant growth or disruption of the rock cover, that could affect the radon attenuation ability of the cover, would be addressed.

6.3 Site Cleanup

6.3.1 Radiological Site Characterization

Soil sampling and radiological surveys at the Slick Rock site identified approximately 621,300 cubic yards of contaminated materials at the two processing sites and adjacent areas. The combined areas total approximately 69 acres. This does not include the 17 acres in the floodplain across the Dolores River from the UC site where DOE proposes to apply supplemental standards. Some other areas originally considered contaminated were determined to be natural uranium deposits that do not require remediation.

Background levels of Ra-226 in the soil were measured in the Slick Rock area and the average value is 1.4 pCi/g. The methods and results of determination of background Ra-226 levels are acceptable to staff.

Characterization of Th-230 was presented in RAP Table B-4 of Volume II in the Information for Bidders. Several locations on the NC processing site have elevated levels of Th-230 with Ra-226 levels below 15 pCi/g, which indicate remediation may be required for the Th-230. Adequate depths of excavation to accomplish soil cleanup of Th-230 are not indicated for three areas on the NC excavation plan (drawing 10-0323). However, the RAP indicates that the UMTRA Project thorium policy will be followed at this site. Staff considers this commitment to be adequate assurance that the Th-230 deposits will be

remediated as necessary.

6.3.2 Cleanup Standards

DOE has committed to excavate contaminated areas to meet the 5 pCi/g (surface) and 15 pCi/g (subsurface) plus background, EPA standard for Ra-226 in soil, and to place the contaminated materials in an engineered disposal cell. The Remedial Action Selection Report indicates that a supplemental standard application for the vicinity property across the Dolores River from the UC site, to leave contaminated material in place, will be submitted for NRC concurrence.

DOE indicated that excavation on the two processing sites will be monitored to ensure that cleanup efforts are complete. Also, there are no buildings or equipment remaining to be decontaminated at the processing sites, and no contaminated material is planned to be released for unrestricted use. Contaminated demolition debris on the sites will be buried in the disposal cell.

6.3.3 Verification

The final radiological verification survey for land cleanup will be based on 100-square-meter areas. DOE may use a variety of measurement techniques, depending on particular circumstances. The standard method for Ra-226 verification is analysis of composite soil samples by gamma spectrometry. Verification for Th-230 will follow the UMTRA Project generic thorium policy.

If areas with a high percentage of cobbly soils are encountered during remedial action, an NRC-approved procedure will be implemented for bulk averaging the Ra-226 and Th-230. This will allow bulk radionuclide concentrations to be used for excavation depth control and for verification.

6.4 Conclusions

Staff considers that DOE's site soil cleanup and verification plans for the Slick Rock processing sites appear adequate. Based on review of the radon attenuation design of the as presented in the final RAP for the Slick Rock site and supporting documents, NRC staff concludes that the current design of the radon barrier does have an acceptable degree of conservatism to accept the preliminary radon flux estimates. The radon barrier design will be substantiated by further testing and analysis during material placement, and the final long-term radon flux analysis will be provided in the Completion Report.

7.0 REFERENCES

Abt, S.R., Khattak, M.S., Nelson, J.D., Ruff, J.F., Shaikh, A., Wittler, R.J., Lee, D.W., and Hinkle, N.E., 1987, Development of riprap design criteria by riprap testing in flumes, phase I: U.S. Nuclear Regulatory Commission, NUREG/CR-4651.

ACE, 1970, Hydraulic Design of flood control channels: U.S. Army Corps of Engineers, EM1110-2-1601.

Bonilla, M.G., Mark, R.K., and Lienkaemper, J.J., 1984, Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement: Bulletin of the Seismological Society of America, v. 74, p. 2379-2411.

Campbell, K.W., 1981, Near-source attenuation of peak horizontal acceleration: Bulletin of the Seismological Society of America, v. 71, p. 2039-2070.

Campbell, K.W., and Bozorgnia, Y., 1994, Near-source attenuation of peak horizontal acceleration from worldwide accelerograms recorded from 1957 to 1993: in Proceedings of the Fifth U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Institute, Chicago, Illinois, V. III, p. 283-292.

Cater, F.W., Jr., 1966, Age of the Uncompahgre uplift and Unaweep Canyon, west-central Colorado: U.S. Geological Survey, Professional Paper 550-C, p. C86-C92.

Cater, F.W., Jr., 1970, Geology of the salt anticlines region in southwestern Colorado: U.S. Geological Survey, Professional Paper 637, map scale 1:62,500, Washington, D.C.

Chow, V.T., 1959, Open channel hydraulics: McGraw-Hill, New York.

Davis, C.V., and Sorensen, K.E., eds, 1969, Handbook of applied hydraulics: Third Edition, McGraw-Hill, New York.

DOE, 1995, Remedial action plan and site design for stabilization of the inactive uranium mill tailings sites at Slick Rock, Colorado: U.S. Department of Energy, preliminary final, September 1995.

DOE, 1996, Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Sites at Slick Rock, Colorado: U.S. Department of Energy, final, May 1996.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Hunt, C.B., 1974, Natural regions of the United States and Canada: W. H. Freeman and Company, San Francisco, California.

Kirkham R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: A preliminary evaluation: Colorado Geological Survey Bulletin No. 43.

Lohman, S.W., 1981, Ancient drainage changes in and south of Unaweep Canyon, Southwestern Colorado: in Western Slope Colorado, R.C. Epis and J.F. Callender, eds., New Mexico Geological Society Guidebook, 32nd Field Conference, p. 137-143.

NGDC/NOAA, 1994, Seismicity within 150 km of 38.08N, 108.87W: National Geophysical Data Center/National Oceanic and Atmospheric Administration, epicenter may and table of earthquake data, Boulder, Colorado.

NOAA, 1977, Probably maximum precipitation estimates, Colorado River and Great Basin drainages: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Hydrometeorological Report No. 49.

NRC, 1989a, Staff technical position on testing and inspection plans during construction of DOE's remedial action at inactive uranium mill tailings sites, Revision 2: U.S. Nuclear Regulatory Commission, January 1989.

NRC, 1989b, Calculation of radon flux attenuation by earthen uranium mill tailings covers: U.S. Nuclear Regulatory Commission, Regulatory Guide 3.64, March 1989.

NRC, 1990, Final staff technical position, design of erosion protection covers for stabilization of uranium mill tailings sites: U.S. Nuclear Regulatory Commission, August, 1990.

NRC, 1993, Final standard review plan for the review and remedial action of inactive mill tailings sites under Title 1 of the Uranium Mill Tailings Radiation Control Act, Revision 1: U.S. Nuclear Regulatory Commission, June 1993.

Oviatt, C.G., 1988, Evidence for Quaternary deformation in the Salt Valley anticline, southeastern Utah, in Salt Deformation in the Paradox region, Doelling, H.H., Oviatt, C.V., and Huntoon, P.W., eds.: Utah Geological and Mineral Survey Bulletin 122, p. 61-76.

Shawe, D.R., Simmons, G.C., and Archbold, N.L., 1968, Stratigraphy of Slick Rock district and vicinity, San Miguel and Dolores Counties, Colorado: U. S. Geological Survey, Professional Paper 576-A.

Sinnock, S.B., 1981, Pleistocene drainage changes in Uncompahgre Plateau - Grand Valley region of western Colorado including formation and abandonment of Unaweep Canyon: A hypothesis, in Western Slope Colorado, Epis, R.C., and Callender, J.F., eds.: New Mexico Geological Society Guidebook, 32nd Field Conference, p. 127-136.

Stephenson, D., 1979, Rockfill in hydraulic engineering: Elsevier Scientific Publishing Co., New York.

Stevens, M.A., Simons, D.B., and Lewis, G.L., 1976, Safety factors for riprap protection: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 102, No. HY5.

USBR, 1977, Design of small dams: U.S. Department of the Interior, U.S. Bureau of Reclamation.

Wong, I.G., 1984, Seismicity of the Paradox Basin and the Colorado Plateau interior: Technical Report prepared by Woodward-Clyde Consultants, Walnut Creek, California, for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Wong, I.G., Humphrey, J.R., and Silva W.J., 1987, Microearthquake studies in the vicinity of the Cane Creek Potash Mine, Paradox Basin, Utah: BMI\ONWI-656, Technical Report by Woodward-Clyde Consultants for Battelle Memorial Institute, Columbus, Ohio.

Woodward-Clyde Consultants, 1982, Geologic characterization report for the Paradox Basin study region, Utah study areas: Technical Report ONWI-290, prepared for Battelle Memorial Institute, Office of Nuclear Waste Isolation.

Woodward-Clyde Consultants, 1983, Overview of the regional geology of the Paradox Basin study area: Technical Report ONWI-92, prepared for Battelle Memorial Institute, Office of Nuclear Waste Isolation.

Stevens, M.A., Simons, D.B., and Lewis, G.L., 1976, Safety factors for riprap protection: American Society of Civil Engineers, Journal of the Hydraulics Division, v. 102, No. HY5.

USBR, 1977, Design of small dams: U.S. Department of the Interior, U.S. Bureau of Reclamation.

Wong, I.G., 1984, Seismicity of the Paradox Basin and the Colorado Plateau interior: Technical Report prepared by Woodward-Clyde Consultants, Walnut Creek, California, for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Wong, I.G., Humphrey, J.R., and Silva W.J., 1987, Microearthquake studies in the vicinity of the Cane Creek Potash Mine, Paradox Basin, Utah: BMI\ONWI-656, Technical Report by Woodward-Clyde Consultants for Battelle Memorial Institute, Columbus, Ohio.

Woodward-Clyde Consultants, 1982, Geologic characterization report for the Paradox Basin study region, Utah study areas: Technical Report ONWI-290, prepared for Battelle Memorial Institute, Office of Nuclear Waste Isolation.

Woodward-Clyde Consultants, 1983, Overview of the regional geology of the Paradox Basin study area: Technical Report ONWI-92, prepared for Battelle Memorial Institute, Office of Nuclear Waste Isolation.