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1.0 INTRODUCTION

The Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978, Public Law 95-604 (PL95-604), grants the Secretary of Energy the authority and responsibility to perform such actions as are necessary to minimize radiation health hazards and other environmental hazards caused by inactive uranium mill sites. These cleanup actions are to be performed in compliance with the U.S. Environmental Protection Agency (EPA) standards (40 CFR 192), which became final on March 7, 1983, and are summarized on Table 1.1.

This Technical Approach Document (TAD) describes the general technical approaches and design criteria adopted by the U.S. Department of Energy (DOE) in order to implement remedial action plans (RAPs) and final designs that comply with EPA standards. It does not address the technical approaches necessary for aquifer restoration at processing sites; a guidance document, currently in preparation, will describe aquifer restoration concerns and technical protocols. This document is a second revision to the original document issued in May 1986; the revision has been made in response to changes to the groundwater standards of 40 CFR 192, Subparts A-C, proposed by EPA as draft standards. New sections were added to define the design approaches and designs necessary to comply with the groundwater standards. These new sections are in addition to changes made throughout the document to reflect current procedures, especially in cover design, water resources protection, and alternate site selection; only minor revisions were made to some of the sections. Section 3.0 is a new section defining the approach taken in the design of disposal cells; Section 4.0 has been revised to include design of vegetated covers; Section 8.0 discusses design approaches necessary for compliance with the groundwater standards; and Section 9.0 is a new section dealing with nonradiological hazardous constituents.

The U.S. Nuclear Regulatory Commission (NRC) has prepared a draft technical position document dealing with standard format and content and documentation for remedial action selection (NRC, 1988), which describes factors to be considered by the NRC in approving a RAP. This document attempts to follow the format of the NRC document in order to facilitate joint use of the two documents. This document supersedes and incorporates the documents "Remedial Action Planning and Disposal Cell Design" (DOE, 1989) and "Alternate Site Selection Process" (DOE, 1988).

The approaches presented herein will be modified and updated as new technology and information become available.

PART 192 - HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM MILL TAILINGS

SUBPART A - Standards for the Control of Residual Radioactive Materials from Inactive Processing Sites

192.02 Standards

Control shall be designed to:

(a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,

(b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not:

(1) Exceed an average release rate of 20 picocuries per square meter per second, or
(2) Increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

SUBPART B - Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) The concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than -

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and
(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

(b) In any occupied or habitable building -

(1) The objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and
(2) The level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

SUBPART C - Implementation (condensed)

192.20 Guidance for Implementation

Remedial action will be performed with the "concurrence of the Nuclear Regulatory Commission and the full participation of any state that pays part of the cost" and in consultation as appropriate with other government agencies.

192.21 Criteria for Applying Supplemental Standards

The implementing agencies may apply standards in lieu of the standards of Subparts A or B if certain circumstances exist, as defined in 192.21.

192.22 Supplemental Standards

"Federal agencies implementing Subparts A and B may in lieu thereof proceed pursuant to this section with respect to generic or individual situations meeting the eligibility requirements of 192.21."

(a) ". . .the implementing agencies shall select and perform remedial actions that come as close to meeting the otherwise applicable standards as is reasonable under the circumstances."

(b) ". . .remedial actions shall, in addition to satisfying the standards of Subparts A and B, reduce other residual radioactivity to levels that are as low as is reasonably achievable."

(c) "The implementing agencies may make general determinations concerning remedial actions under this Section that will apply to all locations with specified characteristics, or they may make a determination for a specific location. When remedial actions are proposed under this Section for a specific location, the Department of Energy shall inform any private owners and occupants of the affected location and solicit their comments. The Department of Energy shall provide any such comments to the other implementing agencies [and] shall also periodically inform the Environmental Protection Agency of both general and individual determinations under the provisions of this section."

Ref: Federal Register, Volume 48, No. 3, January 5, 1983, 40 CFR Part 192.

TABLE 1.1 EPA STANDARDS

REFERENCES FOR SECTION 1.0

DOE (U.S. Department of Energy), 1989. "Remedial Action Planning and Disposal Cell Design," UMTRA-DOE/AL-400503.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1988. "Alternate Site Selection Process," UMTRA-DOE/AL-200129.0007, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

NRC (U.S. Nuclear Regulatory Commission), 1988. "Standard Format and Content for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites," Technical Branch, Division of Low-Level Waste Management and Decommissioning, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

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2.0 REGULATORY COMPLIANCE AND DESIGN CONSIDERATIONS

2.1 REGULATORY COMPLIANCE CONSIDERATIONS

Congress passed the UMTRCA (PL95-604) in 1978, which established a statutory and regulatory framework for the stabilization and control of inactive uranium mill tailings sites (Title I of the UMTRCA) and active uranium mill tailings sites (Title II of the UMTRCA). Title I gives the DOE the responsibility to cleanup and dispose of contamination resulting from the inactive sites. Under the authority of the UMTRCA, 24 designated inactive uranium tailings sites in ten states are to be cleaned up as part of the DOE's Uranium Mill Tailings Remedial Action (UMTRA) Project. The UMTRCA directs the EPA to establish general regulations and standards for the cleanup and disposal of contamination resulting from inactive uranium mill sites. The act gives the NRC concurrence and licensing authority for the DOE's UMTRA Project disposal and cleanup activities.

In January 1983, the EPA issued final standards for the inactive (Title I) sites (EPA, 1983). These standards (40 CFR 192) reflected Congressional desire to have a long-term, permanent solution to uranium mill tailings disposal (Subpart A) and to cleanup and prevent environmental contamination caused by the tailings (Subpart B). Congress wanted the standards to be as consistent with the Resource Conservation and Recovery Act (RCRA) as possible. The regulations established a longevity standard for remediated sites of 1000 years whenever reasonably achievable, but in any case, a minimum performance period of 200 years must be achieved. Maintenance is to be minimized via the use of passive design considerations, such as using earthen materials. In addition, the regulations established radon limits for the stabilized materials and for the cleanup of contaminated land and buildings. The standards called for a site-specific approach to surface and groundwater contamination resulting from milling activities.

In 1985, the Tenth Circuit Court of Appeals remanded the groundwater portion of the standards for inactive sites (40 CFR 192.20(a)(2) and (3)) as the result of a lawsuit by numerous parties. The Court directed the EPA to establish general groundwater standards similar to the ones the EPA had issued for Title II sites.

The EPA published proposed revised groundwater regulations for the Title I sites (EPA, 1987) on September 24, 1987. The proposed regulations establish groundwater standards and requirements for the disposal of tailings under Subpart A and groundwater restoration under Subpart B.

In April 1989, the UMTRA Project Office received from the Office of Nuclear Energy a copy of the EPA draft final groundwater protection standards, dated March 8, 1989. These regulations address various commenters' concerns on the draft 1987 standards. In addition, some changes add clarification to the previous regulations and incorporate some of the Title II groundwater standard regulations. They require groundwater cleanup strategies to be considered and/or developed for each processing

site. These include establishing a monitoring program adequate to determine the extent of contamination in groundwater around each processing site and to identify hazardous constituents of concern, and developing a remedial action plan that addresses groundwater contamination at processing sites and compliance with the groundwater standards.

At the time of this writing, the groundwater regulations have not been issued in final form. It is unknown when the final standards will be promulgated. When that occurs, this document will be reviewed to determine if a revision is necessary. The DOE does not expect the groundwater standards to change appreciably between the draft final and the final versions.

The draft final regulations have been incorporated into this document and into the UMTRA Project planning process. The advent of the proposed standards is one of the main rationales for the revision of this TAD. Additional discussion of the proposed groundwater regulations can be found in Sections 2.1.2 and 8.0.

2.1.1 Radon emanations

Radon emanation from unstabilized and uncontrolled tailings was one of the main driving forces behind the establishment of the UMTRCA. As a result, the regulations contain a radon design standard (40 CFR 192.02(b)), which states that remedial actions should be designed to provide reasonable assurance that releases of radon-222 from residual radioactive materials to the atmosphere will not:

- Exceed an average release rate of 20 picocuries per square meter per second, or
- Increase the average annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

2.1.2 Water resources protection

Groundwater

The EPA incorporated several components of the RCRA into the proposed UMTRA Project groundwater regulations, as per Congressional desire and court remand. The groundwater standards include the concept of a single groundwater protection standard (40 CFR 192.02(a)(3)) for each site, which includes hazardous constituent identification (40 CFR 192.02(a)(3)(i)); the establishment of compliance levels for the identified constituents, which can either be background concentrations, maximum concentration limits, or alternate concentration limits (40 CFR 192.02(a)(3)(iii)); and the establishment of a point of compliance (40 CFR 192.02(a)(3)(iv)). The period of performance is 200 to 1000 years.

In establishing the proposed groundwater standards, the EPA gave the authority to approve the site-specific groundwater protection standards to the NRC.

In addition to establishing the ability to obtain alternate concentration limits for the UMTRA Project, the proposed standards provide the framework for obtaining groundwater supplemental standards for both disposal and cleanup. Supplemental standards (40 CFR 192.21) for disposal sites can be obtained when the groundwater is limited use (previously known as Class III groundwaters). When applying supplemental standards under the limited use criterion (40 CFR 192.22), the remedial actions must come as close to meeting the otherwise applicable standard as is reasonably achievable and must protect human health and the environment.

Surface water

Although there are no specific Title I numerical standards that must be met when addressing surface water contamination, the regulations require that disposal be designed to protect water. The EPA recognized that once the tailings are stabilized, impacts to surface water are substantially minimized (EPA, 1983).

2.1.3 Design considerations

Geologic and geotechnical stability is related to the design requirement in 40 CFR 192.02, which establishes a design objective of 1000 years to be satisfied whenever reasonably achievable, but in any case, a minimum performance period of 200 years must be achieved. As a result, the UMTRA Project disposal cells are designed to withstand maximum credible earthquakes, Probable Maximum Precipitation events, and Probable Maximum Flood events.

2.1.4 Residual radioactive materials and hazardous wastes

The UMTRCA defines residual radioactive materials as those materials, defined as radioactive by the Secretary of Energy, that are the result of the uranium milling operations. These materials have recognized radiological and nonradiological hazards associated with them and can be disposed of according to the Title I regulations of the UMTRCA.

In certain limited instances, hazardous wastes or substances may be encountered at UMTRA Project sites that are not a result of the uranium milling operations. These wastes will be disposed of in accordance with the appropriate environmental regulations and in consultation with the appropriate state and Federal agencies. The DOE is now in the process of developing a policy for dealing with hazardous wastes encountered at UMTRA Project sites.

2.2 PILE LOCATION AND CONFIGURATION

Contaminated materials can be stabilized either on site, in place, or at an alternate site. The final location and configuration of a pile affects every other design consideration and is influenced in turn by any or all of the considerations. Each of the three types of stabilization can vary from above-grade disposal to different degrees of below-grade disposal. The ultimate goal of remedial action is to assess technically acceptable alternatives in determining the most cost-effective option.

The following steps are essential for an adequate evaluation in selecting a preferred final pile location and configuration:

(1) Identify hazards associated for stabilization in place (SIP) and the remedial action necessary for technical acceptability.

(2) Assess the design features necessary for technically acceptable stabilization on site (SOS) if technical acceptability of SIP is not possible or is in question.

(3) Assess potential alternate sites if neither SIP nor SOS are technically feasible. (The assessment of the relocation option is always necessary for comparative purposes.) Remedial measures required to assure technical feasibility of SIP or SOS may result in more costly solutions than relocation.

(4) Identify the hazards and potential design options at one or more potential alternate sites.

(5) Perform cost estimates for each potential SIP, SOS, and relocation option.

(6) Select the preferred alternative for stabilization and final configuration based on the amount of risk associated with any factors that cannot be fully evaluated, as well as the cost.

Many of the various design considerations involved with the three types of stabilization are listed in the following subsections. This listing is not meant to be inclusive; rather, it serves to indicate the variability involved in the process and to identify major considerations.

2.2.1 Stabilization in place (SIP)

An adequate assessment of SIP includes the following design considerations.

- Reconfigure the pile to have stable slopes with a minimum movement of contaminated materials.
- Buttress the sideslopes with clean material to form stable slopes as necessary if exposure of slime pockets will produce unstable conditions.

- Identify the modifications that exist (if any) to avoid the impact of upland drainage areas or nearby large streams.

- Minimize the final pile area that will remain restricted. This is in conflict with minimum material movement unless the depth of the materials is shallow enough that it is more cost-effective to consolidate the material and reduce the final area requiring cover.

- Achieve a balance between minimizing slopes for erosion protection and maximizing slopes for a greater volume-to-pile-area ratio.

- Identify any modifications that exist to avoid differential settlement due to slimes concentrations. The design should evaluate the potential effects on the radon cover and the effect on erosion protection due to drainage flow concentrations.

- Increase radiological characterization as necessary to properly design the radon barrier.

- Reduce the necessary radon barrier through effective use of windblown material spread evenly over the top of the tailings. However, if the quantity to spread is not substantial, it may be more cost-effective to place the windblown materials randomly and provide a thicker radon barrier.

- Ensure that the contaminated materials are well above the groundwater table.

- Identify the risks associated with location in a floodplain (not automatically a reason for relocation). However, it may not be possible to protect the pile from floods depending on the proximity to the stream and the constricted nature of the floodplain.

2.2.2 Stabilization on site (SOS)

An adequate assessment of SOS includes the following design considerations.

- Evaluate the necessity for the movement of all, or the major portion, of the contaminated materials in order to protect them from one or more conditions (e.g., high groundwater, proximity to large streams, slope instability, potential differential settlement, configuration effect upon flood conditions, or geomorphic instability).

- Assess the modifications available to avoid any existing hydrologic impacts. Greater control of hydraulic conditions is possible with SOS than with SIP, thereby reducing erosion protection requirements.

- Minimize the overall pile area to effectively reduce overall cover requirements without adversely affecting pile stability.

- Avoid large slimes pockets by more complete mixing of the materials to reduce the potential for differential settlement.

- Base the final location of the pile upon construction requirements that avoid excessive double handling of materials.

- Improve stability conditions with more complete compaction of the embankment.

- Reduce radiological characterization data needs and simplify the radon barrier design process since mixing the materials averages the emanation rates. Ensure sufficient data are available to determine the averages adequately.

- Evaluate the necessity for substantial erosion protection requirements due to flooding, runoff from upland drainage basins, and flow in stream channels.

2.2.3 Relocation to an alternate site

Relocation to an alternate site requires initiation of the alternate site selection process, as discussed in Section 10.0. Factors included in the selection of an alternate site are as follows:

- Exercise maximum flexibility in selecting a site and choosing a configuration that minimizes hydrologic impacts.

- Improve conditions involving slope stability and differential settlement due to the mixing and recompaction of the entire pile.

- Simplify radiological characterization and the radon barrier design process by mixing the materials; this averages the emanation rates. Ensure sufficient data are available to determine the averages adequately.

- Select the location for an alternate site by evaluating locations near the top of drainage areas with stable existing slopes, seismically stable locations, and locations on government-owned land.

- Avoid sites with shallow groundwater. Shallow groundwater will affect the pile configuration by limiting the degree of below-grade disposal.

- Evaluate partial to complete below-grade disposal in order to obtain cover materials from the disposal site using cut and fill procedures.

- Develop an economic comparison of the possible designs. Different designs may vary from a thick pile above-grade that minimizes the final pile area and cover requirements to a completely below-grade disposal that uses shallow slopes and additional soil below cover depth to eliminate expensive imported rock for erosion protection.

2.3 GEOLOGICAL STABILITY

The geological stability of a site and its impact on disposal cell design is primarily a function of the seismotectonic and geomorphic setting of the site. Studies are conducted to define both the seismic and geomorphic hazards associated with the site.

As part of the design of reclamation works at UMTRA Project sites, studies are conducted to define the seismic hazard. These evaluations result in a seismotectonic characterization of each site and provide a set of earthquake design parameters. The parameters include the design earthquake magnitude; on-site peak horizontal ground acceleration; the distances to and lengths of capable faults; and the types of capable fault displacement. During the seismic investigation, the potential for on-site fault rupture is analyzed.

The geomorphic hazard assessment will (1) identify the geomorphic processes that affect the site; (2) estimate the probability of their occurrence; and (3) evaluate the possible magnitude of their effects during the life of the reclamation.

2.4 GEOTECHNICAL STABILITY

The level of effort expended to protect against settlement and ensure slope stability at UMTRA Project sites depends greatly upon the site-specific conditions and the design concept used. Both surrounding natural slopes and embankment slopes are analyzed. Because of the flatter slopes required to promote surface water runoff and because of erosion considerations, slope stability of the embankment will only be critical for sites exhibiting high seismicity or soft soil zones within or below the embankment. If critical, slope stability considerations could lead to designing flatter or buttressed slopes.

Overall magnitude of settlement is not a critical design control; however, differential settlement, which tends to increase along with increasing total settlement, can cause cracking of the radon cover or drainage flow concentrations. Either condition, if not adequately designed for, could lead to failure of the pile cover system.

2.5 RADON BARRIER

The radon barrier may serve a dual purpose in the design: (1) to reduce the radon emissions (flux) from the contaminated materials, and (2) to reduce the infiltration of water into the contaminated materials, especially in rock-covered piles. This section applies only to the radon flux reduction aspect of the radon barrier; the hydrological aspect is discussed in Sections 2.8 and 2.9.

The pile configuration and type of stabilization influence the required amount of radon barrier. Once a pile exceeds a thickness of seven to ten feet, increased thickness does not affect the required radon barrier. Thus, minimizing the areal extent of a pile may, by increasing thickness, reduce the total radon barrier material needed. Contaminated materials can be layered with the less-contaminated material on top, resulting in less radon barrier material being required.

Stabilization in place provides the least amount of control over the location and layering of contaminated materials, and more radiological characterization data must be obtained in order to design the radon barrier properly. Average values of the parameters for the material in each distinct layer should be used to model the radon emissions because the EPA standards reference the site-averaged radon flux. For SIP, effective use of low radioactivity materials (e.g., windblown contaminated soils) as layers on top of the higher radioactivity materials may reduce the necessary amount of radon barrier materials.

Options requiring excavation and handling of materials (e.g., SOS or relocation to an alternate site) result in better mixing of the materials. This simplifies the design and radiological characterization data needs since the average radioactivity and other parameters for the mixed material may be used; however, sufficient characterization is necessary to ensure that the average values are adequately known. It is beneficial to retain low radioactivity materials separately for placement as a layer over the top of the other materials, as this lowers the radon flux and thus decreases the amount of radon barrier material needed.

If appropriate, acceptable mixing ratios of sandy tailings and slime may be established. This will be done only if it is shown by geotechnical analysis that such mixing ratios are required to control differential settlement.

2.6 SURFACE WATER HYDROLOGY

The type of stabilization used on UMTRA Project sites is greatly influenced by the expected magnitude of hydrologic impacts. The level of effort expended for erosion protection depends upon the site-specific conditions and the final pile location and configuration.

As discussed in Section 4.1, Surface Water Hydrology, three primary design situations affect the stabilized tailings:

- On-pile surface runoff.
- Upland watershed runoff.
- Flooding associated with nearby large streams or large watersheds.

Hydrologic impacts from upland watershed runoff and flooding from nearby streams can prove to be the most disruptive and can necessitate relocation of the pile on the site or to an alternate site. Under SIP or SOS, there are greater restrictions with regard to improving surface water drainage conditions. Upland watershed runoff is generally allowed to drain around a pile in direct contact with protected sideslopes, or is controlled with on-site drainage diversion channels. In either case, adequate sideslopes and toe protection must be provided to assure the longevity of the containment system. If materials are to be stabilized in a major floodplain, the design becomes increasingly difficult due to the magnitude of design flow depths and velocities. At this point, the design must also account for the effect that geomorphic changes can have upon the hydraulic conditions at a site. The design normally requires increased sideslope and toe protection to prevent flooding impacts. Geomorphic considerations (e.g., channel migration and undermining) require additional toe protection in the form of thickened perimeter rock aprons or buried riprap walls. Under severe situations where the longevity of the design is questionable or the design is economically impracticable, relocation to an alternate site becomes necessary.

Under the relocation option, the primary goal is to locate an alternate site that is (1) outside of any floodplain, and (2) at or near the head of any drainage areas. Under any of the options, the pile configuration is very important in affecting the hydrologic impacts. Consideration must be given to dividing the topslope drainage to avoid concentration of large drainage areas down one sideslope. The topslope can also be pitched away from one side to avoid drainage down a longer sideslope. To protect against off-site flooding impacts, it may be necessary to design the overall shape of the stabilized pile based on hydraulic conditions at the site. Within a floodplain, a pile may have to be narrowed substantially to a hydraulically smoother structure so as not to block flood flows. Below an upland watershed, the shape of the pile can be designed to divert drainage so that it affects only a small portion of the pile.

2.7 DISPOSAL CELL DESIGN APPROACH

The remedial action design for each site will meet the design criteria listed in Section 2.1. Because of the requirement for compliance with

the recent changes to the EPA groundwater standards, alternative designs depending on site-specific conditions have been incorporated in the design approach. Different cell and cover designs can be integrated so that the remediated pile will meet the design objectives in a cost-effective manner.

Designs for sites with different climates, location options (e.g., SIP or SOS), site conditions, and groundwater compliance strategies are developed using the checklist design approach. There are essentially three types of disposal cell designs, two types of cover designs, and several options for perimeter dike details in this approach. The remedial action design is an integration of these parameters on a site-specific basis. Specific design considerations are covered in the appropriate section discussing the design component.

2.8 COVER DESIGN

2.8.1 Rock covers

On the UMTRA Project, rock covers have been standard elements in meeting the longevity and performance criteria. Rock covers consist of three components: (1) a radon/infiltration barrier of compacted soil; (2) a bedding/filter layer of sand; and (3) a top layer of rock riprap for erosion protection. Rock covers are generally best applied at the more arid sites and can be optimized so that seepage out of the pile is minimized, to promote compliance with the proposed EPA groundwater standards. In addition to erosion and infiltration protection, rock covers must be designed to provide protection against the effects of freeze/thaw and biointrusion.

2.8.2 Vegetated covers

A vegetated cover may be placed on the topslopes of UMTRA Project piles as an alternative to a rock cover. Vegetated covers are generally not recommended for sideslopes because the vegetation may not be able to resist gullies originating on the steeper sideslopes or advancing headward from off the pile.

A vegetated cover consists basically of plants and soil, sometimes with other earthen materials, that have been selected to maximize transpiration and resistance to erosion. The soil and plants in a vegetated cover have specific performance objectives that must be met if the cover is to achieve its intended goal of controlling water balance, resisting erosion, and otherwise contributing to the long-term integrity of the stabilized pile.

The key to vegetated cover design is to use the proper combination of plants and soil to assure that some plants survive (even if dormant) the dry periods so that adequate transpirational capacity will be available after precipitation events to prevent moisture from infiltrating into the contaminated materials. A rock mulch may be required at exceptionally arid sites to resist

evaporation (making more soil moisture available to plants during dry periods) and to supplement the plants' ability to resist erosion to the cover.

2.9 NONRADIOLOGICAL HAZARDOUS CONSTITUENTS IN SOILS

The DOE is responsible under the UMTRCA (40 CFR 192) for ensuring the protection of public health and the environment from post remediation releases of hazardous constituents and for ensuring that residual levels of hazardous constituents in soils will allow compliance with the groundwater cleanup standards. The DOE shall use a quantitative exposure pathway analysis that is consistent with that being proposed by the EPA for hazardous waste sites (EPA, 1988) to assess potential harm to humans. Where necessary, an ecological risk assessment will be performed to evaluate harm to the environment. A detailed hydrologic assessment will be performed to assess compliance with the groundwater cleanup standards. Further development of these analyses and assessments are provided in Section 9.0.

2.10 DISPOSAL OF CONTAMINATED BUILDINGS AND OTHER MILL FACILITIES

Building materials and other mill facilities contaminated during milling operations can vary from a few concrete foundations to a complete mill (e.g., at the Ambrosia Lake, New Mexico, site). When only a few concrete foundations exist, it is usually more cost-effective to dispose of the materials in the remediated pile than it is to attempt to decontaminate the materials. However, when there is an entire mill, including large steel tanks that would need to be cut up, it may be more cost-effective to perform one or all of the following.

- Decontaminate all materials for unrestricted use.
- Decontaminate those portions of the mill that are salvageable and bury the remainder of the materials in the pile.
- Demolish and place all contaminated materials in the pile.
- Demolish and place all contaminated materials in a pit adjacent to the pile.
- Demolish and place all contaminated materials in a pit at the demolition site, even when the tailings are relocated to a disposal site.

Each of these options has advantages and disadvantages as summarized in Table 2.1.

Table 2.1 Advantages and disadvantages for disposition of contaminated buildings and mill facilities

Alternative	Advantages	Disadvantages
1. Decontamination, total or partial	All decontaminated buildings and facilities can be released for unrestricted use.	Requires verification effort to survey all the work performed.
	The property values of the facilities will be increased.	
2. Demolition and placement of debris in the pile	The pile design will meet the radon release requirement for the debris; no additional design effort is required.	Because excessive settlement may damage the radon barrier, the debris requires excessive handling, cutting into small segments, and more rigid placement criteria.
3. Demolition and placement of debris in a separate debris pit or trench adjacent to the tailings pile	The debris will require only moderate handling and cutting into reasonable segments, and less rigid placement criteria.	Some minor additional design effort may be required.
	Less stringent cover and erosion protection may be required.	More land withdrawal may be required.
4. Demolition and placement of debris in a pit or trench at the demolition location, even if the materials are are relocated	The debris will require only moderate handling and cutting into reasonable segments, and less rigid placement criteria.	Some minor additional design effort may be required.
	Minimum or no hauling distance.	Additional land withdrawal for restricted use will be required.
	Significant cost savings.	

2.11 SUMMARY

Although many different design considerations can be standardized with general guidelines, it is obvious from this discussion that the process is complex. Many different design combinations can occur from the variety of considerations. The design process must be flexible to allow for innovative thought, optimization of various potential alternatives, and proper assessment of risks in order to arrive at a technically acceptable, cost-effective design.

In order to ensure that all aspects of a design are considered, a Remedial Action Plan Checklist has been prepared (Table 2.2) that should be used by those involved in RAP preparation as well as by reviewers as a means of ensuring that the document is complete. Once completed, the checklist will become part of the Quality Assurance/Quality Control documentation.

Table 2.2 Remedial action plan checklist

Item[a]	Coverage		
	Yes	No	Remarks
I. Background groundwater quality			
A. Literature review.			
B. Well and spring inventory for two-mile radius.			
C. Background monitor wells.			
1. Uppermost aquifer.			
a. three or more monitor wells.			
2. Lower aquifers.			
a. three or more monitor wells.			
3. Sampled at least twice.			
a. six or more sample analyses.			
D. Surface water (pile side of stream or river).			
1. Low flow.			
a. Upstream.			
b. Intermediate.			
c. Downstream.			
2. High flow.			
a. Upstream.			
b. Intermediate.			
c. Downstream.			
II. Presence and movement of contaminant plumes in groundwater and discharge to surface water			
A. Contaminant identified.			
1. Source term.			
2. Groundwater.			
a. Vertical extent.			
b. Lateral extent.			
c. Constituents above standards.			
3. Location of groundwater discharge to surface water.			
B. Flow directions and aquifer properties.			
1. Vertical gradients.			
2. Lateral gradients.			
3. Average flow velocities.			
4. Travel times to background concentration or surface water discharge.			

Table 2.2 Remedial action plan checklist (Continued)

Item[a]	Coverage		
	Yes	No	Remarks
III. Prediction of effects of remedial action on groundwater			
A. Flux calculations for saturated zone.			
B. Infiltration through pile.			
C. Estimate dispersion/attenuation of contaminants.			
D. Geochemical controls on contaminant movement, geochemical modeling, precipitation/dissolution, speciation, adsorption, other water-rock interactions, leaching studies on site-specific materials, mineralogical analyses influencing geochemical processes.			
E. Predicted future concentrations.			
IV. Impacts on beneficial use of groundwater			
A. Present value of affected resource.			
B. Potential for human exposure.			
V. Control alternatives for groundwater			
A. Aquifer restoration.			
B. Institutional controls.			
VI. Radiological site characterization			
A. Appropriately spaced grid points.			
B. Borehole drilling/logging/sampling for deep contamination.			
C. Gamma exposure rate measurements.			
D. Soil sampling/delta measurements for shallow contamination.			
E. Soil samplings below tailings for thorium and heavy metals.			
F. Building surveys for salvageable buildings.			
G. Volume calculations, based on reasonable conservative assumptions.			
H. Tailings pile Ra-226 source.			
I. Off-pile Ra-226 source.			
VII. Radon barrier design			
A. RAECOM model.			
B. Geotechnical data (bulk density, porosity, long-term moisture) provided by Engineering.			

Table 2.2 Remedial action plan checklist (Continued)

Item[a]	Coverage		
	Yes	No	Remarks
C. Radon emanation: test for dependence on moisture, Ra-226 contents.			
D. Radon diffusion coefficients.			
1. Measurements for all materials.			
2. Least squares fitting of results.			
E. Radium content: layer average values calculated for each RAECOM layer.			
F. Ambient radon: background site radon levels.			
G. Sensitivity analysis.			
1. Average Ra-226 concentration.			
2. Radon barrier diffusion coefficient.			
3. Tailings diffusion coefficient.			
4. Radon emanating fraction.			
5. Worst case.			
VIII. Surface water hydrology			
A. Consider effect on pile of runoff from: direct precipitation, upland watershed, large streams.			
B. Collect available data.			
C. Do flood studies.			
D. Assess effect of geomorphology on pile.			
E. Review dam failure impact (if any).			
F. Determine PMP and PMF.			
G. Provide diversion facilities to direct off-pile flow.			
H. Provide erosion protection in and around pile for design events.			
IX. Erosion protection			
A. Rock cover.			
1. Select appropriate design methodology.			
2. Identify source of rock.			
3. Size rock.			
4. Size bedding or filter layer.			
5. Check adequacy of protection for ditches, aprons.			
6. Confirm rock durability, check laboratory test list and conformance with requirements.			

Table 2.2 Remedial action plan checklist (Concluded)

Item[a]	Coverage		
	Yes	No	Remarks
7. Check compatibility of filter and erosion barrier.			
B. Vegetated cover.			
1. Geomorphological assessment of gullying potential.			
2. Analyze resistance to erosion-tractive force method.			
X. Geotechnical			
A. Review previous work.			
B. Characterize region and site geology.			
C. Define site geomorphology: gullies, mass movement, slope erosion, tectonism, base level/change.			
D. Define subsurface conditions: archived data, field boreholes, test pits, laboratory test.			
E. Borrow pit definition: material characteristics.			
F. Tailings characteristics.			
G. Construction material characteristics.			
H. Field seismicity: surface and bedrock acceleration, seismic magnitude and intensity, fault locations.			
I. Slope stability: static and seismic, factors of safety adequacy.			
J. Pile settlement: settlement defined, potential effect on pile integrity considered.			
K. Liquefaction potential: adequate soil strength, soil moisture adequacy, compaction of tailings.			
XI. Non-radiological contaminants			
A. Review of existing soil, groundwater, and tailings data.			
B. Run DECHEM™ model for pathways analysis and needed depth of excavation.			

[a]Ra-226 = radium-226; PMP = Probable Maximum Precipitation; PMF = Probable Maximum Flood; RAECOM = the Radon Attenuation Effectiveness and Cover Optimization Model (NRC, 1984).

REFERENCES FOR SECTION 2.0

EPA (U.S. Environmental Protection Agency), 1988. Guidance for Establishing Target Cleanup Levels for Soils of Hazardous Waste Sites, draft prepared for the Office of Waste Programs Enforcement.

EPA (U.S. Environmental Protection Agency), 1987. "Health and Environmental Protection Standards for Uranium Mill Tailings," 40 CFR 192 (52 FR 36000, 9-24-87).

EPA (U.S. Environmental Protection Agency), 1983. "Health and Environmental Protection Standards for Uranium Mill Tailings," 48 FR 602, 40 CFR 192, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1984. Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533, prepared by Rogers and Associates Engineering, Salt Lake City, Utah, for the U.S. Nuclear Regulatory Commission, Washington, D.C.

3.0 DISPOSAL CELL DESIGN APPROACH

3.1 CHECKLIST DESIGN APPROACH

The checklist approach to the design of an UMTRA Project disposal cell and the selection and specification of the details of the cell are based on the idea that any disposal cell consists of two parts: the perimeter dike or embankment, and the top cover. The checklist approach accordingly involves (1) examining the various possible alternative perimeter dike and cover details described in this section; (2) selecting appropriate perimeter and top cover details; and (3) combining appropriate details to constitute a complete disposal.

The perimeter dike, or embankment, and top cover details listed and discussed below constitute a list of alternative details that should be examined and considered when designing a disposal cell. Site-specific factors must be taken into account in selecting appropriate perimeter and top details. The checklist alternatives described below are comprehensive enough to cover most situations likely to be encountered on the UMTRA Project, but if site-specific factors dictate different details, other more appropriate details should be adopted even though they are not found in the checklist.

In design, the selection of the appropriate disposal cell details should lead to a balance of cost effectiveness and control of seepage to the extent necessary to meet applicable site groundwater standards. Furthermore, a balance is to be sought between providing for the physical stability and resistance to erosion of the cell, and the need to control and limit infiltration to the wastes.

The checklist disposal cell design approach may be used not only to select appropriate cell side and top details, but also to document in a rational and consistent fashion that alternative design details are not appropriate. As an example, the designer may document that all but the selected checklist alternative details are not appropriate for particular reasons. A reviewer is then able to confirm that the design details were selected in a reasoned way.

Finally, it is important to note that the Checklist Cover is only a part of the design process. The checklist approach is intended only to assist the designer; it is not a substitute for professional judgment and the compilation of an appropriate site-specific design justification. Data, design evaluations, and calculations are required to validate the suitability of the chosen design for the specific site. The checklist cover approach also facilitates identification of cover design details required to achieve levels that are as low as reasonably achievable (ALARA) when appropriate.

3.2 PERIMETER DIKE DETAILS

Figure 3.1 shows a number of possible designs for the perimeter dikes or embankments of an UMTRA Project disposal cell. To determine the appropriate detail, proceed as follows:

- o Examine possible perimeter dike layouts, shown on Figure 3.1.
- o Evaluate the advantages and disadvantages of alternative perimeter dike details for the specific site.
- o Adopt the appropriate perimeter dike detail, suitably adjusted for site-specific conditions.

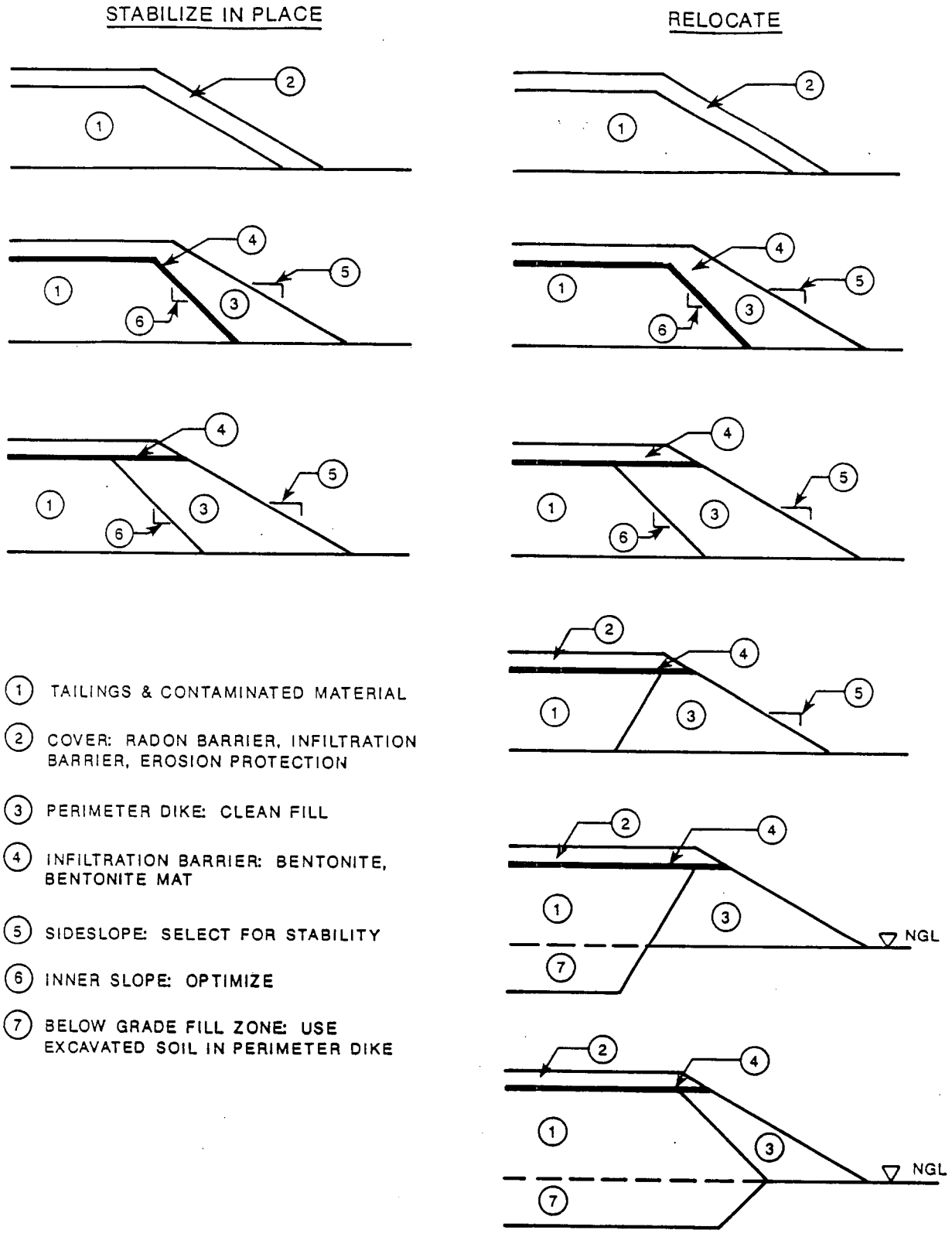
3.2.1 Pile stabilization in place

The perimeter dike design alternatives shown on Figure 3.1 are categorized on the basis of whether or not the contaminated materials are relocated. For materials stabilized in place there are three basic design options. The first option is simply to flatten existing slopes and cover them with an appropriate cover. The second involves placing a layer of bentonite or bentonite-amended soil and stabilizing this with a partial buttress of clean fill. In the third option, the contact between the contaminated materials and buttresses of clean fill slopes outward; the low permeability elements of the cover extend beyond the toe of the waste material on top of the buttress.

The choice of the appropriate perimeter dike detail for a stabilization-in-place disposal cell is to be based on the need to (1) limit infiltration through the sides; (2) ensure that the sideslopes are stable under design static and dynamic loadings; and (3) control or limit the growth of vegetation on the sideslopes. The following discussion of these design objectives is provided in order to assist the design engineer in the choice of design detail. It may be necessary to consider the following factors, and others, in greater detail before making a final choice of detail.

The most economical cover on the sideslope is likely to be a rock cover, which includes a radon/infiltration barrier, bedding, and riprap for erosion control. The design of the riprap is discussed in detail in Section 4.2.1. The design of the infiltration barrier to control and limit infiltration is the critical aspect of the sideslope cover performance affected by the proposed groundwater protection standards. This is discussed in detail in Section 4.2.2.

In arid and semiarid climates with less than nine inches of precipitation per year, initial data from the radon barrier moisture content study (DOE, 1989a) support the assertion that the infiltration barrier on a standard cover sideslope will be partially saturated. In wet climates, such as those with more than fifteen inches



1. TAILINGS & CONTAMINATED MATERIAL
2. COVER: RADON BARRIER, INFILTRATION BARRIER, EROSION PROTECTION
3. PERIMETER DIKE: CLEAN FILL
4. INFILTRATION BARRIER: BENTONITE, BENTONITE MAT
5. SIDESLOPE: SELECT FOR STABILITY
6. INNER SLOPE: OPTIMIZE
7. BELOW GRADE FILL ZONE: USE EXCAVATED SOIL IN PERIMETER DIKE

FIGURE 3.1
"CHECKLIST"
PERIMETER DIKE ALTERNATIVES

of precipitation per year, the sideslope infiltration barrier will probably be saturated. At sites where the annual precipitation is between nine and fifteen inches, the degree of saturation of the sideslope infiltration barrier will probably depend on the details of the topslope cover, as discussed below.

If the topslope cover at a site in an intermediate climate zone incorporates vegetation that sufficiently limits the volume of water entering the cover drain and hence flowing to and over the sideslope infiltration barrier, the infiltration barrier will remain partially saturated. Conversely, if the topslope cover at a site in an intermediate climate zone incorporates only a drain and riprap, significant precipitation runoff from the topslope will flow towards and over the sideslope infiltration barrier. The potential for saturation of the sideslope infiltration barrier is considerably greater for piles without topslope vegetation.

If the degree of saturation of the sideslope infiltration barrier is too great and the resulting water flux through the sideslope cover derogates from achieving the site-specific groundwater compliance standards at a disposal cell's point of compliance, the designer should consider alternative perimeter dike details. A buttressed cell approach may be used; i.e., a bentonite mat or soil amended with a high percentage of bentonite may be placed over the existing sideslopes of the pile, a drain constructed over this layer, and finally, the slopes buttressed by clean fill. The suitability of such an arrangement will have to be confirmed by stability analyses that include consideration of failure along the potential slip surface formed by the low strength bentonite or bentonite-ammended soil.

An alternative to placing the very low permeability layer down the sideslope is to continue the layer out from the topslope at the same inclination as used on the topslope, and extend it sufficiently over the clean fill to preclude infiltration coming through the perimeter dike from contacting the tailings. This arrangement is shown on Figure 3.1. The arrangement is likely to be relatively expensive if the perimeter dike height is great, but it does facilitate construction in that it avoids the need to place a bentonite mat or other low permeability layers on inclined slopes. There is concern that back-flow or seepage through the clean fill could contact the encapsulated materials and become contaminated. To prevent this, it may be necessary to construct a capillary break or drain between the materials and the clean fill, which would increase the cost of this particular perimeter dike design.

A complete dike of clean fill could, in theory, be used to stabilize contaminated materials in place. However, building the dike and filling behind it with contaminated materials is not likely to be economical.

3.2.2 Pile relocation

All three of the perimeter dike details described above could be used if the contaminated materials are relocated. In addition, the three additional perimeter dike details shown on Figure 3.1 are feasible. All three additional perimeter dike details incorporate a clean dike or substantial buttress of clean fill.

The outer slope of a clean fill dike could be placed as flat as five horizontal to one vertical, and it could be covered with erosion-resistant rock riprap. If this is done, the outer slope will differ little from a conventional sideslope. However, because the dike consists of clean fill, it may be possible to increase the outer slope to three-to-one. Erosion control and stability of such a dike will be verified according to the procedures discussed elsewhere in this document.

In order to prevent possible contact of the contaminated materials with water seeping through the dike, it may be necessary to install a capillary break or drain between the materials and the dike. Alternatively, anisotropy of flow may be built into the dike by layered fill placement and compaction. The degree and inclination of the anisotropy would have to be arranged to direct water from the top cover away from the inner part of the dike and away from the materials. It is also feasible that the outer part of the dike could be constructed of material more permeable than the inner part; this would tend to direct flow from the topslope away from the materials.

The material for the dike could be economically excavated from the base of the disposal cell. Such an excavation would increase the capacity of the disposal cell, thereby reducing the cost per unit area of the facility. The depth of the excavation would be limited by the nature of the soils at the site and the depth to the groundwater table beneath the disposal cell. Site-specific investigations are required to optimize the alternative design for each facility.

Perimeter dikes of clean fill are a valuable design option in the groundwater compliance strategy. There is no need to decide if flow through the perimeter dike will be saturated or partially saturated as there are no contaminated materials beneath the dikes and no possibility for contamination of water seeping through the dikes. There is no need to be concerned about freeze and thaw effects on the soil. Vegetation may establish and the roots may grow deep, without concern for biointrusion to the encapsulated materials. Limited erosion of the dike could occur, and the materials would remain safely encapsulated in the disposal cell.

3.3 THE CHECKLIST COVER

3.3.1 Checklist Cover objectives

The Checklist Cover as shown on Figure 3.2 incorporates all reasonable components possibly required at a site to:

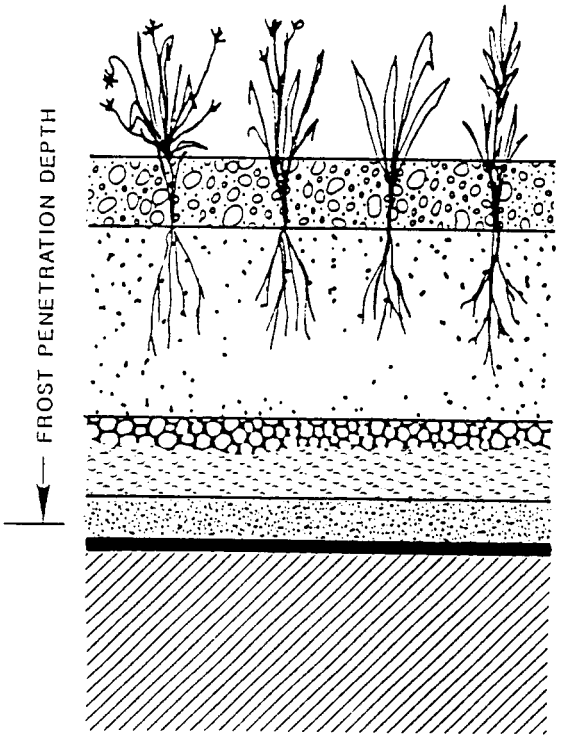
- o Control erosion.
- o Limit infiltration.
- o Provide freeze/thaw protection.
- o Inhibit radon emanation.
- o Drain or shed precipitation.
- o Control biointrusion.
- o Be self-renewing and adaptable to climatic change if vegetation is used.

3.3.2 Application of the checklist top cover approach

In order to determine the appropriate components to be incorporated into the top cover or the perimeter dike cover at a particular site, proceed as follows:

- o Obtain site-specific data.
- o Examine relevant characteristics of the natural landscape (gullies, vegetation, and the like.)
- o Examine the Checklist Cover and eliminate components on the basis of the component elimination criteria list in Table 3.1.
- o Compile the final cover as a composite of the remaining components.

The checklist approach to the design of a cover is simplistic in that each component tends to be viewed in and of itself. In reality, there is considerable interaction of the various components. It has been said that the various components, properly selected, form a functional synergistic entity. For example, in theory the use of a bentonite mat as the only operational infiltration barrier is reasonable. However, demands such as stability constraints dictate relatively flat slopes for the bentonite layer. Thus, there may be little gravity-induced runoff or shedding of precipitation through the drain above the bentonite layer. An hydraulic head could build up above the thin bentonite layer; the



	VEGETATION
0 - 1.0'	ROCK MULCH
3.0'	GROWTH MEDIUM & FROST PROTECTION
1.0'	BIOBARRIER: COBBLES (TOP CHOKED OR FILTERED)
0.5'	DRAIN: CLEAN SAND
	INFILTRATION BARRIER
1.0'	RADON BARRIER: CLAY/SILT

NOTE: THICKNESSES ARE APPROXIMATE.

FIGURE 3.2
"CHECKLIST"
TOP COVER

Table 3.1 Component elimination criteria

Cover component	Purpose and function	Rationale for elimination (based on site-specific conditions)
1. Erosion-barrier vegetation (topslopes only)	o Transpire moisture that enters soil. o Reduce infiltration. o Stabilize soil and reduce erosion. o Minimize impact of rainsplash.	o Topsoil suitable to support vegetation is not available;[a] topsoil is highly erodible because of physical structure or properties. o Large rock would be required to control gullies, and such rock is not available. o "High" quality rock for the biointrusion layer is not available. o Rock quality would have to meet the same requirements as that for frequently saturated conditions--scoring 65% or better. o It is possible to show that a significantly thick rock layer can be placed on the pile to inhibit the establishment of vegetation. o Construction is complete at the pile. o Pile design is too far advanced to change.
2. Erosion-barrier small diameter rock layer above topsoil on pea gravel/soil mulch (topslopes only)	o Provide additional protection against soil erosion used in conjunction with vegetation. o Reduce evaporation rates within the underlying soil layer in drier environments--preclude drying of the radon barrier.	o Vegetation would not be used for any of the reasons stated in No. 1 above. o Environment is wet/humid (semitropical). o Rock is not available. o Component inhibits vegetal growth. o Adequate vegetal coverage to protect against erosion. o Flat enough slopes that additional erosion protection not needed.

Table 3.1 Component elimination criteria (Continued)

Cover component	Purpose and function	Rationale for elimination (based on site-specific conditions)
3. Rooting medium (topslopes only)	o Provide rooting medium for vegetation. o Store water for plant growth. o Protect the underlying biointrusion layer from surface exposure. o Provide frost protection.	o Vegetation would not be used for any of the reasons stated in No. 1 above.
4. Frost protection (random fill) (top and sideslopes)	o Protect the underlying layers from the effects of frost heave and frost penetration. o Preserve the physical properties of the underlying layers.	o Regional frost penetration depth is insignificant; protection, if required, can be afforded by the erosion barrier or rooting medium (if included). o Construction is complete at the pile. o Pile design is too far advanced to change.
5. Choked rock filter (layer of pea gravel overlying layer of coarse aggregate) (top and sideslopes)	o Prevent piping of soil into erosion/biointrusion barrier. o Drain infiltration as rapidly as possible to retard root growth.	o Biointrusion layer would not be used for any of the reasons stated in No. 6 below. o Potential for slope instability exists, particularly on sideslopes.
6. Erosion/biointrusion 2-3 feet of cobbles with a low coefficient of uniformity to prevent biointrusion (top and sideslopes)	o Drain infiltration as rapidly as possible to retard root growth. Impede burrowing animals. o Act as a capillary break at the bottom of the layer to prevent upward movement of water and downward unsaturated flow (enhances moisture storage capacity).	o Biointrusion layer will not be protected from surface exposure by an overlying layer (i.e., topsoil, random fill rock). o "High" quality rock not available (frequently saturated conditions). o Pile design is too far advanced to change. o Deep-rooted species may be excluded by shallow-rooted species via ecological competition.

Table 3.1 Component elimination criteria (Concluded)

Cover component	Purpose and function	Rationale for elimination (based on site-specific conditions)
	o Control topslope erosion if vegetation and topsoil eroded away.	
7. High permeability drain (6"-12" layer of pea gravel overlying clean sand)	o Drain water laterally off the pile to limit infiltration. o Protect the underlying Claymax[R] liner system from displacement and rock penetration.	o Do not have underlying Claymax[R] liner system for any of the reasons stated in No. 8 below. o Potential for slope instability exists, particularly on sideslopes.
8. Infiltration barrier-Claymax[R] liner system (<u>topslopes only</u>)	o Intercept moisture. o Control infiltration. o Inhibit infiltration while mature vegetation community is establishing or after severe disturbance of the vegetation.	o Saturated hydraulic conductivity of radon barrier, amended or not, is low enough to lead to groundwater compliance. o Potential for slope instability exists. o Construction is complete at the pile. o Pile design is too far advanced to change.
9. Radon barrier (clay/silt) (<u>top and sideslopes</u>)	o Inhibit radon emanation. o Limit infiltration.	o Rationale for reducing thickness--Claymax[R] liner system aids in radon gas diffusion.

[a]Availability encompasses volume, quality, and size (for rock only).

result would be an increased gradient and hence increased percolation through the infiltration barrier. To reduct the potential for buildup of water in the drain, it is prudent to place a soil layer (probably required for frost protection) above the infiltration barrier, and to establish vegetation in the soil. The evapotranspiration of the vegetation will reduce the frequency and the amount of percolation reaching the drain, and therefore the need to rely on lateral shedding to remove water from the pile. The designer should always look for opportunities to enhance the interactive or synergistic effect of the various components in a cover.

3.3.3 Specific covers

In theory, the use of the checklist approach could lead to a very large number of different covers. In practice, a limited number of cover types or combinations of cover components has been identified. These are:

- The Simple Rock Cover: The three components are the radon/ infiltration barrier of compacted soil; the bedding layer of fine gravel or sand; and the erosion protection rock. This cover could be used on both the sides and top of a disposal cell.

- The Double Drain Rock Cover: The components are a radon/ infiltration barrier of compacted soil; a drain; a zone of random soil, the purpose of which is to increase the depth of the cover to protect the infiltration barrier against freezing and thawing; a bedding layer; and the erosion-resistant rock. This cover could be used on both the top and sides of a disposal cell.

- The Full Component Cover: This cover incorporates all the elements or components of the Checklist Cover. Because of the difficulty of providing for stability and preventing erosion, this cover is likely to be used only on the top of disposal cell.

- The Simple Vegetated Cover: This cover is similar to the full component cover, except that it does not incorporate a biointrusion barrier. An absence of suitable rock and the specifics of the site vegetation may make this a viable alternative.

3.4 CHECKLIST CELL DESIGNS

Combining a checklist perimeter dike and a Checklist Cover yields a disposal cell design. In theory there are a large number of alternative

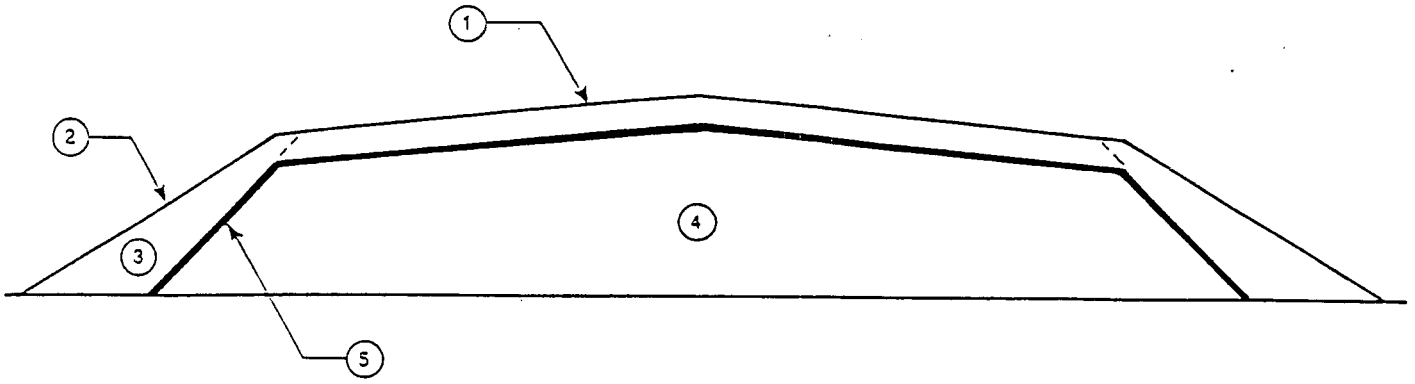
disposal cell configurations that may be derived from the basic perimeter and cover details. In practice, four basic cell designs are identified and should be considered for an UMTRA Project disposal cell. These are:

- The typical cell: Figure 3.3 shows the layout and details of the typical cell. It involves placing an appropriate cover over the top and sides of the stabilized pile or embankment, which has been reconfigured to form a suitable shape--usually with a pyramid top that has a slope of two to three percent and relatively flat (five to one) sides.

- The constrained cell: As shown in Figure 3.4, the essential feature of a constrained cell is surrounding dikes of clean, compacted material. This cell design is likely to be appropriate primarily for sites to which the tailings and contaminated materials are relocated. The advantage of this design is that there is no potential for seepage through contaminated material underlying the sideslopes. This may facilitate compliance with the EPA groundwater protection standards at sites where it is necessary to limit significantly or severely the quantity of contaminated seepage from the cell. The disadvantage is that this cell is likely to be the most expensive to construct. Material for constructing the perimeter dikes may be obtained from an excavation formed before placement of the tailings; determination of the optimum depth of excavation is based on the nature of the foundation materials and the impact of decreasing the distance between the tailings and the groundwater table. The top cover slope and details are selected by considering the Checklist Cover, described later.

- The buttressed cell: As shown in Figure 3.5, a buttressed cell involves buttressing the sideslopes of the in situ tailings pile with clean, compacted material to provide stability. This cell design is likely to be appropriate where tailings are stabilized in place. If the tailings are to be relocated, the design may be used to maximize the cell volume for tailings and contaminated material. The major constraint on the use of this cell is the positioning of the low-permeability layer relative to the buttress of clean material to provide slope stability. Hydrologic calculations should be performed to confirm that infiltration through the low-permeability sideslope layer can be limited to acceptable amounts by placing a drain over the low-permeability element or by the impedance to flow resulting from the presence of the bentonite layer. The topslope cover is selected by considering the Checklist Cover.

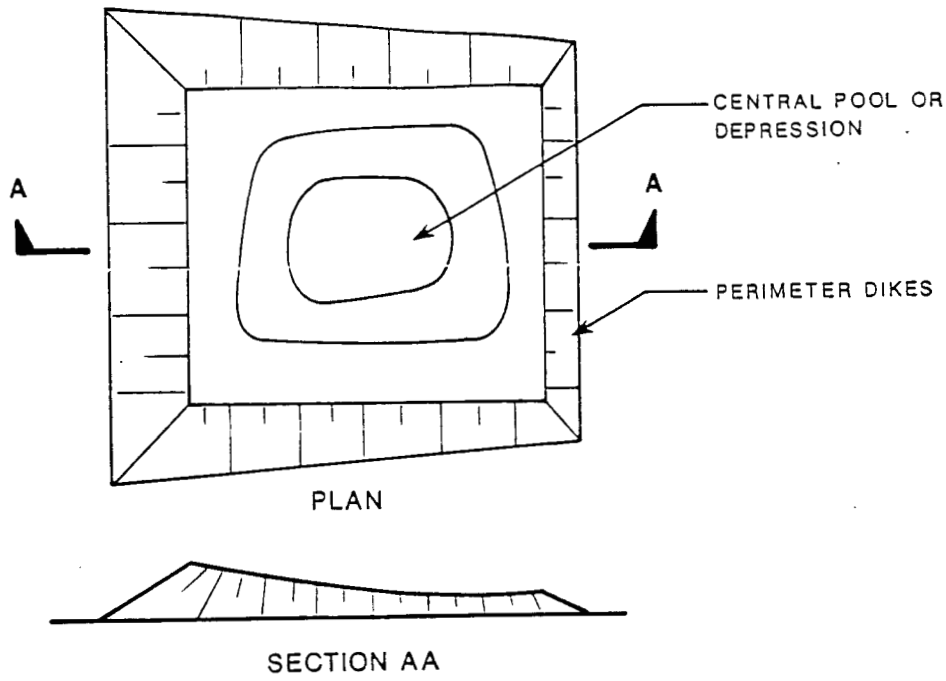
- The top surface swale cell: Figure 3.6 shows the essential features of a cell with a top surface swale. The top surface is contoured so that all flow is directed away from the steeper sideslopes, and not towards and over them. Flow is directed to a broad, shallow swale or topographic low, and the slope from the top of the pile to the surrounding area is gentle. If required, erosion control rock may be placed or base-level features may be constructed in the drainage swale.



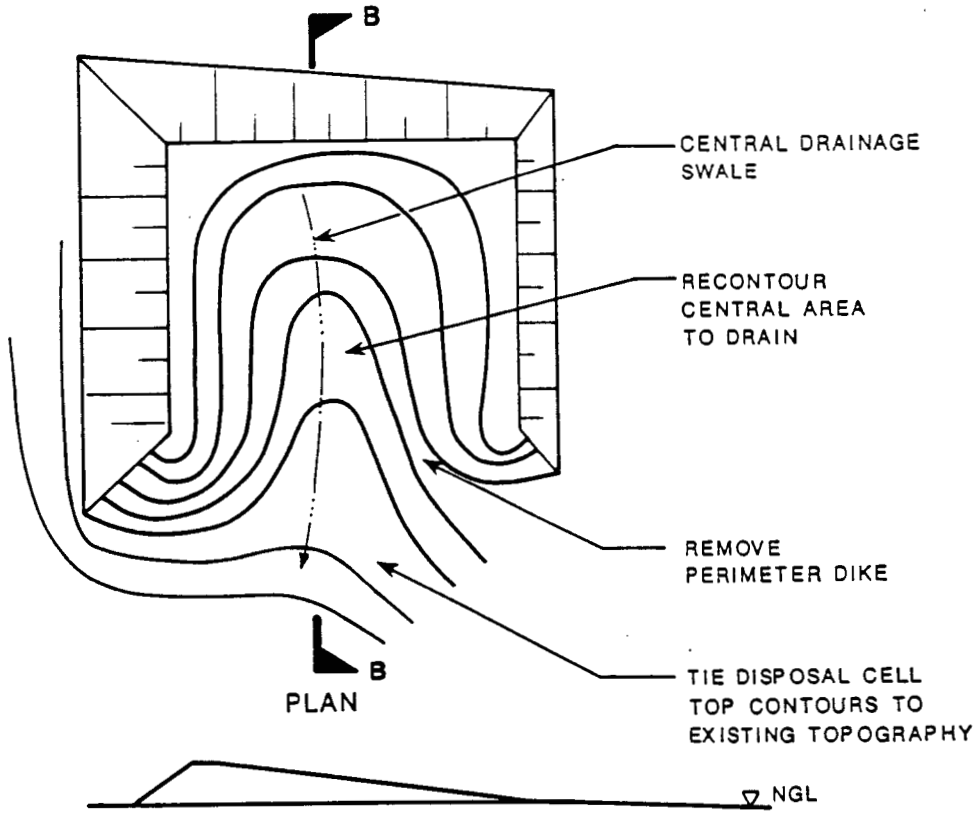
1. TOP COVER: SEE FIGURE 3.2
2. SIDE COVER: EROSION RESISTANT ROCK
3. PERIMETER BERM OR DIKE: CLEAN FILL
4. DISPOSAL CELL: TAILINGS & CONTAMINATED MATERIAL
5. SIDE AND TOP INFILTRATION BARRIER: COMPACTED CLAY, BENTONITE MAT, DRAIN, OR OTHER

FIGURE 3.5

BUTTRESSED CELL

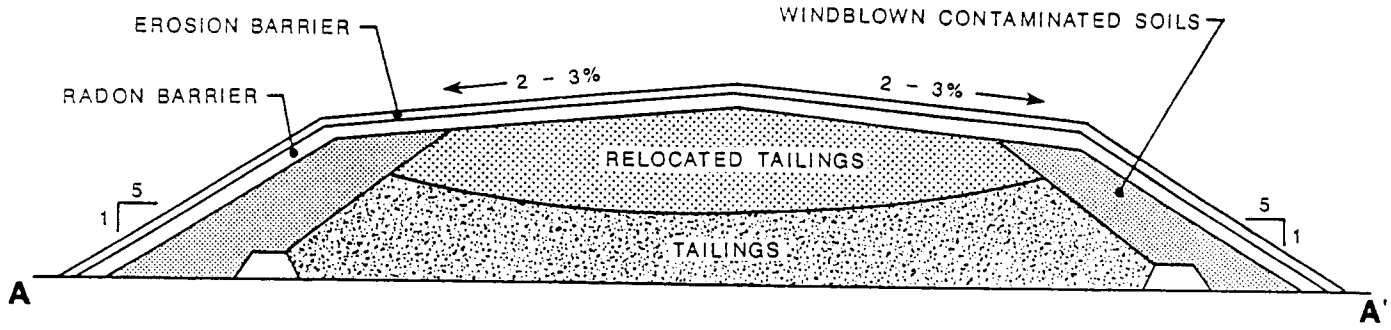


LAYOUT BEFORE REMEDIATION



LAYOUT AFTER REMEDIATION

FIGURE 3.6
TOP SURFACE SWALE CELL



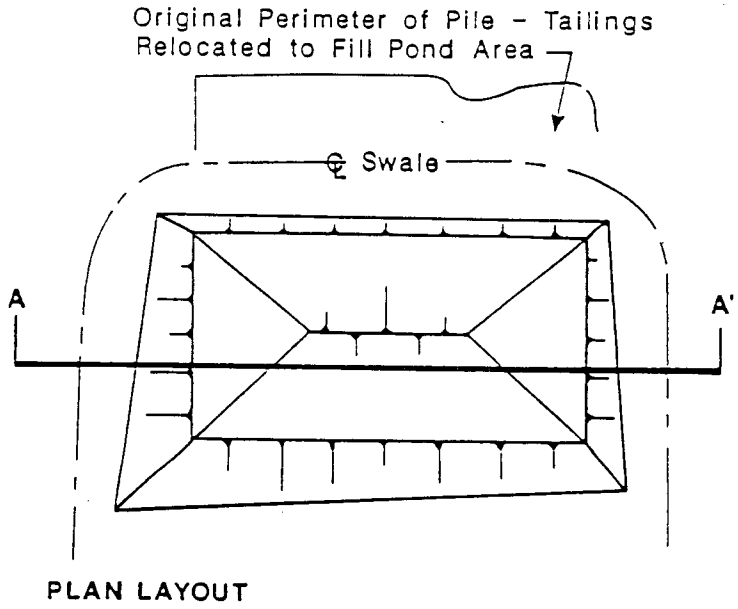
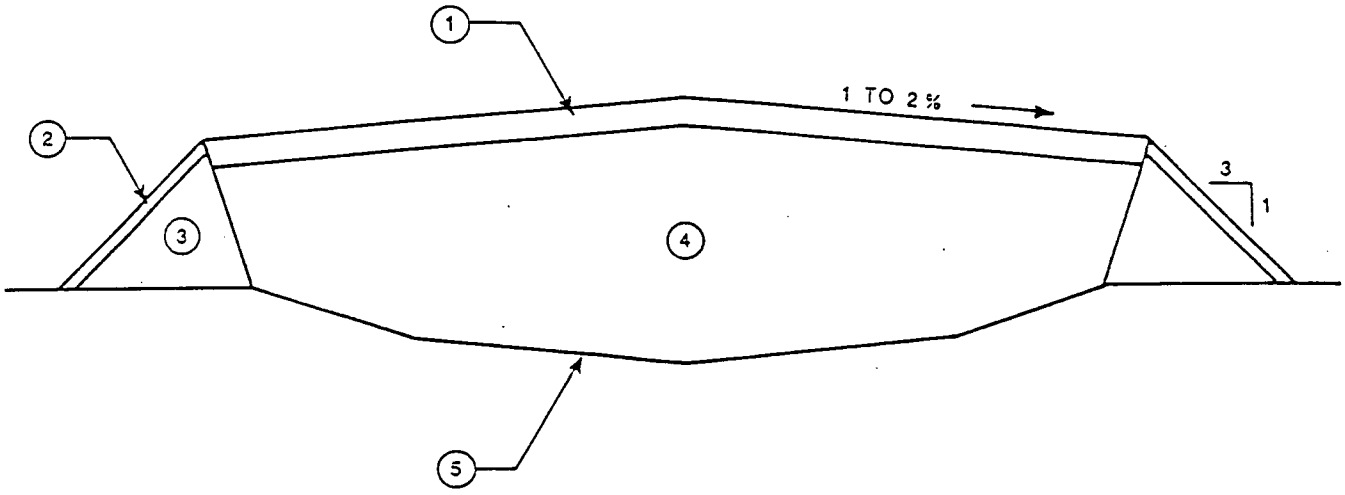


FIGURE 3.3
TYPICAL CELL



1. TOP COVER: SEE FIGURE 3.2
2. SIDE COVER: EROSION RESISTANT ROCK
3. PERIMETER DIKE: COMPACTED SOIL & ROCK
4. DISPOSAL CELL: TAILINGS & CONTAMINATED MATERIAL
5. BASE: EXCAVATED SOIL

FIGURE 3.4
CONSTRAINED CELL

Two other disposal cell layouts or remedial action approaches are discussed here for the sake of completeness. The first of these is to relocate the contaminated materials and place them on top of another pile, called "colocation." The obvious advantage of colocation is the presence of one rather than two piles, particularly if groundwater conditions at the colocation site are conducive to compliance with the standards.

Another possible disposal cell layout listed for completeness is termed the "cigar pile." The tailings and other contaminated materials would be placed into a long, narrow pile oriented perpendicular to the prevailing groundwater flow gradient. In theory, the potential for meeting EPA maximum concentration limits (MCLs) at the point of compliance is enhanced because the impact of contaminant seepage from the pile is spread over a greater distance and diluted by a greater volume of groundwater beneath the pile. Another advantage of this cell is the relatively short sideslopes, which can be kept steep to increase the rate at which the pile sheds precipitation, thus minimizing infiltration. Difficulties in implementing this type of pile include nonuniformity of the groundwater flow gradient over the length of the pile; the increased volume of cover relative to the encapsulated volume; and the absence of a topslope where very low permeability elements may be used to limit infiltration.

3.5 EVALUATION OF POTENTIAL FOR GROUNDWATER COMPLIANCE

Several disposal cell designs and covers should be evaluated for each selected disposal site. Designs should be compared with relative costs to determine the most cost-effective design that is most likely to comply with the EPA groundwater protection standards. Specifically, long-term seepage through the disposal cell cover and transient drainage of tailings fluids or water used during construction, as well as other groundwater design considerations, must be evaluated in determining the potential for compliance with the groundwater protection standards.

3.5.1 Steady state seepage

Long-term seepage rates through the disposal cell are generally related to infiltration through the disposal cell cover. It is necessary to investigate the aquifer parameters and chemical transport properties to determine what long-term seepage rate will allow compliance with the EPA groundwater protection standards. A cover design that provides sufficient reduction in seepage will be selected (see Section 3.3). Measurements of aquifer parameters and transport properties and methods of calculating long-term seepage through the disposal cell are provided in Section 8.0.

At sites where the full component cover is proposed it is not possible to state definitively a single value for the flux through the cover. The DOE considers that inherent uncertainties in the individual performance of the separate components of the full component cover, and uncertainties regarding the interaction or synergistic effects of the various cover components, make it

necessary to consider a range of possible infiltration fluxes through a full component cover.

The actual flux through a full component cover is likely to vary from about 1 x 10^{-8} centimeters per second (cm/s) to less than 1 x 10^{-9} cm/s. The DOE considers that it is not possible to establish the actual operative flux for a specific case. Variations in materials, the performance of the individual cover components, the configuration of the cover geometry, and the interaction of site climate and cover response make it theoretically impossible to establish a single point value for the flux. In reality there is some (as yet undetermined) probability distribution curve for the flux through a full component cover.

Neither the DOE nor anyone else has technical data to support a proposed probability distribution curve of flux through a full component cover. It is probably not possible to establish analytically or by testing the range and distribution of flux through a full component cover; it is also probably not necessary as long as the assessment of the performance of a disposal cell considers the range of possibilities and establishes a suitable groundwater compliance strategy for reasonable water fluxes.

The DOE proposes that the "likely operative water flux" through a full component cover will be 2 x 10^{-9} cm/s. As the term for this flux implies, it is the most likely value for the seepage rate through the full component cover. There is a small possibility that the actual flux will be less, and there is a possibility that the flux will be more. The likely operative water flux is proposed as 2 x 10^{-9} cm/s because this is the test hydraulic conductivity of the lowest permeability element in the cover, i.e., the CLAYMAX^{R}. (See DOE, 1989b for test data.) The possibility for greater fluxes arises because of the limited chance that precipitation and/or snowmelt will actually seep through the overlying soil before it is evapotranspired, and thus increase the hydraulic gradient across the bentonite mat to a value greater than unity. Assessment of the way in which a disposal cell complies with the EPA groundwater protection standards will consider the range of possible fluxes.

The DOE proposes that 5 x 10^{-9} cm/s be used as a conservative average water flux through the full component cover. It is at least conceivable that the actual flux through the cover is equally likely to be greater than or less than this flux. It is also realized that actual cover flux will vary above and below the average depending on seasonal variability. This value is proposed because it represents a rounded value of overall flux through a CLAYMAX layer. Approximately five percent of the CLAYMAX layer is considered to be inoperative, and is underlain by and interacts with a radon barrier with a hydraulic conductivity of 1 x 10^{-8} cm/s, a reasonable value for a partially saturated soil at the base of a full component cover.

The DOE proposes that the upper bound value of the water flux through a full component cover be 1×10^{-8} cm/s. While it is conceivable that that the actual flux could be greater, the DOE considers the possibility very small.

As with the full component cover, it is not possible to state definitively single values for fluxes through the three different sideslope covers. The DOE considers that inherent uncertainties in the individual performance of the separate components of the sideslope covers make it necessary to consider a range of possible infiltration fluxes through the sideslope covers. The actual fluxes through the standard and double drain sideslope covers are based on the permeability of the lowest permeability layer (i.e., the infiltration/radon barrier) and are likely to vary from about 1×10^{-7} cm/s to 1×10^{-9} cm/s. As with the full component topslope cover, the DOE considers that it is not possible to establish actual operative fluxes for specific cases. There are some (as yet undetermined) probability distribution curves for the fluxes through the two sideslope covers.

The DOE has no technical data to support proposed probability distribution curves of flux through the standard and double drain sideslope covers. It would be very difficult to establish analytically or by testing the range and distribution of fluxes through these covers. It is also probably not necessary as long as the assessment of their performance considers the range of possibilities and establishes suitable groundwater compliance strategies for reasonable water fluxes.

The DOE proposes that the "likely operative water flux" through the standard and double drain sideslope cover will be designated on a site-specific basis. The designated value will be based on the unsaturated hydraulic conductivity of the lowest permeability layer at a conservative anticipated operative moisture content (i.e., the infiltration/radon barrier). There is a possibility that the actual flux will be higher and a possibility that it will be lower than the selected design unsaturated hydraulic conductivity. The variability will depend upon the properties of the barrier material and the site-specific climatic conditions.

The DOE proposes that the conservative average water flux through the standard sideslope cover be considered equivalent to the saturated hydraulic conductivity of the lowest permeability layer. The actual value will be obtained from test data and will represent the harmonic mean saturated hydraulic conductivity. In general, the conservative average water flux will vary from 10^{-7} to 10^{-8} cm/s.

The conservative average water flux for the double drain sideslope cover will be the harmonic mean saturated hydraulic permeability based on actual test data for the saturated hydraulic conductivity of the lowest permeability layer.

The DOE proposes that in the absence of specific laboratory and field test data to confirm a lower value, the upper bound value of the water flux through a standard and double drain sideslope cover be set at 1×10^{-7} cm/s. This value is considered to be a reasonable value that is relatively easily achieved in the field with normal soils. It is conceivable that the actual flux could be greater; however, the DOE considers the possibility is very small.

3.5.2 Transient drainage

The period between the completion of construction and the establishment of equilibrium moisture content and seepage conditions is considered to be the period of transient drainage. With time, the excess moisture initially in the tailings and contaminated materials will drain and the long-term or equilibrium moisture conditions will be established. The equilibrium moisture content may be less than the initial moisture content.

The seepage rate from the disposal cell during the period of transient drainage may exceed that which will occur under steady state conditions. If the transient seepage rate does not cause an exceedance of MCLs, or the applicable site groundwater protection standards at the point of compliance of the facility, the steady state or equilibrium condition governs the choice of the disposal cell groundwater compliance strategy. If the transient seepage rate could cause exceedance of MCLs, or applicable standards, appropriate technical approaches or groundwater compliance strategies must be adopted; for example, it may be necessary to dry the contaminated materials before completion of the disposal cell, or a case for ACLs for transient drainage may have to be established. (Refer to DOE, 1989d, for a more complete discussion of transient drainage and its impact on disposal cell design.)

Analysis

If the tailings will be stabilized in place, the analysis of transient drainage starts with a determination of the current in situ moisture content of the tailings. Next, it is necessary to establish by laboratory testing the relationship between the moisture content of the tailings and the partially saturated hydraulic conductivity. The long-term moisture content or specific retention must be determined. Conventional analyses of the steady state seepage through the disposal cell will be completed in order to establish the equilibrium or long-term moisture content of the materials in the disposal cell (including the cover, the tailings, the contaminated materials, and possibly the liners or their equivalents).

If the following materials are relocated (both for pile stabilization in place or on site), water may be added to achieve desired in-place densities. In order to achieve proper compaction

3.5.3 Other compliance considerations

While steady state seepage and transient drainage affect concentrations of hazardous constituents in groundwater, other groundwater factors must be considered in the design as they influence the longevity requirement of the disposal cell and protection of human health and the environment or other applicable state standards.

The depth to groundwater is important in that maximum fluctuations of the water table should not extend into the foundation of the disposal cell. If the water table inundates the contaminated materials, hazardous constituents may be leached at a rate that is substantially greater than the long-term seepage rate from the pile. Furthermore, the inundated materials may create stability problems or a liquefaction potential.

The hydraulic conductivity of the foundation materials should be adequate to accept seepage from the disposal cell as unsaturated flow. This will prevent the perching of seepage at the contact between foundation materials and the pile and, thus, the creation of a surface water seep. Similarly, the redistribution of moisture within the materials should be predicted to make certain that surface water seeps do not develop from the creation of a phreatic surface within the pile. If the materials are placed wetter than specific retention or will drain in such a fashion that a phreatic surface develops within the pile, a liner will be required. Where the subpile foundation materials are very permeable, it may be necessary to place a layer of lower-hydraulic conductivity materials so that travel time to the water table is increased. In some cases, the use of a liner under unsaturated conditions may allow the disposal cell to comply with the EPA groundwater protection standards based on the principle that the travel time to the point of compliance in groundwater is roughly equivalent to the longevity requirements. However, the hydraulic conductivity of the underliner of the disposal cell must be designed so that there is no surface expression of perched seepage.

Under some circumstances, a geochemical underliner may be necessary to allow compliance with the groundwater standards. The geochemical liner could either be constructed as a layer or a geochemical sump into which seepage drains. Hazardous constituents with the potential to exceed concentration limits in groundwater could either be adsorbed onto the geochemical liner matrix, be chemically reduced, or be precipitated as a result of neutralization. The potential for the use of geochemical modification of tailings seepage has been assessed in two DOE special studies (DOE, 1989a; DOE, 1989b). The addition of geochemical layers must not adversely affect the geotechnical stability of the disposal cell.

3.6 CELL FOUNDATION CONSIDERATIONS

Another disposal cell design concern is the placement of the cell foundation, i.e., above or below grade. The depth to bedrock, depth to groundwater, proximity to an existing pit, availability of cover soil, possible use of excavated soils as restoration material, geomorphic stability, and availability of rock for erosion protection should be considered when locating the disposal cell. The relative importance of these considerations is site specific and should be compared for the most cost-effective design.

of tailings, the moisture content of the tailings must be at or close to the optimum moisture content. The optimum moisture content of a material is that moisture content at which, for a given compactive effort, the maximum density is achieved. Tailings such as slimes may be wetter in situ than their optimum moisture content and therefore will have to be dried prior to placement. Sandy tailings may be drier than their optimum placement moisture content, and it may be necessary to add water to them before compaction.

Materials may be compacted into place dry or wet of the optimum moisture content. Practical construction moisture contents may be higher than the long-term equilibrium moisture content of the materials.

In order to reduce the quantity of construction water seeping from the tailings, the tailings, when relocated, are placed at as dry a moisture content as is technically consistent with attaining densities that ensure the integrity of the disposal facility. The following test data should be obtained to calculate possible transient seepage from the tailings:

- Compaction moisture density relationships.
- The relationship between the moisture content and the partially saturated hydraulic conductivity.
- The long-term equilibrium or gravity-induced drainage moisture content of the tailings.
- The collapse potential of tailings as a function of placement density.

At some sites it may be possible to limit the placement percent saturation of the materials so that the unsaturated hydraulic conductivity is similar to that of the cover. If this is not possible, transient drainage will be modeled to determine what percent saturation will allow compliance with MCLs or applicable groundwater protection standards.

To assure that the required moisture content in the contaminated material is achieved during construction, the placed materials must be monitored. Instruments are available that can be inexpensively installed and that provide instantaneous determination of soil moisture. By monitoring instruments installed in the pile as construction proceeds, the contractor can control moisture added to specified tolerances. Direct measurement of water used for construction (including dust control and compaction) is not appropriate because it is not possible to determine how much infiltrates and how much is lost to evaporation. Because the piles will be graded during construction to promote runoff and will be covered by geomembranes during long periods of shutdown, water from precipitation events infiltrating into the

pile during construction will be relatively minimal and will not significantly affect either transient or long-term seepage from the pile.

With the above parameters and others that may be needed for a particular computer code, the rate and the period of steady state drainage may be calculated. Conventional computer codes such as UNSAT2, HELP, SUTRA, or SPLASHWT2 may be used. By evaluating the impact of the transient seepage from the base of the disposal cell on the groundwater beneath the site, the potential for exceeding the MCLs may be established. If the transient seepage rate is likely to cause an exceedance of the MCLs or the applicable site groundwater protection standards at the point of compliance, it will be necessary to adopt one or more of the technical or compliance strategy approaches discussed in Section 13.5.

It is possible that during construction of a disposal cell that incorporates relocated materials, the moisture content at the end of construction may, in spite of the best efforts of all concerned, exceed the moisture content at which transient drainage will not cause an exceedance of MCLs or background levels. In such a case it may be necessary to reevaluate the technical solution and the groundwater compliance strategy for the facility. In practice, there is no difference between such a situation and the situation of a pile stabilized in place that has an unacceptably high initial moisture content. Accordingly, such situations may be evaluated and dealt with according to the procedures described in this section for piles stabilized in place.

Alternatives for compliance

If the transient seepage could lead to an exceedance of the groundwater protection standards at the point of compliance of the facility, one or more of the following technical approaches may be adopted to reduce the moisture content of the pile and hence to achieve MCLs or the appropriate site standards during the period of transient drainage:

- Change the pile remedial action plan, and relocate the materials to another site.
- Alter the in situ moisture content of the materials by artificially induced drainage (using well points, horizontal drains, or electro-osmosis, for example).
- Pick up and dry the materials to a moisture content consistent with their long-term equilibrium condition.

REFERENCES FOR SECTION 3.0

DOE (U.S. Department of Energy), 1989a. Moisture Contents and Unsaturated Conditions in UMTRA Project Radon Barriers, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1989b. Summary Report on Geochemical Barrier Special Study, UMTRA-DOE/AL-400643.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1989c. Source Modification Special Study, UMTRA-DOE/AL-400653.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1989d. Remedial Action Planning and Disposal Cell Design, UMTRA-DOE/AL-400503.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

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4.0 COVER DESIGN

The cover of the stabilized pile is the key element in meeting the performance criteria established by the EPA in 40 CFR 192. Although site geological and geotechnical stability are critical, the cover design must be adequate so that the 200- to 1000-year longevity criteria are met and the performance of the disposal cell will not deteriorate excessively over its design life. In order to achieve these objectives, the cover must be designed to (1) protect against erosion from surface water and wind; (2) meet the longevity criteria (through the use of natural materials); (3) protect against biointrusion; and (4) protect against infiltration for long-term compliance with the groundwater standards.

Two different approaches, or cover systems, to meet the above design considerations have been developed: rock and vegetated covers. Rock covers are the most cost-effective design for arid sites where unsaturated conditions occur in the cover and where rock is readily available. Vegetated covers will transpire water out of the cover system, achieving low moisture fluxes through the cover. The components of each cover system are combined to meet all of the design criteria. The previous section detailed the selection process and criteria for choosing the type of cover system; this section details the methods for designing each cover component.

4.1 SURFACE WATER HYDROLOGY

4.1.1 Introduction

The principal design objective of the UMTRA Project is to provide engineering designs that, with reasonable assurance, meet the long-term containment and stability requirements of the EPA standards. One of the most disruptive natural phenomena affecting long-term stability is water erosion. It is therefore important that the RAP contain sufficient hydrologic site characterization to evaluate long-term erosion protection adequately.

The purpose of this section is to describe the design procedures related to this aspect of remedial action at UMTRA Project sites. This discussion is not concerned with the impacts of surface water drainage during construction. Construction procedures not affecting the final design are not addressed in this document.

4.1.2 Design sequence

A determination of the hydrologic impacts to any site requires an assessment of several design situations. These design situations involve impacts to the stabilized tailings pile as a result of the following:

- Runoff across the top and sideslopes of the pile from intense, local precipitation events.

- Runoff from small upland watersheds.
- Flooding from nearby large streams or rivers.
- Human-related discharges.

The following steps are essential for an adequate evaluation of hydrologic impacts:

- Collection and review of available data.
  - Topographic and soil survey maps.
  - Aerial photographs.
  - Records from nearby stream gauges and weather stations.
  - Any existing flood studies for the same or nearby drainage areas.
  - Present land use and future land use plans.
  - Vegetation and soil infiltration characteristics.
  - Location of existing water control structures including design and operating characteristics.
- Field investigation.
  - Discussion with local authorities of present and future land use plans if necessary.
  - Identification of size and location of existing water control structures including design and maintenance information.
  - Estimation of cross sections of stream or drainage routes at selected locations in drainage basin.
  - Observation of vegetation, soil, erosion, and deposition characteristics of drainage area, especially nearby streams.
- Hydrologic description of the site.
  - Identification of the relationships of the site to surface water features in the site area.
  - Identification of mechanisms such as floods and dam failures that may require the implementation of special design features.

- Alternative designs to a remedial action designed for a lesser event are uneconomic or are technically unfeasible.

- A complete and reasonable design cannot be implemented. (Show that alternative design layouts have been considered and cannot be implemented for valid technical reasons.)

- It is technically unfeasible to provide secure engineering features for the PMF, whereas this is possible for a lesser event.

- Materials that are able to meet design requirements are not readily available.

The NRC has recognized that it may not be possible to design for the PMP and PMF and has proposed a step-by-step procedure to determine if erosion protection is cost-effective. This step-by-step procedure is as follows:

Step 1. Identify the least expensive of several remedial action designs and design configurations that could be implemented to withstand the PMP/PMF.

Step 2. Identify the erosion protection costs associated with the least expensive design that will be capable of withstanding the PMP/PMF. Costs should be broken down by unit cost and total cost in the following categories:

- Erosion protection for top of pile.

- Erosion protection for sides of pile.

- Erosion protection for aprons/toes.

- Erosion protection for drainage and diversion channels.

- Erosion protection for banks of large adjacent streams.

- Earthwork and miscellaneous features needed specifically for erosion protection.

Step 3. Identify the costs associated with moving to the least expensive alternate site where protection can be provided (cost breakdowns included as above).

Step 4. Identify rock sources readily available in the site area that could be used at a cost savings. (Several sources should be identified and compared for cost, rock size availability, and durability.)

Step 5. Determine the magnitude of the flood (and the percentage of the PMP/PMF) that a less expensive rock source and design will withstand. The analysis should assume designs and computational methods similar to the designs and computational methods employed in Step 1, and should assume that the less expensive erosion protection design will be used.

A plot should be developed to show graphically the relationship of erosion protection costs versus the percentage of the PMP/PMF that can be withstood. If a well-defined "break point" exists in the graph where the costs increase dramatically as a result of an increase in the flood discharge, this break point may provide a reasonable basis for determining an appropriate flood magnitude for design.

Step 6. Fine-tune the design, as necessary, and determine the erosion protection costs associated with the less expensive design in each of the categories identified in Step 3.

Step 7. Compare the total costs of the project and the costs of the erosion protection. In order to determine if the costs of providing erosion protection to withstand the PMP/PMF are clearly excessive, the following minimum criteria are suggested:

- The costs of erosion protection for the PMP/PMF design significantly exceeds the average cost for other similar sites.
- The costs of erosion protection for the PMP/PMF design, as a percentage of the total project cost, is significantly greater than the average percentage for other similar sites.
- A significant savings results from using the less expensive design.

Step 8. Demonstrate that EPA standards are met by the reduced design. Information and analyses that should be provided include the following:

- Drawings and supporting hydraulic calculations for each design analyzed.
- Backup calculations that provide the bases for the cost estimates identified for each design analyzed.
- Supporting hydraulic calculations for determination of PMP/PMF and selected design flood.
- Supporting logic and databases which document that the design selected meets, or exceeds, EPA longevity criteria including required maintenance or possible repairs resulting from the "lesser events" used for design.

- Flooding determinations.
  - Selection of a design flood event that will meet EPA standards.
  - Assessment of the precipitation potential, precipitation losses, and runoff response characteristics of the watershed.
  - Determination of the critical water levels and velocity conditions at the site due to the design flood event runoff occurring off the pile, from small upland watersheds, or from large nearby streams.
- Geomorphic considerations.
  - Identification of types of geomorphic instability as defined by Section 5.2, Geomorphology.
  - Assessment of potential changes and impacts to predicted flood levels and velocities due to geomorphic changes.
  - Evaluation of mitigative actions for erosion protection design that will reduce or control any geomorphic instability.
- Dam failure considerations.
  - Initial assessment of documentation that any upstream reservoir structure has been, or will be, designed for seismic and hydrologic events that are equivalent to the remedial action site design event. If this documentation is obtained, then dam failure and flooding analyses may not need to be performed.
  - Assessment of longevity of structure.
  - If necessary, the assessment of potential hazards due to a failure of upstream water control structures from seismic or hydrologic causes, resulting in the determination of critical water levels and velocity conditions at the site.
- Erosion protection design.
  - Summary of the flooding and water erosion conditions for each design situation to determine critical condition(s) for cover design.
  - Assessment of erosion protection requirements according to methodologies outlined in Sections 4.2.1 and 4.3.3.
  - Evaluation of the capability of achieving long-term stabilization with erosion protection designs that are economically feasible.

- Assessment of potential reductions in design criteria while still meeting EPA standards, should the cost of erosion protection be clearly excessive.

4.1.3 Methodology and analysis

Design event selection

In providing engineering designs for long-term performance to meet EPA standards, the selection of the design precipitation and flood event is critical. The selection should not be based on the statistical extrapolation of limited databases, due to the unknown level of accuracy involved with such estimates. However, the Probable Maximum Flood (PMF) and the Probable Maximum Precipitation (PMP) are based on site-specific physical meteorological limitations that eliminate the uncertainties associated with extensive extrapolation of limited databases. Therefore, the use of these phenomena for the long-term design of reclamation covers provides an acceptable design basis.

It is recognized, however, that many existing uranium mills are poorly sited; some are immediately adjacent to rivers with a high potential for extensive erosion. For these sites, the PMF forces may be so large as to preclude economical long-term stabilization. In these cases, it is concluded that a flood smaller than the PMF may be considered if it is documented that: (1) implementation of a design to protect against the PMF is clearly impractical; and (2) the design chosen meets EPA criteria.

In determining what constitutes "clear impracticality," each case will be considered on its merits. In considering the factors that may constitute clear impracticality, the following definitions are adopted:

A Lesser Event. A precipitation event or flood smaller than the PMP or PMF for which the probability of occurrence during the design life of the project (200 years and, where possible, 1000 years) is greater than 10 percent.

Uneconomic. It will cost between 15 and 20 percent more to design for a PMF than to adopt a design suitable for a lesser event unless the total cost difference is relatively small.

The following are considered to be factors that singly or in combination could constitute a case of clear impracticality:

- The precipitation event or flood has less than a 10 percent chance of occurring during the project design life, and the damage to the pile will not cause loss of life, will not result in significant dispersion of the tailings, and will cause only damage that can be repaired within the project surveillance and maintenance program.

PMP determination

Prior to determining the runoff from the design drainage basin, the analysis requires determination of the PMP amounts and hydrographs for the various regions in the drainage basin. Techniques for determining the PMP and the resulting hydrograph have been developed for the entire United States primarily by the National Oceanographic and Atmospheric Administration (NOAA, 1977a,b,c) in the form of hydrometeorological reports for specific regions. These techniques are commonly accepted and provide straightforward procedures with minimal variability.

Hydrologic modeling

Determination of runoff is dependent on several factors, many of which require engineering judgement. Due to the lack of a standard, numerous methods and models for determining runoff have been developed. Several of the methods available may be applicable to a particular drainage basin and it is up to the design engineer to choose the most applicable, based on the degree of accuracy desired and the size of the drainage basin.

Runoff across the top and down the sides of the tailings pile. Procedures for determining the amount of PMP runoff from the stabilized tailings pile are contained in Section 4.2.1, Erosion protection.

Small upland watersheds. Drainage from small watersheds upland of the tailings piles is controlled by either of two methods. The runoff is allowed to drain around an embankment in direct contact with the sideslope or is controlled with on-site drainage diversion channels. In either case, adequate erosion protection must be afforded to ensure long-term stability of the cover system.

For small watersheds, two methods are employed at UMTRA Project sites to determine the design runoff discharge:

1. The Rational Method (AISI, 1971).

$$Q = CiA$$

where

Q = peak rate of runoff (discharge).

C = weighted runoff coefficient.

i = average intensity of rainfall; see Section 4.21, Erosion protection, for determination of this parameter.

A = drainage area.

If Q is expressed in cubic feet per second, i in inches per hour, and A in acres, then C is approximately 1.0 for the PMP condition.

The Rational Method is a widely used and misused method for determining peak runoff. It is well known that the Rational Method should be applied only to relatively small drainage basins. It is generally believed that the assumptions made in applying this method do not involve serious errors for areas less than 200 acres. This method is generally used for quick estimates on rough conceptual designs.

2. The "Santa Barbara Method," a linear reservoir routing technique (Stubchaer, 1975), using Green-Ampt infiltration parameters (Sabol and Ward, 1985). Final design may require independent confirmation of results using other methods such as those used by the U.S. Soil Conservation Service or U.S. Army Corps of Engineers for a variety of watersheds.

   When refinement of runoff and hydrograph information is necessary for detailed conceptual design, this method is more appropriate and sophisticated yet simple to use. The method is limited to drainage areas up to 500 acres. Under this method, rainfall is subjected to infiltration losses, the magnitude of which depends on antecedent rainfall conditions. The resulting rainfall excess is multiplied by the watershed area to obtain an instantaneous hydrograph that is routed through an imaginary linear reservoir with a routing constant equivalent to the time of concentration to obtain the final hydrograph.

   All rainfall losses are compared to precipitation such that losses are less than or equal to precipitation. Soil infiltration is accumulated after each specified time step; therefore, the Green-Ampt infiltration equation accounts for soil moisture and the resulting infiltration rate is a function of the existing soil moisture conditions. In order to obtain conservative discharge estimates it is assumed that the watershed soils are initially close to saturation.

It is recognized that there are sites with upland watersheds exceeding 500 acres that do not have well-developed stream tributaries. For these cases, hydrologic modeling using U.S. Soil Conservation Service (SCS) hydrograph methods with stream routing (as discussed in the next section) is more applicable.

Large stream tributary impacts due to flooding. Flooding impacts from large nearby streams or rivers can prove to be the most destructive to UMTRA Project sites in major floodplains. The watersheds for these sites can be as large as several thousand square miles. The PMP can result in flood flows that completely surround

entire floodplain and should be perpendicular to the anticipated flow lines. Occasionally it is necessary to lay out cross sections in a curved or dog-leg alignment to meet this requirement. Every effort should be made to obtain cross sections that accurately represent the stream and floodplain geometry (COE, 1982). Ideally, two-foot contour maps would be used; however, these are not always available. In lieu of this, U.S. Geological Survey 7.5- or 15-minute quadrangle maps, in addition to field observation, must be relied upon.

It is recognized that (as discussed in the next section on geomorphic considerations), due to the longevity requirements of design and the magnitude of PMF erosive forces, there is no guarantee that the existing boundary geometry will be a reasonable representation of future conditions. Therefore, design considerations are implemented that attempt to compensate for these uncertainties.

- Roughness coefficient. Values of roughness coefficients (Manning's "n") are specified for channel and overbank areas.

  Values of Manning's roughness coefficients are varied to account for conveyance differences and to impose constrictions where topography alone would not adequately define flow paths. Commonly used ranges of "n" values are given in Chow (1959). Some variance from this rule occurs in order to achieve reasonable conveyance values for differing topographic conditions along the profile. Also, equations have been developed by the COE (1970) that can be used to relate the depth of flow to rock size (see Equation 8 in Section 4.2.1).

Geomorphic considerations. When dealing with the EPA longevity requirement, a design that considers flood encroachment only for existing conditions is not sufficient. The design philosophy for long-term control must also consider that geomorphic changes could have a profound effect on the hydraulic conditions at a site and create a condition in variance to existing conditions.

The primary geomorphic concern with long-term stabilization of sites in floodplains is the potential for lateral movement of a stream channel, causing undermining or erosion of the tailings impoundment. Stream channel migration can occur gradually during the design life of the containment. A more severe situation that can occur, however, is a rapid channel shift in response to a major flood event. The impacts caused by geomorphic changes will depend, to a great extent, on the flows of the river, the velocities associated with those flows (particularly at the site), the extent to which significant erosion can occur, and the mitigative procedures provided to control or reduce erosion.

Depending on the geomorphic hazard evaluation discussed in Section 5.2, it may be necessary to compute water surface profiles and flood velocities with revised boundary geometry to model the sensitivity of geomorphic changes. It is recognized that considerable judgement must be used to determine long-term geomorphic instability and the potential effects of such instability on the remedial action design. The acceptability of any design considerations provided to mitigate geomorphic effects on the flood protection design depends on the conservatisms in the analysis and the sensitivity of the various parameters in the analysis.

Dam failure modeling. As stated previously, if it can be documented that a reservoir has been, or will be, designed for the dam site equivalent of the remedial action site design earthquake and the PMF, no flooding analyses due to an upstream dam failure need be performed. For these cases, the normal flood analysis for the drainage basin is performed conservatively assuming no storage effects from existing reservoirs.

If an upstream dam failure analysis is deemed necessary, then the "worst conditions" that will be postulated in the analysis are: (1) an approximate 25-year flood on a normal reservoir pool level coincident with the dam site equivalent of the earthquake for which the remedial action project is designed; (2) a flood of approximately one-half the severity of a PMF on a normal reservoir pool level coincident with the dam site equivalent of one-half of the earthquake for which the remedial action project is designed; and (3) a PMF (or design flood) on a normal reservoir pool.

Conditions (1) and (2) are applied when the dam is not designed with adequate seismic resistance; condition (3) is applied when the dam is not designed to store or pass the design flood safely. In most cases, it is much easier to perform simplified flood analyses assuming a dam failure, rather than detailed analyses of the seismic resistance of a dam.

The following is presented as a step-by-step analysis procedure for dam failure analysis:

1. Assume an instantaneous failure (complete removal) of the dam embankment and compute the peak outflow rate in accordance with methods such as those given by Henderson (1971). If this outflow rate is less than the design flood rate, no additional analyses will be performed.

2. If the instantaneous dam failure flow rate exceeds the design flood rate, a second, possibly more realistic, method of computing the peak outflow is to assume that the entire volume of the reservoir is emptied in the time that it takes the dam failure flood wave to travel upstream along the reservoir length. Methods for determining upstream wave velocity are discussed by Henderson (1971).

the pile and rise as high as 10 feet up the side of the embankment. In some cases, this may be a reason to relocate the pile to an alternate site; at others, special design features may be necessary to ensure adequate long-term protection.

The most common and widely used technique for computing the magnitude of the PMF for large drainage basins involves the use of the U.S. Army Corps of Engineers HEC-1 model (COE, 1981). The HEC-1 model is designed to simulate the runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. This model can be used for watersheds of a few hundred acres to as large as several thousand square miles.

The confidence level of flood estimates from this or any other model is a matter of engineering judgement. It is primarily based upon the amount of available watershed data, the degree of conservatism in each parameter used in the estimate, and the relative sensitivity of each parameter as it affects the flood levels or flood flow velocities.

Three major input parameters are estimated in order to model the basin:

- PMP amount and temporal distribution. Determination is according to procedures outlined in the appropriate hydrometeorological reports. The PMP amount and temporal distribution will vary greatly depending on the size and shape of the drainage basin and differences in precipitation potential across the basin if the basin is sufficiently large.

- Lag times or runoff within the basin. Lag times for subbasins throughout a watershed are typically computed using the lag time empirical relationship contained in Design of Small Dams (DOI, 1977). Experience has indicated that this relationship generally gives longer, less conservative lag times than those that might actually occur during a PMF. The approach of the UMTRA Project is to calculate initial lag times with the above-stated relationship. The resulting peak flows for each subbasin hydrograph are used with Manning's equation to determine a better estimate of channel velocities. The velocities are used to recalculate the routing lag times.

- Retention loss rate of precipitation within the basin. This loss rate is highly variable depending on the vegetation and soil characteristics of the watershed. Soils in any watershed are classified by the SCS into four hydrologic soil groups. Each soil group has recommended ranges of minimum infiltration rates after saturation depending on vegetation characteristics. The SCS runoff curve numbers or uniform loss rates can then be selected using this information tempered with engineering judgement. This selection can be

greatly aided with recommendations from local and Federal agencies concerning site-specific information for the drainage basin involved.

Hydraulic modeling

Once the design flood amounts have been estimated, it is necessary to determine the flow depths and velocities in order that adequate flood protection can be designed. Three conditions are considered; these are discussed further below.

- o Overland flow depth and velocity off the tailings embankment.
- o Depths and velocities of flow confined against the embankment or within on-site drainage channels due to pile and upland watershed runoff.
- o Depths and velocities of flow against the tailings embankment due to flooding of a large adjacent stream.

Overland flow off the tailings pile. Procedures for estimating the depth and velocity of flow off the top and sideslopes of the pile are contained in Section 4.2.1 of this document.

Concentrated on-site drainage flow. As stated previously, this type of flow is the result of combined runoff from the pile and any upland watershed area. Depending on the site-specific design, this flow may (1) be confined to diversion drainage channels adjacent to the stabilized embankment, or (2) be allowed to flow directly against the embankment as it drains off the site. In either case, the depths and velocities of flow can be determined using Manning's formula (COE, 1970).

Large stream drainage flows. Once the HEC-1 hydrologic modeling has been completed and the PMF determined, the analysis involves the consecutive use of the U.S. Army Corps of Engineers HEC-2 model (COE, 1982). The HEC-2 model is useful for determining stream hydraulics resulting in water surface elevation and velocity gradients at a tailings site.

The primary input parameters for this model are as follows:

- o Boundary geometry. Boundary geometry of the floodplain is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths).

  Cross sections are located at intervals along a stream to characterize the flow-carrying capability of the stream and its adjacent floodplains. They should extend across the

If this average outflow rate is less than the peak flood rate, no additional analyses will be performed.

3. If the simplified analysis indicates a potential flooding problem, the analysis will be repeated using more refined techniques. Detailed failure models, such as those of the U.S. Army Corps of Engineers (COE, 1981) and the National Weather Service (Fread, 1984), will be used to estimate the outflows, various failure modes, and resultant water levels at the site from the routing of the failure hydrograph.

As discussed previously, a flood less severe than the PMF may be acceptable in those cases where it can be documented that it is clearly impractical to design for a dam failure due to a PMF and that the design will meet EPA criteria.

Design considerations

Due to the assumptions required in this analysis, uncertainties exist in both the hydrologic and hydraulic modeling. Also, geomorphic conditions can produce unpredictable results. In order to compensate for the uncertainties, the following items are implemented for the design:

- Flow characteristics are determined for flow discharges greater and less than the design PMF flow rate. This checks the sensitivity of the system to changes in hydrologic characteristics and ensures a conservative design.

- It is assumed for many large channels that during a PMF, deposition and scour will occur such that mean channel depth and velocity are approached across the entire flow width. In assessing the possible depth of scour, factors such as depth to bedrock, stream valley deposit composition, and the effect of stream meander and associated erosion will be considered.

- Mean channel depths and velocities are used for the erosion protection design. This design feature attempts to compensate for uncertainties due to geomorphic effects.

- Riprap protection is provided to bedrock or to depth of scour, or provided as a thickened apron with sufficient quantity to extend to bedrock or scour depth if undercutting occurs. Riprap provided as a thickened apron is designed for the mean channel depth and velocity using an assumed 2:1 sideslope for the potential undercut condition.

- Sensitivity analyses of the required rock size are also performed by varying the energy gradient to ensure a conservative design.

- The riprap design is based on the Safety Factors Method as discussed in Section 4.2.1.

4.2 ROCK COVER DESIGN

It is extremely important that rock covers be designed to maintain their integrity for the design life of the facility (200 to 1000 years). Processes that threaten the integrity of the cover are wind and water erosion, degradation of rock materials, cracking of the soil due to desiccation, invasion by roots from plants or trees, and animals burrowing into the soil. Rock used in the design of the cover is usually defined by the median particle size. However, in order to define the size of rock required better, the maximum and minimum rock sizes as well as the grading of the material have been incorporated into these procedures.

Depending on the erosive forces for a particular site, a single rock layer may have the proper size and gradation to meet the criteria for erosion protection and also serve as a filter/bedding layer for the radon barrier. In general, however, it will be necessary to have an intermediate sand or gravel layer to protect against erosion of the radon barrier due to transport of soil particles through the rock cover.

The design of a rock cover system that will be effective for a specific site requires consideration of each of the following factors:

- Grain size of radon barrier.
- Particle size and durability of available rock.
- Velocities of runoff and floods coming in contact with cover.
- Type of vegetated cover that may invade.
- Wind and water erosion factors.
- Minimizing infiltration.
- Construction requirements.

The purpose of this section is to describe the design procedures that will be used for remedial action at UMTRA Project sites, in order to have a consistent design approach which can be applied on a site-specific basis. These procedures have been adopted after a careful review of existing literature and design procedures, and incorporate the most current and reliable methods.

4.2.1 Erosion protection

Before designs can be developed to meet the standards established by the EPA, methodologies must be identified. In the case of UMTRA Project sites, a design life of 200 to 1000 years without

sites, Hydrometeorological Report (HMR) No. 49 (Hansen et al., 1977) is the most appropriate. Next, the time of concentration (t_c) is determined. This can be estimated by determining the largest length of flow (L), dividing that length by 2, and then dividing that length by the estimated flow velocity (V_{est}). Once t_c is determined, this number is used as the most intense period of time for the PMP. In all cases, a time of concentration no smaller than 2.5 minutes is used. Another method available for determining the time of concentration for sheet flow off a stabilized pile is the formula proposed by Brant and Oberman (1975), shown as Equation 1.

$$t_c = C(L/Si^2)^{1/3} \qquad (1)$$

where

C = Coefficient: 0.5 for paved areas, 1.0 for bare earth, and 2.5 for turf.

L = distance of overland flow (feet).

S = slope of land (feet per foot).

i = rainfall intensity (inches per hour).

Next, the rainfall intensity is calculated using Table 4.1, an extrapolation of the values in HMR 49, based on discussion with the National Oceanic and Atmospheric Administration (NOAA) (NRC, 1985). For a six- to one-hour ratio of 1.2 to 1.3 and a curve fit of the proposed percentages, the appropriate ratio for the calculated time of concentration is chosen to calculate the intensity by using Equation 2.

Table 4.1 Incremental rainfall duration percentages

Rainfall duration (RD) (minutes)	Percentage of one-hr PMP (%)
2.5	27.5
5	45
15	74
30	89
45	95
60	100

% of one-hr PMP = RD/(0.0089 x RD + 0.0686)

$$i = PMP_{(t_c)} \times \frac{60}{t_c} \quad \text{(inches/hour)} \tag{2}$$

where

$PMP_{(t_c)}$ = the incremental rainfall amount (inches) for the time of concentration.

t_c = time of concentration (minutes).

Using the previously calculated intensity, total flow over the pile can be determined. For the case of sheet flow, the quantity of flow or discharge (Q_T) is calculated by Equation 3.

$$Q_T = CiA \tag{3}$$

where

C = constant, assumed to equal 1.0 (see Rational Method, p. 51).

i = the one-hour intensity corresponding to the time of concentration.

A = area (L x W).

If Q_T is expressed in cubic feet per second, i in inches per hour (iph), and a unit width is used, then A is equal to the length of flow (feet) and a factor of 1/43,200 is used to convert iph to feet per second.

Next, the interstitial flow in the rock layer is calculated. The interstitial flow is that portion of the flow occurring within the rock layer. To calculate this quantity, the velocity of flow is calculated first. One such equation to calculate the velocity is the one suggested by Leps (1973), which is shown as Equation 4.

$$V = Wm^{0.5}i^{0.54} \tag{4}$$

where

V = average velocity of water in the voids of the rock layer (inches per second).

W = empirical constant (33 for crushed gravel to 46 for polished marbles).

m = hydraulic mean radius.

i = hydraulic gradient (slope feet per foot).

Using W equal to 33 to be conservative since a smaller constant results in a lower velocity and thus a smaller interstitial flow, and assuming uniformly sized rock, Table 4.2 presents the factors that should be used for various rock sizes.

planned maintenance presents a unique problem. Relating the design life to probability means that if the stability period of concern is for only one year and the design is meant to withstand a 100-year event, the probability of occurrence is 0.01.

When the recurrence interval for a structure using a design life of 200 years is calculated using a level of risk corresponding to a probability of 0.10, the recurrence interval is approximately 2000 years. Clearly, there are no means available to define the methodologies needed to design for such a large recurrence interval. Also, there is no known way to extrapolate to 2000 years based on only 50 or 100 years of record. Therefore, design methods must be adopted that incorporate conservatisms into the design. The design criteria for the stability of the UMTRA Project tailings piles due to erosive forces resulting from rainfall across the top and down the sides of the stabilized embankment are based on runoff from the localized PMP. For flow occurring as a result of rainfall on the watershed above the stabilized pile, the pile is designed to resist runoff from the PMF as a result of the PMP.

The PMP is the most severe possible event that could occur as a result of combination of the most severe meteorological conditions occurring over a watershed at the same time. Although no recurrence interval can be assigned to this event (since no records are available in excess of 100 years), it is felt by most hydrologists that the recurrence interval is on the order of 100,000 years. This range may be excessive given evidence of post-glacial maximum precipitation events, as demonstrated by geomorphic conditions during the last 15,000 years. When analyzing the effects of the PMF on the design, if the cost of designing for the PMF is excessive (see Section 4.1) a storm of lesser intensity may be used as long as it meets EPA standards and justification for a lesser storm can be provided.

Erosion protection design methodology

At UMTRA Project sites where a rock cover will be used to protect the pile from erosion, the design of the cover accounts for erosive forces associated with runoff both on and adjacent to the pile. Based on the PMP/PMF for a particular site, the cover material can range from a coarse sand and gravel to large boulder riprap, depending on the size of the storm, the size of the drainage basin, and the velocities associated with the runoff. Procedures investigated for calculating the required mean rock size needed to provide a stable rock slope include those used by:

- Bureau of Public Roads (Searcy, 1967).
- U.S. Army Corps of Engineers Waterways Experiment Station (COE, 1970).
- California Division of Highways (CA-DPW, 1970).

- ASCE Task Committee on Preparation of Sedimentation Manual (ASCE, 1975).
- Bureau of Reclamation (BOR, 1958).
- Lane's Method (Lane, 1953).
- Campbell's Method (Campbell, 1966).
- Safety Factors Method (Stevens et al., 1976).
- Rockfill Hydraulic Engineering (Stephenson, 1979).

Design methods and recommendations presented in NUREG/CR-4620 and NUREG/CR-4651, which evaluated most of the above references, were also used in developing the design procedures described in the following section.

The design method most applicable to the design of a reliable rock cover for erosion protection is the "Riprap Design with Safety Factors Method" developed for the Wyoming State Highway Department by Stevens et al. (1976). The theory and formulation of this method are not discussed as part of this section since they are well documented in the published paper. This method is based on the theory of critical shear stress and allows more flexibility in design because the designer is able to choose the factor of safety needed for the design of a particular site and work through the analysis to determine the required rock size. This flexibility is particularly important when considering the conservatism associated with using the PMP as the design storm for on-pile runoff. As will be discussed in more detail in the following section, another method available for shallow flow on steep slopes is the method proposed by Stephenson (1979), based on critical shear stress and empirical solutions that take into account interstitial flow.

Since the design of rock covers for the UMTRA Project is based on the PMP, a factor of safety of 1.0 against the PMP is used. This means that the factor of safety for all other flood events is higher than 1.0. This criterion is supported by the Colorado State University Civil Engineering Group (NRC, 1983) and is presented here as one of the project design methodologies.

Riprap design for top and sideslopes

The first step in the design of the riprap layer is the calculation of the time of concentration of runoff for the most intense period of rainfall during the PMP.

The one-hour rainfall intensity is calculated by first determining the local PMP for the pile location and then determining the storm rainfall distribution using the appropriate hydrometeorological report based on geographical locations. For most UMTRA Project

Table 4.2 Empirical correlations for flow in rock

Rock size (inches)	$Wm^{0.5}$ (inches per second)
2	16
6	28
8	32
24	58
48	84

Equation 4 should only be used if the grading of the rock shows that less than 30 percent of the rock is $\leq$ 1.0 inch. If more than 30 percent of the rock is $\leq$ 1.0 inch, then the rock layer should be treated as an earthfill and interstitial flow would be negligible.

Once the velocity is calculated, the quantity of flow (discharge) per foot can be calculated by Equation 5, assuming a porosity of 0.33.

$$Q_i = VA \tag{5}$$

where

Q_i = discharge/unit width.

V = average velocity of water in voids of rock.

A = area/unit width = thickness of rock layer times the rock porosity.

If V is in units of inches per second and thickness in feet, then V must be divided by 12 inches per foot to calculate Q_i in cubic feet per second per foot.

Once the interstitial flow (Q_i) is calculated, the flow on top of the rock layer (Q) can be calculated by subtracting the Q_i from the total flow.

The depth of flow over the rock is then calculated using Manning's equation for sheet flow as shown in Equation 6.

$$Y = \left[\frac{n \times Q}{1.486 \times S^{1/2}}\right]^{3/5} \tag{6}$$

where

Y = depth of flow (feet).

n = Manning's friction factor.

Q = quantity of flow (cubic feet per second) on top of the rock layer.

S = slope of bed top or sideslope (feet/foot).

The velocity of the flow on top of the rock can then be calculated by Equation 7:

$$V = Q/A \tag{7}$$

where

V = velocity (feet per second).

A = Y x unit width (square feet).

One number critical to making the calculations is Manning's friction factor ("n"). This number is very subjective and is usually based on previous experience. Tables have been published that give values of "n" for various types of vegetation. Most of these published values are for river channels or overland flow and are difficult to apply to a pile covered with rock and sparse vegetation.

One method of calculating "n" is by a formulation developed by the COE (1970), which is related to the depth of flow and size of rock as shown by Equation 8.

$$n = \frac{R^{1/6}}{23.85 + 21.95 \log_{10}(R/k)} \tag{8}$$

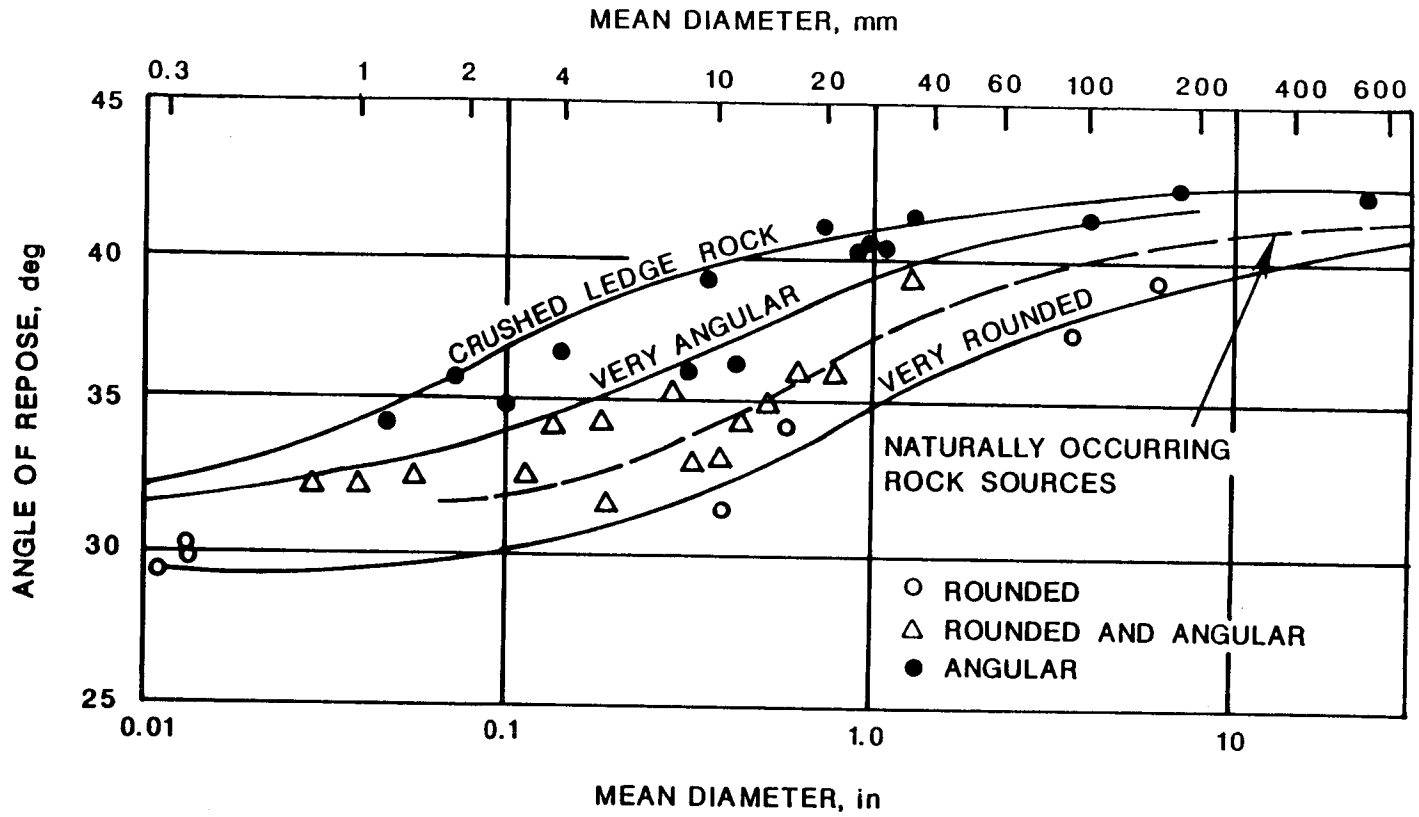
where

R = hydraulic radius or depth of flow for sheet flow (feet).

k = mean diameter of rock (feet).

For some combinations of flow depth and rock size (i.e., when the ratio becomes less than 1.0), this equation gives values of "n" that may be either too conservative or not conservative enough. Therefore, when using Equation 8, a lower bound of 0.02 and an upper bound of 0.08 for "n" should be used.

Equation 9 has been recently developed and is based on large-scale flume studies (Abt et al., 1987).



REF: NUREG/CR-4651

FIGURE 4.1
ANGLE OF REPOSE FOR ROCK OF VARIOUS DIAMETERS

where

G_s = specific gravity of the rock.

N = stability number calculated from the formulations in the Safety Factors Method.

Calculating shear stress is therefore an iterative process because first a value of K must be assumed to solve for the calculated K. The value for Y must be compatible with the corresponding design values for flow velocity and total flow rate.

For shallow flow on slopes in excess of 10 percent, i.e., sideslopes, a design method by Stephenson and described in NUREG/CR-4651 should be used. This method, based on flume studies by Olivier (1967), is an empirical solution corroborated by a series of tests in which different-sized rock layers and different slope angles (two to 20 percent) were tested to evaluate failure conditions of various sized rock and slope conditions and the factors involved (Abt et al., 1987).

Based on this work, a formulation for which rock slopes would not fail was derived. This formulation is conservative and includes a safety factor on the order of 1.2 to 1.8 depending on the input parameters.

The input parameters for this method are as follows and result in a mean rock size.

- o Quantity of flow (cubic feet per second) (Q).
- o Angle of slope (T).
- o Constant (C) (varies from 0.22 to 0.27).
- o Specific gravity (G_s) of rock to be used.
- o Angle of repose (P) of rock to be used.
- o Gravitational acceleration (g) (32.2 feet per square second).
- o Porosity (p) of rock fill.

The formulation is shown as Equation 12.

$$k = \left[\frac{Q(\tan T)^{7/6} p^{1/6}}{C g^{1/2}[(1-p)(G_s-1)\ \mathrm{Cos}\ T\ (\tan P - \tan T)]^{5/3}}\right]^{2/3} \qquad (12)$$

where

k = mean rock size, D_{50} (feet).

$$n = 0.0456\ (D_{50} \times S)^{0.159} \qquad (9)$$

where

D_{50} = mean rock size (inches).

S = slope (feet per foot).

Equation 9 was developed for the usual design range of slopes, depths of flow, and rock sizes used on tops and sideslopes of tailings piles. When appropriate, Equation 9 should be used.

Once all design parameters have been calculated, they can be input into the equations for determining mean diameter rock size. The Safety Factors Method has four sets of equations depending on the type of flow. These flow conditions are:

- o Non-horizontal flow on a sideslope.
- o Horizontal flow on a sideslope.
- o Flow on a sloping bed.
- o Flow on a horizontal bed.

Flow conditions 1, 2, and 4 are used when flood flow from the associated drainage area flows adjacent to the pile. Flow condition 3 is used for flow that occurs due to rainfall that falls on the pile and flows across the top and down the sideslopes.

Once the flow condition is determined, it is a simple calculation to determine the mean rock size (D_{50}) that will be required to protect against the PMP.

Information needed to design riprap by the Safety Factors Method is:

- o The angle of repose of rock.
- o The specific gravity of rock.
- o The slope of the bed or sideslope over which the rock will be placed.
- o Direction of flow over the rock.
- o The velocity of flow over the rock.
- o The depth of flow over the rock.

The angle of repose of the rock depends on the angularity and diameter of the rock and routinely varies from about 35 to 42 degrees, with most naturally occurring rocks falling in the range of

36 to 40 degrees as shown on Figure 4.1. This factor has a small effect on the final mean rock size; wherever data are not available, the graph shown in Figure 4.1 will be used to determine the angle of repose.

The specific gravity of a rock depends on the mineralogy and structure of the rock and can vary from 2.5 to 2.9. Where data are not available for planning purposes, a nominal estimate of 2.65 can be assumed.

The slope(s) of the bed, sides, and top will vary and will be part of the design. Typically, the topslope will be two to five percent and the sideslope will be 20 percent or less. The channel bedslope depends on the topography.

The velocity (V) and depth of flow (Y) are related to the quantity of flow (Q) that occurs either on or adjacent to a stabilized tailings pile. The method used to calculate a design value for Q is somewhat controversial for rainfall on the pile itself. The controversy is centered on whether the flow across the top of the pile and down the sideslopes is in the form of sheet flow, or whether there are flow concentrations that cause the flow per unit area to increase. The design concepts implemented on the UMTRA Project will result in a pile that, in the case of a relocated, recompacted pile, will be placed and graded in such a way that sheet flow over the pile will occur. At piles where excessive differential settlements are predicted to occur, an increase in the flow due to some flow concentration will be calculated based on the area of flow and the area of differential settlement that would contribute to the increased flow.

Another point that requires clarification is the method of calculating the shear stress for sheet flow. The most common method adopted is to use Equation 10.

$$\tau = \gamma_W R S_e \qquad (10)$$

where

τ = average shear stress acting on the wetted perimeter.

γ_W = unit weight of water.

R = hydraulic radius (depth of flow, Y, for sheet flow).

S_e = slope of energy grade line.

Mean rock size (K) is then calculated by Equation 11.

$$K = 21 \times \tau/((G_S - 1) \times \gamma_W \times N) \qquad (11)$$

If rounded rock is proposed for use as erosion protection, the calculated D_{50} should be checked against the D_{50} calculated by the procedures described in NUREG/CR-4651. In this procedure, rounded rock is oversized by approximately 40 percent with respect to angular rock.

Riprap design for ditches

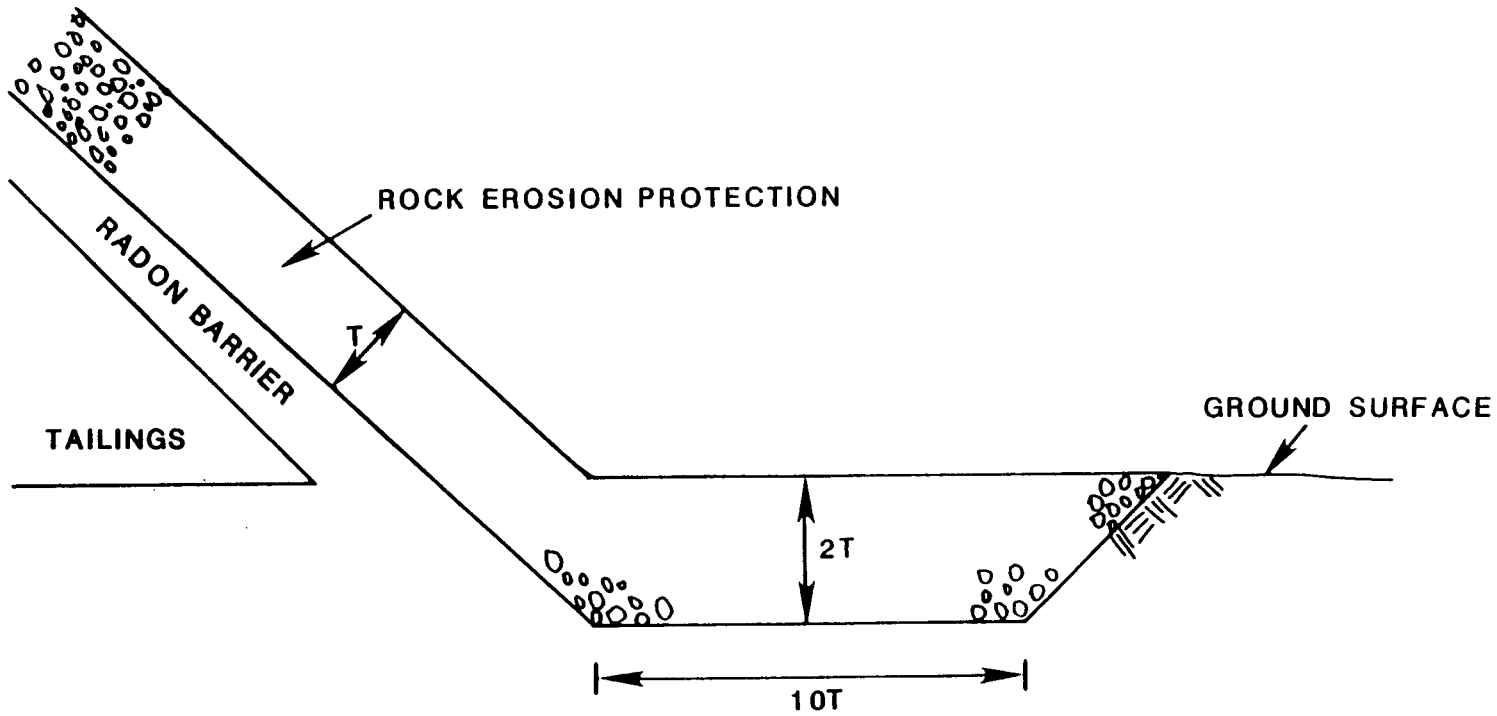
When designing erosion protection for ditches or swales, the Safety Factors Method should be used for the case of flow adjacent to a sideslope. The shear stress should be calculated using Equation 10 and using the depth of flow instead of the hydraulic radius. This results in a suitable calculation of peak shear stress for wide trapezoidal ditches. Correction factors for peak shear stress in narrow trapezoidal ditches or vee ditches should be used to avoid calculating an overconservative design shear stress in these ditches (Anderson et al., 1970). By using a trapezoidal ditch in which the bottom width is three times the depth of flow, the depth of flow approaches the hydrologic radius and there is little change in the rock size or in the amount of rock required.

Manning's "n" can be calculated using either Equation 8 or 9. There is no need to take into account interstitial flow since the flow will be insignificant compared to the flow in the ditch. The flow from the drainage basin above the stabilized pile into the ditches should be calculated using approved methods such as the Santa Barbara Method or HEC-1 models. This flow should be added to the flow from the top and sides of the pile to calculate a total peak flow that will be in the ditch. When adding flow, it is not a direct addition of the peak flows since the time of concentration (t_c) for the off-pile runoff may be longer or shorter than the on-pile runoff. To calculate the peak flow, the two hydrographs are added.

Toe protection

When ditches are not required or needed (e.g., piles where the sheet flow off the sides of a pile will continue as overland flow on the natural ground), some type of toe protection is required.

The toe protection required is somewhat subjective; however, the minimum recommended cross section based on experience and U.S. Army Corps of Engineers' literature is shown in Figure 4.2. This figure shows that the toe protection should be a minimum of two times the rock cover thickness and have a width at least five times the rock cover thickness. When designing toe protection against river flooding, scour depth must also be considered and enough material provided so that scour will not erode below the toe protection. Toe protection depth should be adequate to remain stable following any anticipated long-term erosion of adjacent natural ground.



NOT TO SCALE

FIGURE 4.2 TOE PROTECTION

Off-pile protection from gully intrusion

Geomorphic analyses may indicate the need to protect piles from gully intrusion from off the site. Methods of design are similar to those used for sizing on-pile erosion protection. Design features may take the form of the toe protection shown in Figure 4.2, or may include armoring of existing erosional features at the gully head. Modification of the width and depth of the gully may be made depending on the anticipated depth of erosion. Should off-site erosion be severe, setback distances to the pile may be designed on a site-specific basis using available geomorphic evidence of gully advancement.

Rock durability

Rock durability is defined as the ability of the material under consideration to withstand the forces (i.e., chemical or physical) of weathering. Therefore, the durability of rock riprap is a major concern in the design and long-term stability of erosion barriers. Long-term records (200 to 1000 years) of rock weathering are usually not available.

Factors that affect rock durability are the (1) potential chemical reactions with water that comes in contact with rocks; (2) amount of time that the rock is saturated; (3) temperature of the water; (4) raindrop impact and scour of sediments carried by flow against the riprap; (5) amount and velocity of windblown sand impacting the rock; and (6) effect of wetting and drying together with temperature changes. These effects become more serious in climates that experience large changes in temperature and especially in those climates with frequent freeze-thaw cycles.

One important study on weathering rates as a function of time for various rock types is a study by Colman (1981). Colman's study reviewed work by 50 researchers around the world. The study showed that as rocks weather, they tend to build up a residue or "rind" that reduces the weathering rate with time. Several other researchers have examined the thickness of weathering rinds on rocks in glacial deposits less than 10,000 years old. Included in these studies have been rocks from the Colorado Front Range and the San Juan Mountains in Colorado. The weathering rates for these rocks generally fits a square root of time or exponential function. One researcher showed that for sandstone boulders under the conditions studied, the rate of rind development occurs according to the following equation (Chin, 1981):

$$d = 0.004\ t^{0.81} \qquad (13)$$

where

d = rind thickness in millimeters.
t = time in years.

Based on Equation 13, sandstone would weather approximately seven millimeters in 10,000 years.

The implication of these studies is that laboratory tests can be extremely conservative and do not truly represent the weathering or durability of a particular rock. For design purposes, the inverse problem exists, i.e., predicting the future performance of a given rock material under anticipated conditions in use. In order to get a qualitative, more reliable answer to the question of durability, the following section discusses the method of selection and testing required to determine the relative durability of a rock proposed for use as erosion protection on a pile.

Material selection, testing, and placement

Investigations should be conducted to identify several sources of available rock within a reasonable distance from the site. The suitability of the rock for protective covers should then be assessed by laboratory tests to determine the physical characteristics. The results of these tests will be used to classify the rock as being of poor, fair, or good quality and to assess the expected long-term performance of the rock.

When rock of good quality is reasonably available, the cover design should incorporate this rock. In those cases where only rock of less-than-good quality is reasonably available, increases in the average rock size and riprap layer thickness may be necessary. An acceptable procedure for oversizing or using less durable rock is discussed below.

In many cases, it may difficult to demonstrate that less-than-good quality rock will be durable for 1000 years. Therefore, in accordance with the 200-year durability criteria of 40 CFR 192, the use of rock that is not of good quality should be clearly documented and justified. This documentation and justification should include analyses and discussions regarding the location, durability, and costs associated with the most practical source of good-quality rock and/or the difficulties and costs associated with its placement.

It should be emphasized that the oversizing procedure is an attempt to quantify additional rock size requirements, based on experience with evaluating rock durability at several UMTRA Project sites and limited field data. The procedure should be used with engineering judgment and should be used only in those cases where it is clearly documented that good-quality rock is not reasonably available.

Pre-selection methods, both field and laboratory tests, should be used before a complete suite of laboratory tests are performed to classify the rock as to its suitability for erosion protection.

Petrographic and X-ray diffraction tests may, in the judgment of the engineer, eliminate a rock source from consideration based on the amount of smectite (clay minerals with swelling properties) present. A "good" or "fair" rock would have no significant smectite minerals present; "poor" rock would have significant smectite present. This judgment of rock quality can also be applied in the field investigation. A rock receiving a "poor" rating has clay and weathering rinds over one centimeter (cm) thick and a rock receiving a "fair" rating can have clay and weathering rinds from zero to one cm thick. "Good" indicates no rinds are present. The presence of substantial amounts of secondary minerals, or alteration minerals like sericite mica or pyrite, may be discerned in the field. The Schmidt hammer test is also appropriate for use in the field as a screening test.

Once a potential borrow source has been selected, a suite of laboratory tests will be performed on several samples. The appropriate tests will be determined by the engineer and will depend upon the type of rock and its placement location on the pile. Included in the choice of tests are:

- Petrographic examination (ASTM C295). Petrographic examination of rock is used to determine the physical and chemical properties of the material source in question. The examination should establish whether the rock contains chemically unstable minerals such as soluble sulfates, or volumetrically unstable materials. This examination is a qualitative analysis that can be used to identify potential borrow sources and the relative quality of each source prior to performing the laboratory test.

- Bulk specific gravity (ASTM C127). The specific gravity of rock is an indicator of its strength or durability; the higher the specific gravity, the better the quality of the rock. The specific gravity is also a good indicator of a rock's ability to withstand freeze and thaw cycles.

- Absorption (ASTM C127). A low absorption is a desirable property to prevent rapid disintegration of the rock by salt action and mineral hydration. Absorption is not a good stand-alone indicator of a rock's ability to withstand freeze-thaw cycles.

- Sulfate soundness (ASTM C88). In locations subject to freezing or where the rock is exposed to salt water.

- Freeze-thaw (AASHTO 103). A good guide to weathering resulting from crystallization processes, especially for frequently saturated areas.

- Schmidt Rebound Hammer. Measures the hardness of a rock; can be used in either the field or laboratory.

- Los Angeles Abrasion (ASTM C131 or C535). A measure of a rock's resistance to abrasion.

- Splitting tensile (Brazilian disk) (ASTM D3967). An indirect test of the tensile strength of a rock.

All samples for laboratory testing will be taken in accordance with Standard Practices for Sampling Aggregate (ASTM D75). A step-by-step procedure for scoring rock durability is summarized below and is to be used with the scoring criteria in Table 4.3.

1. The test results are compared on a scale of zero to 10. Test results of eight to 10 are considered "good," five to seven are considered "fair," and one to four are "poor." Results noted as zero fall below the least acceptable test result. The good-fair-poor rating is used only for assessment and not for actual scoring. The rock must be rated as good or fair in petrographic analysis before being considered as a suitable source; this rating is used as a screening method for potential sources.

2. The score is multiplied by a weighting factor, shown on Table 4.3, appropriate for the particular rock type (limestone, sandstone, or igneous) and for the specific test.

3. The weighted scores are totaled, divided by the maximum possible score, and multiplied by 100, resulting in the percent of the maximum score.

4. The score must meet the criteria for the rock's specific use. For use in occasionally saturated areas, which include the top and sides of the pile, the rock must score 50 percent or greater. For use in frequently saturated areas, which include all channels, buried toes and aprons, the rock must score 65 percent or more.

An occasionally saturated area is defined as an area with underlying filter/bedding layers and slopes (at least two percent) that provide adequate drainage and that is located well above normal groundwater levels. Aprons, natural channels, and engineered diversions are defined as frequently saturated areas regardless of drainage or climate.

The effect of the weighting factor is to focus the scoring on those test types that are the most or least critical for the particular type of rock being considered. The guidelines recommended by the NRC for the determination of rock quality are as follows: The number of the test types used (six physical tests, X-ray diffraction, and petrographic analysis) is typically determined by the design engineer; there must be at least four or five repetitions of each test type to provide an average of test results and to represent better the poorest rock condition for material to be

Table 4.3 Rock quality scoring criteria

	Weighting factor			Score										
	Lime-stone	Sand-stone	Igne-ous	10	9	8	7	6	5	4	3	2	1	0
Specific gravity	12	6	9	2.75	2.70	2.65	2.60	2.55	2.50	2.45	2.40	2.35	2.30	<2.3
Absorption (%)	13	5	2	0.1	0.3	0.5	0.67	0.83	1.0	1.5	2.0	2.5	3.0	>3.0
Sodium sulfate (%)[a]	4	3	11	1	3	5	6.7	8.3	10	12.5	15	20	25	>25
Abrasion (%)[b]	1	8	1	1	3	5	6.7	8.3	10	12.5	15	20	25	>25
Schmidt Hammer	11	13	3	70	65	60	54	47	40	32	24	16	8	<8
Tensile strength (psi)	6	4	10	1400	1200	1000	833	666	500	400	300	200	100	<100
Freeze-thaw (%)[c]	7	2	13	0	0.25	0.5	1	2.5	5	7.5	10	15	20	>20

[a]Five cycles.
[b]100 revolutions.
[c]250 cycles, ASTM C-290, 3-inch sawn cubes, 8 cycles per day.

NOTE: Scores derived from Tables 6.2 and 6.7 of Ref. 1. Any rock to be used must be qualitatively rated at least "fair" in a petrographic examination conducted by a geologist experienced in petrographic analysis. Weighting factors derived from Table 7 of Ref. 2, based on inverse of ranking of test methods for each rock type. Test methods should be standardized (e.g., ASTM) and should be those used in Ref. 2.

Ref. 1. Lindsey, C. G., Long, L. W., and Begej, C. W. (1982), Long-Term Survivability of Riprap for Armoring Uranium Mill Tailings and Covers: A Literature Review, U.S. Nuclear Regulatory Commission, NUREG/CR-2642.

Ref. 2. De Puy, G. W., "Petrographic Investigations of Rock Durability and Comparison of Various Test Procedures," in Engineering Geology, Vol. 2, No. 2, July 1965.

placed in significant amounts relative to the total quantity placed. Engineering judgment should be used to determine the particular type of tests based on pre-screening methods.

The weighting factors for the three types of rock show that for limestone the most significant tests, in order of importance, are absorption, specific gravity, Schmidt hammer, and freeze-thaw. For sandstone the significant tests are Schmidt hammer, LA abrasion, absorption, and specific gravity; while for igneous rock the tests are freeze-thaw, sodium sulfate soundness, tensile strength, and specific gravity. The LA abrasion test is the least significant test for limestone and igneous rock, with a weighting factor of only one.

If a rock source of "good" durability cannot be found, the size of the rock should be increased to take into account the degradation of the rock with time. The increase in size is subjective, since present technology has not looked at the interaction between tests to determine if a rock should be oversized. Most rock testing has been associated with typical construction aggregates (i.e., concrete or road base) and a determination as to whether the aggregate is good or bad with no intermediate evaluation. However, the quality of rock used to protect against occasional erosional forces may allow for some oversizing to compensate for minor degradation in service. Consequently, a method of oversizing to account for weathering is required so that rock used for erosion protection will not erode to a weight or size that would be carried away during the design event.

The oversizing methodology is based on the assumption that the controlling failure mechanism is cyclic freezing and thawing. This is a reasonably good assumption provided the rock contains an insignificant amount of smectite clay minerals. Insignificant amounts of these clays are evidenced by the absence of well-defined X-ray diffraction peaks used in their identification or failure of the rock to react to ethylene glycol. The presence of smectite minerals suggests that the rock is already in an advanced stage of chemical weathering and that further mechanical weathering is controlled by cyclic wetting and drying, or by slaking and abrasion, rather than by cyclic freezing and thawing. Hence, the oversizing methodology does not apply to rocks containing significant amounts of smectites.

The need for oversizing is based on the final durability scoring of the rock samples. Rock that meets the minimum criteria but scores less than 80 percent for both occasionally saturated areas and frequently saturated areas must be oversized. Oversizing is determined by the numerical difference between the minimum rock score of the materials being placed and 80 percent; e.g., rock scoring 68 percent would have to be oversized by 12 percent. Table 4.4 lists the procedures for selecting the most cost-effective rock for erosion protection.

Table 4.4 Design procedure for rock selection

I. Locate and Test Rock Sources

1. Locate least expensive source(s) of "good" (80 to 100 percent score) rock.

2. Locate least expensive source(s) of "other quality" (50 to 80 percent score) rock.

II. Develop Best Designs

1. Using oversizing criteria, if necessary, develop designs for rock sources identified above.

2. Develop unit cost data for each rock size for each design.

3. Develop a final design utilizing the best rock that is reasonably available.

III. Develop Alternate Compensating Designs

Assuming either:

a. that only poor-quality (less-than-good quality) rock is available and oversizing is not reasonably feasible, or

b. that good-quality rock is reasonably available but is not of adequate size.

then:

a. use methodology (see Section 4.1) to justify use of a flood less than the PMF, and

b. develop alternate designs based on less than PMP/PMF.

When placing the rock, each load of riprap should be reasonably well-graded from the smallest to the maximum size specified. Gradation can be verified during placement by visual comparison of material placed with a sample of known, acceptable gradation already placed. If any differences of opinion occur between the engineer and the contractor, the difference shall be resolved by dumping and checking the gradation of any two random truckloads of rock. Alternatively, if the rock size is not greater than three inches, the rock can be physically tested using United States standard sieves of the appropriate size.

Filter requirements and design

When designing the cover system, the need for a filter layer between the radon barrier and the erosion protection layer must be evaluated. Most of the research on the need for a filter and filter design criteria is over 20 years old and has varied.

Investigations by Sherard (1985) and Sherard et al. (1984a, 1984b) have shown that design criteria for various impervious soils are dependent on the fines content (percent < No. 200 sieve) and fall into the categories shown in Table 4.5.

It is recommended that Table 4.5 be used as the criteria for all filters. These criteria can be relaxed in some instances for a clay with a high plasticity or if there are fairly low flow gradients. In addition to the above criteria, the following requirements for a graded filter should be met:

- The filter material should pass the three-inch sieve for minimizing particle segregation and bridging during placement. Smaller maximum particle sizes may be specified if practical. Also, filters must not have more than five percent passing the No. 200 mesh sieve to prevent excessive movement of fines in the filter.

- Filter material should be reasonably well-graded throughout the in-place layer thickness.

- Filters for gap-graded base soils may require a more finely graded filter than the filter determined using the criteria above.

- The minimum thickness of the layer should be six inches in order to facilitate ease of construction during placement.

When a rock cover is to be used over a filter, the rock used should be essentially equidimensional and well-graded in size. The rock blanket should also meet the filter criteria of Table 4.5 so that the filter material does not migrate through the voids in the rock. The thickness of the rock layer should not be less than the spherical diameter of the upper limit of D_{100} rock or less than 1.5

Table 4.5 Filter design criteria

Soil group	Percent fines[a] < No. 200 sieve	Recommended design criteria[b]
1	85 to 100	$D_{15}/D_{85} \leq 9$ mm
2	40 to 85	$D_{15} \leq 0.7$ mm
3	0 to 15	$D_{15}/D_{85} \leq 4$ mm
4	15 to 40	Intermediate between groups 2 and 3

[a]Percent fines is the fines content of the sand fraction (≤ No. 4 sieve) of the radon barrier material.
[b]mm = millimeters.

times the spherical diameter of the upper limit of D_{50} rock, whichever is greater.

Design sequence

The following steps are essential for the erosion protection design of an adequate rock cover system for tailings embankments:

1. From the borrow site investigation, a composite plot of all the grain size distributions from the radon barrier borrow site can be made. From this plot, a determination can be made of the practical upper and lower bounds of grain size distribution after material placement.

2. Next, the characteristic velocities of the flood flow on and adjacent to the pile can be determined. Flood flow can occur either from a storm occurring in the watershed above the pile and producing a flood flow adjacent to the pile, or from a storm occurring on the pile and producing sheet flow across the top and down the slopes of the pile. Velocities, depths, and flows adjacent to the pile are normally obtained with the use of the HEC-2 computer program, which calculates water-surface profiles for steady, gradually varied flow in natural or engineered channels.

   Velocities and depths of flow for a storm occurring on a pile are more difficult to calculate. When a pile is designed with a rock cover and no topsoil for vegetation, sheet flow hydraulics should be used to calculate the total

flow. The local PMP should be calculated using the appropriate HMR report. Next, the time of concentration should be calculated. This is an iterative process based on the velocity across the pile, Manning's friction factor, the size of rock, and the depth of flow. Then, using the time of concentration, the maximum one-hour intensity can be computed (Equation 2). Once the maximum one-hour intensity is calculated, the total flow can be calculated using Equation 3.

3. The mean rock size needed to resist erosion of the stabilized pile can be determined from the calculated velocities and depths of flow. For flow adjacent to the pile and across the topslopes, the Safety Factors Method should be used. For sizing riprap or sideslopes greater than 10 percent, Stephenson's Method is most applicable. When determining the rock size gradation, the grain size distribution should meet the criteria used by the U.S. Corps of Engineers (COE, 1970).

4. Rock borrow source data should be reviewed to determine rock durability. If rock durability meets the criteria, no adjustment in the rock size will be needed; if the rock does not meet the criteria, the rock sizes should be increased proportionally to the percent that the rock failed the tests below 80 percent.

5. The filter requirements for the rock cover and the radon barrier should be calculated to determine if there is a need for a filter between the two layers. If a filter or gravel layer is needed, ensure that filter requirements are met for all cover materials, with the most flexibility being in the central filter.

4.2.2 Infiltration protection

The amount of infiltration into the tailings can be minimized through proper design of a rock cover. Depending on the hydrogeologic conditions, cover characteristics, and climate at a site, a rock cover may be the appropriate design for complying with the groundwater standards. The various means that can be used to demonstrate minimal infiltration or reduce infiltration are as follows: (1) unsaturated conditions in the radon barrier; (2) highly permeable bedding layer; or (3) infiltration barriers, such as bentonite-amended soils.

Unsaturated conditions

The findings of the cover moisture study (DOE, 1989) at the Shiprock (NM) site can be applied to other sites in similar climates. These sites include Clive (UT), Ambrosia Lake (NM), Green

River (UT), Lakeview (OR), Slick Rock (CO), Mexican Hat (UT), and Tuba City (AZ). Long-term infiltration can be modeled on rock covers at these sites using the Shiprock data to determine boundary conditions. The combination of the low unsaturated conductivity of the radon barrier and climate is an effective design that prevents the radon barrier from becoming saturated and limits infiltration into the contaminated materials. Therefore, it is qualitatively predictable that similarly designed rock covers in similar climates will function the same as the Shiprock cover.

Modeling at the previously mentioned similar sites will be conducted where necessary to document compliance with the groundwater standards. The modeling will involve modifying the upper boundary condition of the radon barrier measured at Shiprock to represent site-specific climate and material properties as input to a numerical model to predict long-term percent saturation and seepage rates. It should be recognized that this modeling effort is really a sensitivity analysis of the boundary conditions, as the actual conditions at each site have not been measured.

Highly permeable bedding layer

Shedding of precipitation more rapidly off the pile will result in less moisture available for infiltration into the radon barrier and contaminated materials. More rapid shedding can be accomplished by either increasing pile slope angles, decreasing slope lengths, or increasing the hydraulic conductivity of the bedding/filter layer. Because of stability, constructibility, and cost concerns, increasing the hydraulic conductivity of the bedding layer is the best alternative. In order to incorporate this concept, the designer should follow the procedures for bedding layer design previously presented and use the largest D_{15} for the bedding materials possible while still meeting the filter criteria.

Infiltration barrier

An infiltration barrier may be needed to minimize the amount of water reaching the radon barrier and contaminated materials in order to achieve compliance with the groundwater standards. An infiltration barrier can be one or more of the following: (1) a low-permeability soil that also functions as the radon barrier; (2) a soil amended with bentonite that functions as the radon barrier; or (3) a bentonite mat, which is a commercial product that consists of a thin layer of bentonite between two geotextiles.

Low-permeability soils

If suitable low-permeability soils are available for use as the radon barrier, they may act as the infiltration barrier also, depending upon site conditions. They may be suitable at standard

placement density (95 percent standard Proctor), but it may be necessary to increase only the compaction requirements (i.e., to 100 percent standard Proctor) to achieve a lower hydraulic conductivity that will reduce infiltration to the degree necessary for compliance. The use of this option would be on a site-by-site basis.

Bentonite-amended soil

An alternative solution would be to amend the available soil with up to 30 percent bentonite by volume. The void space of a sand or silt is about thirty percent of the total volume, and filling this space with bentonite should produce a material with a very low hydraulic conductivity, i.e., 1 x 10E-8 centimeters per second (cm/s) or less. The actual hydraulic conductivity achieved with the addition of the bentonite is material-specific and, therefore, would have to be determined on a site-by-site basis. The hydraulic conductivity necessary for compliance is also site-specific and would have to be considered in the design and percent bentonite added. A laboratory testing program that varies the amount of bentonite added to the soil will enable the selection of the proper amount of bentonite to be added.

Complete mixing of the soil and bentonite, necessary to achieve the minimum practical hydraulic conductivity and field compaction of high percent bentonite soils, is difficult. This would require field verification as to the constructibility of the infiltration barrier. Limited data are available on the strength of high-percent bentonite mixes. Without testing the amended soils, mixes should be placed only on pile topslopes with less than 4.5 percent slopes. If used on the sideslopes of the pile, testing at the design mix would be required to assure stability of the layer. If the strength of the material was found to be not adequate, then the sideslopes may be buttressed to attain the desired factor of safety.

Bentonite mat

A bentonite mat is a commercially available product that consists of a thin layer of bentonite (0.25 inch thick) between two layers of geotextile materials. When hydrated, the bentonite would swell to 0.33 inches if subjected to overburden stresses similar to those in a typical UMTRA Project rock cover. The following should be considered when incorporating a bentonite mat in the design: (1) the mat has an hydraulic conductivity of 2 x 10E-9 cm/s; (2) the mat has an effective angle of internal friction of four degrees; (3) seams are not required when installing the mat--only overlapping of adjacent panels by about six inches is needed; and (4) the geotextiles are not long-term elements of the mat--they will deteriorate and should not be relied on as a functional part of the cover.

The following are some design details for the use and construction of covers that include a bentonite mat as the operative infiltration barrier.

- Place the mat above the radon barrier and below a sand drain. The mat is placed above the radon barrier because the fine-grained soils of the barrier make an ideal bedding layer. The mat should not be placed within the radon barrier because the permeability of the soils of the radon barrier is such that drainage is not facilitated and hence an hydraulic head could build up above the mat and increase the water flux through the mat. The radon barrier should be sloped at least two percent so that precipitation entering the drain above the mat can flow off the pile.

- Cover the mat with a filter. The particle gradation should be primarily a clean sand. The hydraulic conductivity preferably should be no less than 0.1 cm/s, provided the filter criteria are met. The drain thickness should be about six inches. The purpose of the drain is to preclude the buildup of an hydraulic head above the mat; water will flow downslope through the drain and off the pile, and will not accumulate above the mat and increase the hydraulic gradient through the bentonite.

- Place the mat beneath depth of freeze/thaw. Data to prove conclusively that the bentonite is not affected by freezing and thawing are not currently available; tests are in progress and they indicate that freezing and thawing will not decrease the bentonite's permeability. Until data become available to prove there is no reduction in hydraulic conductivity with repeated freezing and thawing, the conservative approach of placing material beneath the predicted depth of frost penetration should be adopted.

- Do not use the mat on unbuttressed sideslopes. Bentonite has a very low strength and should be used with extreme caution on sideslopes. The buttress detail shown on Figure 3.5 may be adopted if slope stability analyses confirm adequate factors of safety against sliding, deformation, or other instability.

- Construct a topslope of 4.5 percent or less. The factor of safety of an infinite slope of 4.5 percent that incorporates a material with an angle of friction of four degrees is 1.5. To maintain static stability, 4.5 percent is therefore the maximum topslope inclination that should be used unless more detailed analyses are completed to demonstrate stability. For dynamic, or earthquake, loading conditions, a pseudo-static analysis using the site design acceleration should be completed to confirm that the topslope will remain stable.

4.2.3 Biointrusion protection

A cover design with rock over soil will have some potential for invasion and establishment of volunteer plant species. The degree of biointrusion hazard is related to local environmental conditions and to anticipated pile characteristics. Some environmental conditions related to a higher potential for intrusion are (1) nearby deep rooted plants; (2) prairie dog colonies or other burrowing animals nearby; (3) humid to subhumid climate; (4) long to moderate growing season; and (5) deep or rich top soil.

The likelihood of volunteer plant growth on rock covers can be evaluated by assessing the risk levels associated with specific characteristics of the cover design. Table 4.6 lists these cover design characteristics and their associated levels of risk. The table suggests a number of options that may be used to resist plant invasion onto a pile with a rock cover. For instance, a lower risk may be achieved by providing a greater depth of rock on the surface, using smaller rocks, or using a soil beneath the rock that is inhospitable to the germination and growth of plants. The depth of rock required to deter plant invasion depends on rock size, climate, and properties of the underlying soil. Plant germination will be minimized if materials under the riprap layer are drier, which can be achieved if rapid shedding of precipitation occurs. As discussed in the previous section, a more highly permeable bedding layer will drain faster, thus minimizing the potential for plant growth. Volunteer growth will also be reduced if the soil underneath the rocks has unfavorable chemical properties. For example, saline groundwater was used as a moisture conditioner at the Clive pile with the result that the soils of the filter layer and radon barrier are quite saline and, presumably, somewhat inhibitory to plant growth.

For design purposes, the most cost-effective design features to reduce the potential for plant germination and growth are (1) to design the bedding/filter layer to be as permeable as possible while meeting the filter criteria previously defined; and (2) to use saline water, if available, for compaction water during construction of the radon barrier.

4.3 VEGETATED COVER DESIGN

A vegetated cover may be placed on the topslopes of UMTRA Project piles. Vegetated covers are generally not recommended for sideslopes because the vegetation may not be able to resist gullies originating on the steeper sideslopes or advancing headward from off the pile. A full discussion of vegetated covers and their applicability to the UMTRA Project is in the "Vegetative Covers Special Study" (DOE, 1988). Additional information on vegetated covers for mill tailings impoundments also appears in Beedlow (1984) and Beedlow and Hartley (1984).

Table 4.6 Characteristics related to the potential for plant invasion onto a pile with a rock-over-soil cover design

Element	Higher risk conditions	Lower risk conditions
1. Rock	o Large rock of 8 inches or greater with well-sorted sizes and large interstices	o Small rock (resulting in higher temperatures and small discontinuous voids); less than 6 inches in diameter
	o Thin layer 3 or fewer particles deep	o Thick layer of rock 4 or more particles deep or at least 15 inches deep
	o Design or environment that encourages eolian deposition	o No eolian deposition
2. Bedding underlying rock cover	o Poorly drained, high water retention (too many capillary pores)	o Well drained or absent
3. Restrictive layer (e.g., Claymax^{R})	o Absent, allowing infiltration of moisture into radon barrier	o Present, encouraging rapid lateral drainage
4. Radon barrier	o High shrinkage, limited clay content (greater cracking potential)	o Low shrinkage, limited clay content (lower cracking potential)
	o High optimum moisture content by Standard Proctor method	o Low optimum moisture content by Standard Proctor method
	o Susceptibility to freeze/thaw weathering	o Protected from freeze/thaw weathering
		o Highly saline or sodic soil

A vegetated cover basically consists of plants and soil, sometimes with other earthen materials, that have been selected to maximize transpirational removal of water and resistance to erosion. It is important to note the distinction between a vegetated cover and a soil cover, in which soil is applied to the surface and allowed to revegetate naturally or is seeded with casually selected seedmix for purely aesthetic reasons (e.g., on the stabilized pile at Canonsburg, Pennsylvania). A vegetated cover is one in which the soil and plants have been selected and the construction sequence has been formulated to establish a vigorous and enduring community rapidly. The soil and plants in a vegetated cover have specific performance objectives that must be met if the cover is to achieve its intended goal of controlling water balance, resisting erosion, and otherwise contributing to the long-term integrity of the stabilized pile.

The principal attributes of a vegetated cover are:

- Control of water balance, by evapotranspiring moisture back to the atmosphere rather than allowing it to infiltrate into tailings.
- Relative freedom of the stabilized pile from surveillance and maintenance; specifically, freedom from biointrusion by plants and animals.
- Compliance with longevity requirements for stabilized piles because a "climax" plant community may be established on the cover that will, by definition, persist indefinitely, resisting minor disturbances and repairing itself after major disturbances.

Vegetated covers may be less effective in controlling the water balance at sites with humid climates because the amount of precipitation will exceed the transpirational capacity of the vegetation. On the other hand, a vegetated cover may be established at sites in the most arid climates. The key is to use the proper combination of plants and soil to assure that some plants survive the dry periods (even if dormant) so that adequate transpirational capacity will be available after precipitation events to prevent moisture infiltration into the tailings. A rock mulch may be required at exceptionally arid sites to resist evaporation (making more soil moisture available to plants during dry periods) and to supplement the plants' ability to resist erosion of the cover.

4.3.1 Plant community

The goal is to establish a plant community with the highest potential productivity, hence capacity to transpire water, that the local climate and soils will support. High productivity will also result in rapid accumulation of organic matter. A high percentage of foliar cover will protect the underlying soil from the direct impact of raindrops, which may dislodge soil particles and initiate erosion.

If a vegetated cover is to be used at a site, then the various plant communities within a few miles of the site should be surveyed

for that which might serve as a model for the community to be established on the stabilized pile. Ideally, a community should be used that is associated with the most favorable edaphic characteristics (soil properties as related to vegetal growth); however, in some cases, this would mean that economically valuable soils (such as for agriculture) would have to be used, or that soils would have to be transported from a long distance away. Ultimately, the model community that is selected for a site will be one that can grow on the soil that is best for the project in terms of many factors, including availability and cost. Ideally, on-site soils will be used.

The physiognomy (morphological structure) of the selected community will be closely emulated, and the species composition will be matched to the extent possible. In other words, if a high desert perennial grassland is judged to have the desired characteristics, then a similar community should be established on the stabilized tailings pile. However, the species may differ depending upon the availability of seed for cultivars (domesticated varieties) that have proven successful in local revegetation efforts.

Once a general community model has been selected, the species composition in the seed mix needs to be optimized relative to a variety of criteria such as drought hardiness, nutrient relations, and seasonality of water use. For instance, a blend of cool-season and warm-season grasses should be used to provide transpirational capacity over the longest time period each year.

The plant community should be established using the latest techniques for revegetation. After the rooting medium and seedbed have been prepared (see Section 4.3.2), seeds may be applied using a seed drill, or containerized plants may be installed. Irrigation may be necessary at arid sites for the first growing season to promote rapid germination and establishment, because desert climates usually do not provide enough moisture to support plant reproduction except once every few years. The amount of irrigation should be adjusted to simulate the conditions of a naturally wet growing season for a given climate, but should not be so great as to encourage community dependency on moisture levels that will not be present after the termination of irrigation. A simple monitoring program may be used (for instance, with buried psychrometer probes) to ensure that irrigation water is not seeping below the root zone. See the "Vegetative Covers Special Study" (DOE, 1988) for a more detailed discussion of irrigation practices and associated monitoring.

The final selection of a seed mix (or transplantation program) should reflect the natural communities and the experience of local reclamationists, who will indicate what species have done particularly well in local revegetation programs or seeding trials. The revegetation plan should include a seedmix or transplantation program with adequate species diversity, because different species will

flourish initially than later, depending upon the climatic conditions. Different species will also respond differently to disturbance and a variety will transpire moisture over a longer time of the year.

The vegetation community will be an important element in arguments regarding the pile's compliance with the UMTRA Project's longevity requirements. The community must consist of locally adapted species that, in combination, conform to the concept of a "climax community." A climax community is one that will persist indefinitely or, if disturbed, will ultimately prevail under the environmental conditions at a given site. By definition, a climax community or one of its subclimax (immature) communities will occupy the topslopes for the life of the pile.

4.3.2 Rooting medium

The most important component of the vegetated cover is the soil, because this must support the growth and reproduction of many generations of plants. The soil provides mechanical support for plant roots, but, more importantly, it stores water and nutrients. Ideally, the soil will store all the water that falls on the cover (and does not run off) until that water may be transpired by plants. This may be achieved by providing an adequate thickness of soil as suggested by water-balance models such as HELP (Schroeder et al., 1984) or CREAMS (Knisel, 1980). The rooting medium also serves as frost protection for the underlying layers.

As mentioned in Section 4.3.1, the best possible soil should be used for the cover in terms of edaphic properties, although factors such as availability and cost must be considered. The most important edaphic property is texture, which affects the storage capacity for and availability of water in the soil. Specifically, the soil should have a relatively even mix of particle sizes (sand, silt, and clay), and hence should be a "loam" (Brady, 1974). Ideally, the soil will retain 30 percent or more of its weight in water at field capacity, but will release all but 10 percent to plants at the wilting point. Organic matter can be added to increase water storage capacity without raising the wilting point.

It is also important to avoid soils with unfavorable chemical properties such as a lack of nutrients (particularly trace metals, which are not easily replaced in a fertilization program) or a high concentration of sodium or phytotoxic metals. Such problems are almost always evident in the plant communities growing on these soils in their natural setting.

Many of the principles for handling the soil may be adapted from the field of mine reclamation. For instance, the physical and chemical properties of the soil must be protected during collection,

transportation, stockpiling, and redistribution. Stockpiled soil must be well drained to prevent anaerobic chemical processes that introduce sulfides and other inhibitory agents. Ideally, many of the microscopic organisms and their spores will survive in the soil until its redistribution on the cover, as these will accelerate the early growth of plants and eventual establishment of a stable community (Whitford and Elkins, 1986).

The wet bulk density of soil must not be allowed to exceed 1.6 grams per cubic centimeter (g/cm^3) during redistribution, so periodic ripping may be appropriate. It is especially important to establish proper tilth in the upper six inches, because this zone will be the seedbed for germination and early growth. Fertilizer may be applied and disked into the seedbed to encourage early growth. A number of surface treatments such as mulching with straw or pea gravel may enhance plant growth, while also protecting the soil against erosion during the initial unvegetated period. A thin layer of rocks on the surface of a rooting medium can protect against erosion and improve water relations (Waugh, 1988; Beedlow, 1984). A rock mulch is generally appropriate for arid environments, where vegetation alone may be inadequate to stabilize the surface.

4.3.3 Erosion protection

A vegetated cover is much less resistant to erosion than a rock cover and much more resistant than a cover of bare soil. Vegetation resists erosion by the following mechanisms (verbatim from Gray and Leiser, 1982):

Interception: foliage and plant residues absorb rainfall energy and prevent soil compaction from raindrops.

Restraint: root system physically binds or restrains soil particles while above-ground residues filter sediment out of runoff.

Retardation: above-ground residues increase surface roughness and slow velocity of runoff.

Infiltration: roots and plant residues help maintain soil porosity and permeability.

Transpiration: depletion of soil moisture by plants delays onset of saturation and runoff.

Two general categories of soil erosion should be addressed in the design of vegetated covers: uniform soil removal across the cover via sheetwash erosion or deflation, and concentrated removal via rills and gullies. In both cases, a vigorous stand of vegetation will greatly enhance the cover's ability to resist erosion. Even when dead or dormant, plants will protect and bind the soil.

At very arid sites, where vegetation on the cover may be sparse or absent (in the case of a sustained drought), a rock mulch will improve the erosion resistance (Beedlow, 1984; Waugh, 1988). This simulates the natural source of stabilization of desert soils provided by desert pavement (Potter, 1989).

Rates of soil loss to sheetwash erosion and deflation may be estimated using one of two mathematical methods. These are the Universal Soil Loss Equation (USLE) and the Modified Universal Soil Loss Equation (MUSLE). Both are based on regression models and are empirical formulas for predicting soil losses due to sheet or rill erosion. The major factors that control soil erosion rates, such as the type and degree of vegetal cover, rainfall and runoff, soil properties, and topography, are taken into account in both formulas. One advantage of the MUSLE over the USLE is that it can be used to evaluate average soil losses for certain types of slopes as a function of time. Another is that the topographic and erosion control factors presented for many construction conditions are not identified in the USLE. Furthermore, the USLE requires that an entire site be evaluated as one single component, whereas the MUSLE can be applied to multiple components of a single site, allowing for a more accurate evaluation of a complex cover design (Abt and Ruff, 1978).

Limitations of both equations are that they do not consider the potential for gully development or intrusion, nor do they predict gully erosion, sediment yield, or snowmelt erosion. The accuracy is dependent upon how well the assumed field conditions compare to general conditions depicted in tables and figures; the factors used in the equations relate an average condition. Finally, they do not incorporate the concept of the PMP, but rather a rainfall factor based on historical rainfall values.

The USLE developed to estimate gross soil losses due to water erosion is:

$$A = RKLSCP$$

where

A = Soil loss (tons/acre/year).

R = Rainfall erosivity factor. This factor expresses the erosion potential of the average annual rainfall in an area. It is the product of the storm's rainfall energy and the maximum 30-minute intensity.

K = Erodibility factor. It is an indication of soil erodibility based upon the soil properties that are influenced by the flow of water. These properties include general soil structure, permeability, and soil composition.

LS = Slope length and slope gradient factor (topographic factor). It expresses the overland flow of water as a function of the slope length and percent slope.

C = Cover or crop management factor. It is an indicator of how various ground covers, rates of mulching, and methods of revegetation can affect water-related erosion.

P = Support practice factor. It accounts for the effect of erosion management procedures such as contouring on erosion.

Tables and figures are available in the literature for determining these factors (Nelson et al., 1986; Abt and Ruff, 1978).

In the MUSLE, the cover and erosion control factors ("C" & "P") are replaced by the VM factor. The VM factor accounts for measures implemented at the construction site to include vegetation, mulching, chemical treatments, and sprayed emulsions to impede or reduce erosion due to the overland flow of water (Nelson et al., 1986).

If the calculations described above indicate that unacceptable soil loss will occur from sheetwash erosion in deflation of a vegetated cover, then measures such as the use of a rock mulch or reduction in grade may be required.

In addition to designing against erosion from sheetflow, the cover will be designed to minimize the potential for gullying. Slopes will be kept below the angle required for gullies to develop as determined by both geomorphological and analytical/empirical methods.

Geomorphological methods

The potential for gullying can be evaluated using the threshold-for-gullying approach, in which drainage basins in the vicinity of the disposal area are analyzed to determine under what conditions gullies form.

This method is applicable in determining the relative stability of soil-covered constructed slopes, such as the topslope of the disposal cell; of reconstructed natural slopes, such as the apron that surrounds the toe of the pile; or of natural slopes adjacent to the pile. The method is not quantitative and demonstrates only the potential for gullying, and should be used together with an analysis of the tractive force method, particularly where reconstructed or constructed surfaces are considered.

The procedure described by Wells and Gardner (1985), and by Schumm et al. (1984), shows the validity of the relationship of slope versus drainage area for discrete basins in defining the threshold for gullying. Wells and Gardner (1985) have compiled data from several studies that have determined the thresholds for gullying in their respective study areas. These data are plotted as slope (surface) versus drainage area and can be used to assess the potential for gullying at UMTRA Project sites.

The elements of the investigative procedure to be followed are described as follows:

- Examine appropriate basins; i.e., those which have similar soil, bedrock, climatic conditions, and vegetation. The proximity of these basins to the site will assure that climatic conditions and geomorphic processes will be similar.

- Assess each basin, evaluating any evidence of disturbed surfaces upslope of the lowest point in the basin.

- Document the analysis of each basin studied by color photographs and enlarged plan views of the topography that will permit adequate measurement by planimeter of the basin area and clearly show the outline of the basin relative to the elevation contours.

- Provide a calculation of the method of determining the basin area of the site slope that is being evaluated. For the topslope this requires some conservative assumptions on how the area is defined. For natural or constructed slopes, this involves using the grades shown on the final design for construction.

Some of the difficulties with applying this procedure are the availability of adequate topographic maps where the contour interval allows a reasonable definition of discrete basins, and accessibility to the land areas as affected by seasonal weather conditions and considerations for private land.

Analytical/empirical method

The analytical/empirical method is applicable for determining the erosion resistance of vegetated topslopes with grades no greater than five percent. The method applies only to slopes with established vegetation, such as would be expected under long-term conditions. Under these conditions, the topslope should be able to withstand the PMP. The method also analyzes the topslope for less severe conditions (i.e., the 100-year hydrologic storm event) for the period before a good stand of vegetation is established (e.g., immediately after construction or after a prolonged drought during the design life of the disposal cell).

Topslope cover soil materials need to be thoroughly characterized. It is desirable to obtain these soils within the immediate vicinity of the disposal site to reduce environmental impacts and costs incurred with borrow materials and to approximate natural conditions for vegetation. Laboratory tests should be performed to classify dispersion, gradation, and moisture-density properties. Results from these tests are used to calculate the allowable tractive shear stress, as outlined in subsequent sections. Tractive shear stress is analyzed to determine the shear stress along the topslope soil from flow of surface waters. The tractive shear stress is based on design hydrologic events.

Vegetation on a slope or in a channel carrying water creates considerable turbulence, which impedes the water flow through energy losses. The impedance is a function of the density and height of the vegetation. Experiments conducted by the SCS were performed on various types of grasses to determine their ability to impede water flow (Ree, 1949; Ree and Palmer, 1949; SCS, 1947). It was found that Manning's resistance coefficient, "n," is related to the product of the hydraulic radius, "R," and the mean velocity, "V." Depending on the type of vegetation and how well it is established in conjunction with hydraulic properties, five different levels of impedance can be identified and defined.

The ratio of the allowable to actual tractive shear stress must be greater than unity if the soil is to resist erosion. The actual tractive shear stress arises from a pulling force in the direction of flow that develops on a soil particle. Vegetation dissipates energy within the flow field through eddies and localized turbulence adjacent to individual vegetal stems or leaves, thus reducing the total available energy of the fluid. The reduced total energy results in less energy to be mobilized into tractive pulling forces to entrain soil particles. The tractive shear stress mobilized on a non-vegetated slope is denoted the actual tractive shear stress (τ_a). The reduced tractive force mobilized on a vegetated slope is denoted the effective actual tractive shear stress (τ_e).

Soil materials to be used on a topslope that will support vegetation should be characterized using the following tests.

- Sieve analysis (ASTM C136).
- Atterberg limits (ASTM D4318).
- Double hydrometer analysis (ASTM D442).
- Pinhole test (ASTM Proceedings STP623).
- Moisture-density relationships (ASTM D698).

- Remolded vane shear strength testing on saturated samples (either field or laboratory).

Classification tests are used to determine the allowable tractive shear stress; the vane shear tests are a check on the upper boundary of the allowable tractive shear stress. If the dispersivity tests indicate dispersion, the material should not be used.

Methods to determine the allowable tractive shear stress are presented by Temple et al. (1987) and Vanoni (1975). Both references give the same procedure to determine the allowable tractive shear stress for noncohesive granular soils. This procedure is based on research by Lane (1955) on relatively coarse materials where stability of the sediment bed controls design. The relationship is:

$$\tau_a = 0.4d_{75} \tag{14}$$

$d_{75} > 0.05$ inch (1.27 millimeters).

where

τ_a = is the allowable tractive shear stress in pounds per square foot (PSF)

d_{75} = is the particle diameter in inches, for which 75 percent of the material by weight is finer than this diameter as determined from the sieve analysis.

If the material classifies as a fine-grained material by the Unified Soil Classification System (USCS) or does not meet the gradation limit specified by Equation 14, the allowable tractive shear stress for the fine-grained cohesive soils should be used. For fine-grained soil materials, the allowable tractive shear stress is not clearly defined. Due to the relatively small size of the individual particles, which are normally cohesive, the physiochemical properties of the particle dominates behavior. Behavior is generally indicated by the plasticity index (PI) of the fine-grained fraction of the soil and the soil fabric. The plasticity index is defined as the differential water content between the liquid and plastic limits of the material finer than a number 40 standard sieve. These properties are determined by Atterberg limit testing (ASTM D4318).

Temple et al. (1987) and Vanoni (1975) indicate that the allowable tractive shear stress is a function of the plasticity index and void ratio of the sediment. The relationship presented by Temple et al. (1987) is:

$$\tau_a = \tau_{ab} C_e^2 \tag{15}$$

where

τ_{ab} = base allowable tractive shear stress as a function of the plasticity index (PSF).

C_e = void ratio correction factor.

Graphical determination of both τ_{ab} and C_e are reproduced from Temple et al. (1987) and presented in Figures 4.3 and 4.4. Analytical formulations are given by Temple et al. (1987). A lower limiting value for the allowable tractive shear stress is considered to be 0.02 pounds per square foot (psf).

The tractive shear stress applied to a soil by a flowing fluid is the force with which the fluid pulls on individual soil particles. This force is given by the DuBoys formula (Horton, 1945):

$$F = w_1(\delta_x/12) \times \sin \alpha \qquad (16)$$

where

F = force required to dislodge an individual soil particle.

w_1 = unit weight of the fluid (pounds per cubic foot, or pcf).

δ_x = depth of flow (inches).

α = angle of the bed from horizontal (degrees).

The DuBoys formula is rewritten as the tractive force formula,

$$\tau = \gamma DS \qquad (17)$$

where

τ = tractive shear stress (PSF).

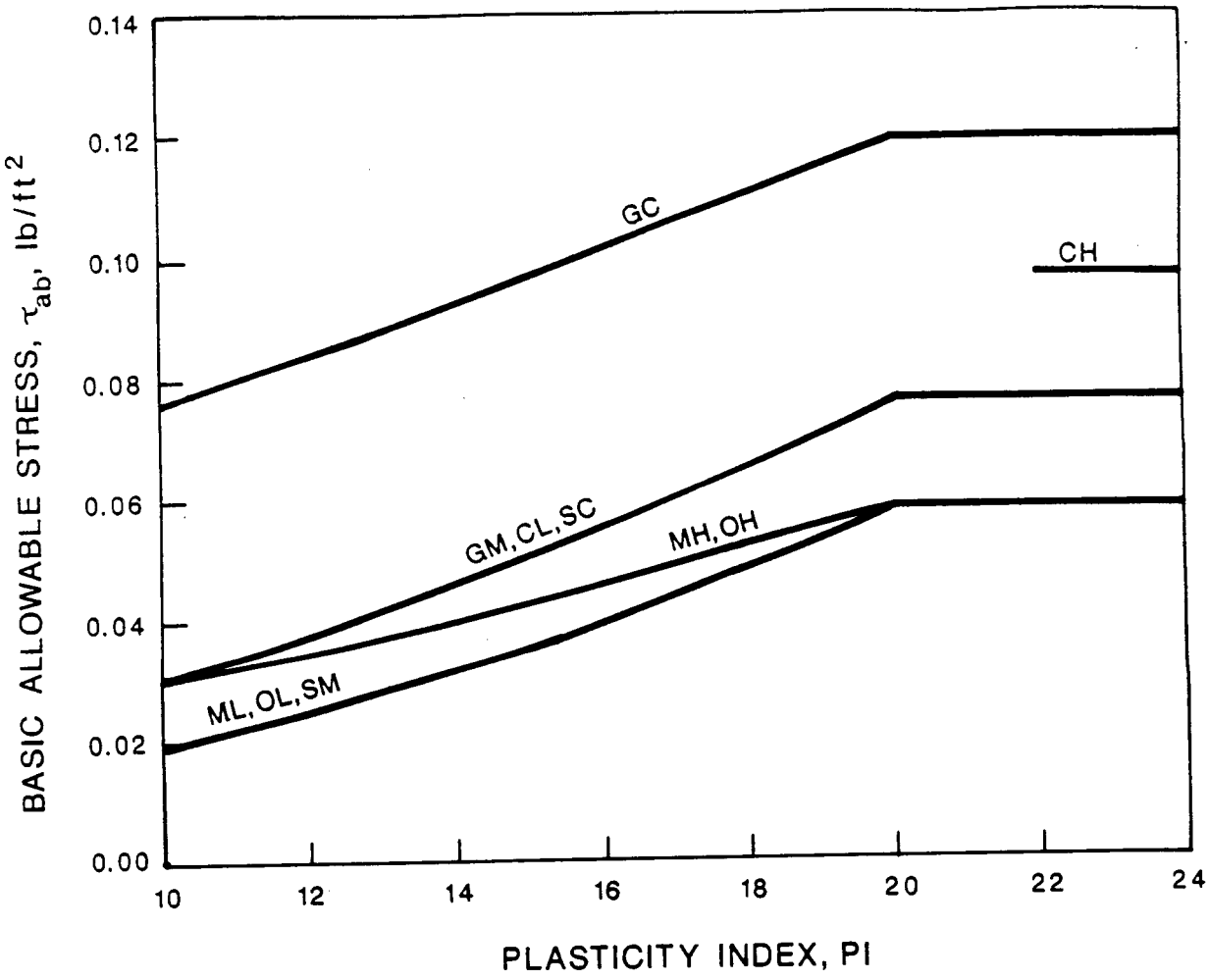
γ = unit weight of fluid (pcf).

D = depth of flow (feet).

S = slope of the energy grade line (feet/feet).

Analysis using Equations 16 and 17 are almost the same for bed angles less than 15 degrees from horizontal (27 percent). The unit weight of water (62.4 pcf) should be assumed to be the unit weight of the fluid; this assumption is good prior to erosion.

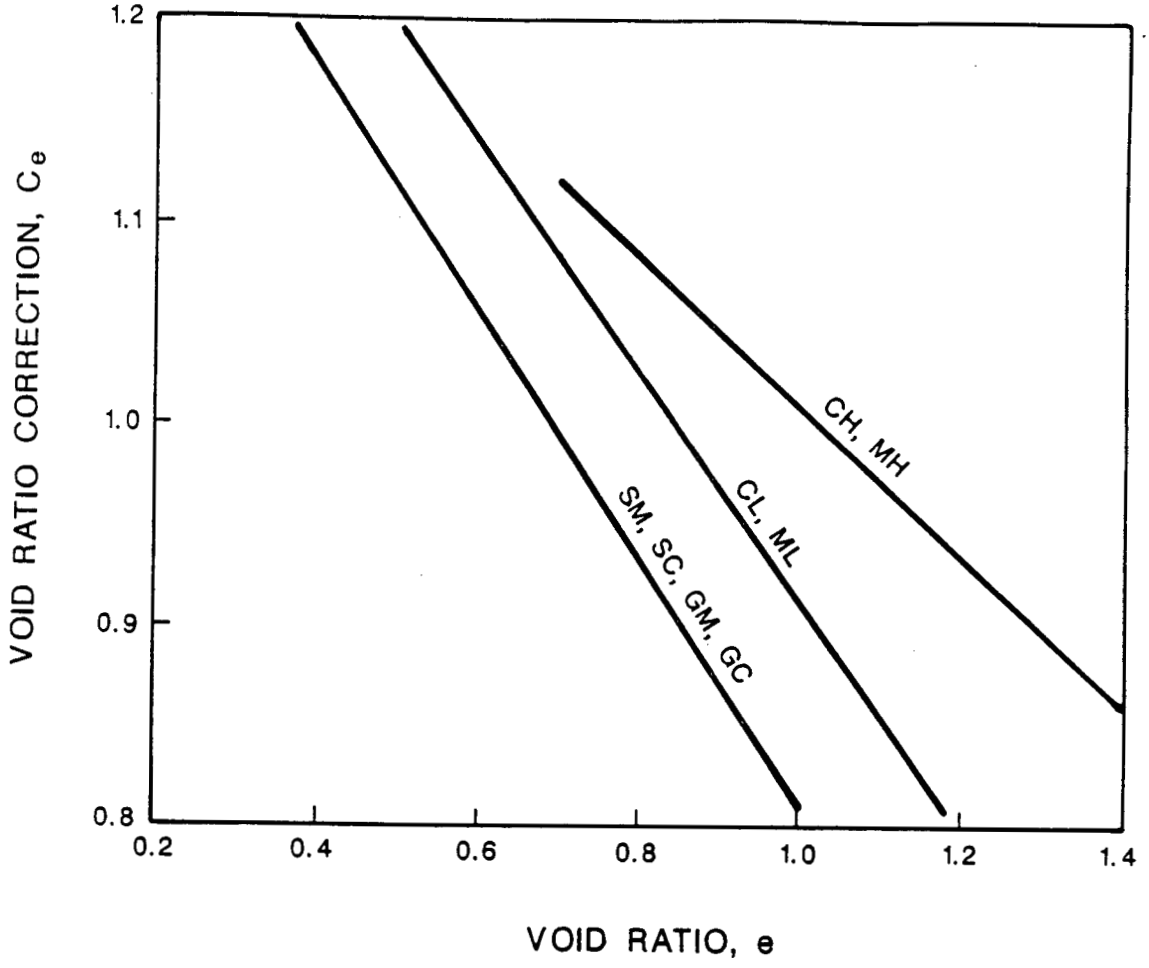
To use the tractive force formula, the depth of flow must be known. It is determined with Manning's equation:



REF: TEMPLE, 1987.

FIGURE 4.3

BASIC ALLOWABLE EFFECTIVE STRESS FOR COHESIVE SOILS



REF: TEMPLE, 1987.

FIGURE 4.4
VOID RATIO CORRECTION FACTOR FOR COHESIVE SOILS

$$V = 1.486/n \times R^{2/3} \times S^{1/2} \quad (18)$$

where

V = mean velocity of flow (feet per second, or fps).

n = Manning's resistance coefficient.

R = hydraulic radius (feet).

S = slope of the energy grade line (feet per feet).

Under sheet flow conditions the hydraulic radius is taken to be the depth (D) of flow. Equation 18 can be rewritten:

$$V = 1.486/n \times D^{2/3} \times S^{1/2} \quad (19)$$

The mean velocity of flow may also be determined by dividing the depth of flow into the unit discharge, q (cfs/foot). The unit discharge is determined using the Rational Formula (Section 4.1.3).

The unit discharge is further modified to account for flow concentrations and infiltration. For design purposes, the unit discharge should be multiplied by the product of a flow concentration factor and an infiltration factor. The infiltration factor is represented by runoff coefficients (C_R) presented in Table 4.7. A flow concentration factor of three (Abt et al., 1988) is recommended. Thus, the runoff ratio (F_{ci}) is defined as:

$$F_{ci} = 3 \times C_R.$$

Applying a unit width of one foot to the runoff area results in the runoff area equaling the length of the flow path. The maximum design flow will arise in the longest flow path. The unit discharge, q, can now be calculated as:

$$q = F_{ci} \times I \times L \quad (20)$$

where

I = rainfall intensity (inches/hour).

L = longest flow path (feet).

To have q in feet per second, divide I by 43,200 (inches per hour consistent with feet per second). From continuity, the velocity of flow can be calculated as $V = q/D$.

Using a trial and error procedure and by assuming and iterating values for "n" and by knowing q and S, the velocity and depth can be found to agree in both equations. The actual tractive shear stress can then be computed once the depth is known.

Table 4.7 Values of runoff coefficient (C_R)

Character of surface	Runoff coefficients	
	Range	Recommended
Pavement--asphalt or concrete	0.70-0.95	0.90
Gravel, from clean and loose to clayey and compact	0.25-0.70	0.50
Lawns (irrigated) sandy soil		
Flat, 2 percent	0.05-0.15	0.10
Average, 2 to 7 percent	0.15-0.20	0.17
Steep, 7 percent or more	0.20-0.30	0.25
Lawns (irrigated) heavy soil		
Flat, 2 percent	0.13-0.17	0.15
Average, 2 to 7 percent	0.18-0.23	0.20
Steep, 7 percent or more	0.25-0.35	0.30
Pasture and non-irrigated lawns		
Sand		
Bare	0.15-0.50	0.30
Light vegetation	0.10-0.40	0.25
Loam		
Bare	0.20-0.60	0.40
Light vegetation	0.10-0.45	0.30
Clay		
Bare	0.30-0.75	0.50
Light vegetation	0.20-0.60	0.40

Ref. Nelson et al., 1986.

In the extensive testing by the SCS to determine vegetal impedance as a function of Manning's "n" and the product of the velocity and hydraulic radius, five vegetation categories were defined. A "good" stand of vegetation describes the vegetation in each category. These categories are based on vegetation type, quality of the cover, and plant height. Temple (1980) fit curves to the data in each category by varying Manning's "n." The curve fitting was performed using a bi-level least square fitting routine to an exponential equation. This equation, relating Manning's "n" to the vegetal conditions within the flow field, is:

$$n_r = e^{(0.01329C_I\{\ln(RV)\}^2 - 0.09543\, C_I \ln(RV) + 0.2971C_I - 4.16)} \tag{21}$$

where

n_r = Manning's computed flow resistance coefficient.

e = naperian logarithm.

C_I = empirical parameter describing vegetal conditions within the flow field.

RV = product of the mean flow velocity and hydraulic radius. For sheet flow conditions this product is the velocity and depth of flow, VD or q.

Temple et al. (1987) related the empirical parameter, C_I, to each of the five categories of vegetation. The relationship between measurable vegetal properties and the parameter is:

$$C_I = 2.5 \times (h \times (M)^{1/2})^{1/3}$$

where

h = representative stem height (feet).

M = average stem density (stems per square foot).

The impedance potential as determined by the impedance curve index, C_I, should be determined on a site-specific basis. Since the vegetal cover will ultimately equal or exceed the natural succession (climax) vegetation present in the site area, a study of the local vegetation should be conducted to determine the height and stem density expected along with the type of vegetation. The stem length must be adjusted for the anticipated conditions at the time of expected flow; i.e., the longest length would be in late summer and the shortest in early spring. Table 4.8 (Temple et al., 1987) should be used as guidance in determining C_I.

Table 4.8 Empirical vegetal parameters for good uniform stands of each cover

Cover	C_f	C_I[a]	Reference stem density (stems/square foot)[b]
Burmuda grass, 12-inch height	0.9	10.00	500
Weeping lovegrass			500
Buffalo grass			400
Kentucky bluegrass	0.87	7.64	350
Blue gramma			350
Grass-legume mixture	0.75	5.60	200
Weeping lovegrass	0.75	5.60	350
Burmuda grass, 6-inch height	0.75	5.60	350
Yellow bluestem	0.75	5.60	350
Alfalfa[c]	0.5	4.44	350
Lespedeza sericea, 2-inch height[c]	0.5	4.44	300
Common lespedeza	0.5	4.44	150
Sudan grass	0.5	2.88	50
Bermuda grass, burned stubble	0.5	2.88	50

[a]If vegetation is not uniformly distributed over the areas present, C_I and C_f will be set equal to zero. In other words, the cover will be designed as if it were bare soil only.

[b]Multiply the stem densities given by 1/3, 2/3, 1, 4/3, and 5/3, for poor, fair, good, very good, and excellent covers, respectively. The equivalent adjustment to C_f remains a matter of engineering judgment until more data are obtained or a more analytical model is developed. A reasonable, but arbitrary, approach is to reduce the cover factor by 20 percent for fair stands and 50 percent for poor stands. Values of C_f for untested covers may be estimated by recognizing that the cover factor is dominated by density and uniformity of cover near the soils surface. Thus, the sod-forming grasses near the top of the table exhibit higher C_f values than the bunch grasses and annuals near the bottom.

[c]For the legumes tested, the effective stem count for resistance (given) is approximately five times the actual stem count very close to the bed. Similar adjustment may be needed for other unusually large-stemmed, branching, and/or woody vegetation.

Ref. Temple et al., 1987.

The resistance from detached soil particles at the soil/water boundary must also be accounted for when determining an effective Manning's "n" for vegetal resistance. This is done through Manning's "n" coefficient for the soil grain roughness, n_s. For coarse-grained soils this value is defined by Lane (1955) as:

$$n_s = \left(d_{75}^{1/6}\right) \div 39 \tag{22}$$

For fine-grained soil materials where d_{75} (see Equation 14) is less than 0.05 inch (1.27 millimeters), the soil grains are considered to be submerged in a viscous bedload sublayer of the flow. The influence of the soil grain roughness is considered to remain constant under these conditions at a limiting value of 0.0156 (Temple, 1980). The combined influence of the vegetation and soil roughness is accounted for in the Manning's coefficient of resistance on a vegetated slope as:

$$n_v' = (n_r^2 - (0.0156)^2 + n_s^2)^{1/2} \tag{23}$$

A coefficient K_v, relating the effects of the vegetal resistance, may now be defined. This coefficient relates the effects of vegetal impedance in the flow field (C_I) and in the immediate vicinity of the soil/water boundary (C_f). Typical values for C_f are also presented by Temple et al. (1987) and are listed in Table 4.8.

$$K_v = (1-C_f) \times (n_s/n_v')^2 \tag{24}$$

where

K_v = coefficient of vegetal resistance.

C_f = empirical parameter relating the potential of the vegetal cover to dissipate energy through turbulence in the immediate vicinity of the soil/water boundary.

n_s = Manning's coefficient associated with soil grain roughness as defined above.

n_v' = Manning's coefficient of resistance on a vegetative slope as defined in Equation 23.

The actual effective tractive shear stress applied to a vegetated soil slope at the soil/water boundary is the product of the computed actual tractive shear stress on a bare slope consisting of the same soil matrix and the coefficient of vegetal resistance, $\tau_e = \tau_0 \times K_v$.

The procedure for qualitatively determining the erosion resistance of a vegetated topslope is outlined below.

1. Determine the allowable tractive shear stress for the design soil matrix, τ_a, using Equation 14 or 15.

2. Determine the unit discharge rate, q, resulting from both the 100-year storm event and the PMP event.

3. Decide on an appropriate Manning's "n" for the soil matrix on the non-vegetated slope from values given in Chow (1959) or elsewhere.

4. Determine the flow depth for sheet flow down the slope using Manning's equation and the 100-year storm event unit discharge rate multiplied by F_{ci} and utilizing a trial and error iterative technique.

5. Calculate the actual tractive shear stress on the non-vegetated design slope, τ_o.

6. Calculate the shear stress ratio, τ_a/τ_o, for the non-vegetated slope conditions at the end of construction.

7. If the shear stress ratio is less than unity, the slope is unstable and will erode. The slope angle should be decreased or the soil properties changed until the ratio is greater than unity.

8. Estimate the empirical vegetal coefficients, C_I and C_f, for vegetation conditions expected to exist under long-term conditions at a given site.

9. Determine Manning's "n" for soil roughness, n_s.

10. Determine the computed flow resistance coefficient, n_r.

11. Compute Manning's coefficient of resistance on a vegetated slope, $n_v' = [n_r^2 - (0.0156)^2 + n_s^2]^{1/2}$.

12. Compute the flow depth down the vegetated slope using Manning's coefficient of resistance on a vegetated slope and the unit discharge from the PMP event using a trial and error technique.

13. Determine the coefficient of vegetal resistance, K_v.

14. Determine the effective actual tractive shear stress, τ_e, as the product of K_v and the actual shear stress, τ_o, using the PMP event to determine the flow depth.

15. Determine stability of the slope under long-term vegetated conditions through the stress ratio. Divide the allowable tractive shear stress, τ_a, by the effective shear stress, τ_e.

16. If the stress ratio is less than one, reassess long-term vegetation conditions and recalculate.

4.3.4 Biointrusion protection

In most cases, a vegetated cover should be underlain by a biointrusion layer to prevent roots and burrowing animals from penetrating the radon barrier and decreasing its resistance to the passage of moisture and radon gas. A loose-cobble biointrusion layer (biobarrier) has proven to be an effective impediment to the advancement of roots and burrowing animals (Hakonson, 1986). The barrier works because the interstitial airspaces are devoid of the soil and capillary water that plants need to grow and survive. The rocks also serve as a mechanical barrier to prairie dogs, rabbits, ground squirrels, and other burrowing animals that could move onto a stabilized pile.

A layer of choked rocks or geotextile should be placed on top of the cobbles to prevent the filtration of soil fines into the interstitial voids. Further, the cobbles should be underlain by a drain system to ensure that water does not accumulate in the biobarrier, but rather is quickly moved off the pile.

The loose-cobble biobarrier also contributes to the desired water balance, i.e., the promotion of evapotranspiration relative to the drainage of water into the tailings. The rock layer is expected to act as a capillary barrier to the downward movement of water, allowing significant quantities of moisture to drain out of the overlying soil only when that overlying layer is saturated. This prolongs the period during which water in the overlying layer is available for evapotranspiration.

Preliminary cover designs for proposed waste isolation cells at the Hanford Reservation (Waugh, 1988) incorporate cobble biobarriers of a meter or more in thickness. This thickness is greater than should be necessary for the UMTRA Project because uranium mill tailings are less hazardous and the design life is less than for the Hanford program (which has a 10,000 year performance requirement). The position of the DOE on biointrusion is that a biobarrier thickness of greater than one foot is impractical over the large surface areas of stabilized UMTRA Project piles. Instead of producing a thick biobarrier, the approach should be to construct an efficient layer in which interstices remain free of soil and water, and any given root will be obstructed by at least two voids between the overlying soil and underlying waste. Rocks in the barrier will have a minimum diameter of one inch and a maximum diameter of less than one-half the total layer thickness. With these specifications, few roots will reach the contaminated materials.

The cobble biobarrier described above is appropriate beneath a vegetated cover consisting of soil and selected plant species. An

additional strategy to prevent root penetration is to provide a sufficiently large region (thickness of soil) with favorable water relations and nutrient capacity so that plants will not be perpetually stressed, hence will not be as likely to extend their roots into an unfavorable medium (the biointrusion layer) for water and nutrients. The same logic applies to burrowing animals in that prairie dogs or ground squirrels will not attempt to move into a rocky, unfavorable medium if a generous layer of favorable soil is available.

The decision on whether to underlay the soil of a vegetative cover with a loose cobble biointrusion layer will depend on the local climate, the properties and thickness of the soil used as a rooting medium, and the rooting characteristics of the plant community anticipated on the cover. Table 4.9 lists factors that may be considered in judging the biointrusion hazard (specifically, the likelihood that roots will penetrate the radon barrier) of a vegetative cover with and without a biointrusion layer. In some cases, it may be possible to place a thick layer of soil with the appropriate properties to encourage the growth of shallow-rooted species. For instance, a thick layer of clay-rich soil may be applied over the radon barrier and seeded with local range grasses, which should competitively preclude the invasion of the vegetated surfaces by deep-rooted trees and shrubs. This is possible where the climate will support a more or less uninterrupted cover of perennial grasses (on the appropriate soil). In every case, the decision to establish a vegetative cover without an underlying biointrusion layer should be made only after a thorough investigation of the local climate, soils, and vegetation. This will insure that potential biointrusion scenarios are accounted for and that the cover may be engineered to favor a plant community that will minimize the likelihood of root penetration of the radon barrier.

4.3.5 Water balance assessment

The ability of a vegetated cover to maintain the desired water balance can be optimized and assessed using water balance models such as CREAMS and HELP (Knisel, 1980; Schroeder et al., 1984, respectively). Table 4.10 lists the various features of the models. None of the models currently incorporates all of the major phenomena needed to simulate moisture movement through UMTRA Project covers accurately, although they may be useful in making predictions. The models are being continually upgraded, and the user should ascertain that he/she is working with the most current version, or with the version that most strongly applies to the UMTRA Project.

During the design process, a water balance model may first be used to optimize elements of the vegetated cover. Design parameters may be experimentally manipulated to determine which configuration results in the highest percentage of moisture being transpired and the smallest percentage being allowed to percolate into the tailings.

Table 4.9 Characteristics related to the likelihood of biointrusion in a stabilized pile with a vegetative cover

Element	Higher risk conditions	Lower risk conditions
Biota	o Large trees or deep-rooting shrubs (e.g., phreatophytes)	o Predominantly grassy vegetation in vicinity
	o Long growing season	o Little or no topsoil in region
	o Humid to subhumid climate	o Short growing season
	o Colonies of burrowing animals (prairie dogs, gophers)	o Arid or semiarid climate
Cover Design		
1. Topsoil	o Not underlain by a biointrusion barrier	o Underlain by biointrusion barrier
	o Less than optimal thickness as predicted by water-balance models	o Optimal thickness for moisture retention
	o Poor moisture and nutrient relations (too much sand or clay)	o Favorable moisture and nutrient relations (loamy soil)
2. Biointrusion barrier (choke rock cap and poorly graded cobbles)	o Absent	
	o Not properly drained by conductive and restrictive layers	o Well drained with adequate choke rock design
	o Poor choke rock design	
	o Rock size (and pore size) too small to allow adequate void air space	o Rock size of two inches or larger
	o Layer too thin (fewer than two interstitial voids along the path of a given root)	o High quality rock with low percentage of absorbency
3. Conductive (drain) layer (also called filter bedding)	o Low permeability	o High permeability
	o Too thin	
4. Restrictive layer (e.g., Claymax[R] and/or radon barrier)	o High permeability	o Low permeability
	o Susceptible to freeze-thaw action or cracking action or other weathering	o Insulated from or resistent to freeze-thaw

Table 4.10 Comparison of features of some infiltration models with explicit vegetative transpiration terms

Feature	Model	
	HELP (Version 2)	CREAMS
Vertical unsaturated flow	Gross water balance-Darcian flow with free outflow (unit gradient), unsaturated hydraulic conductivity as function of water content (modified Brooks-Corey equation).	Gross water balance-Darcian flow analogue with approximate unsaturated hydraulic conductivity. For "breakpoint" precipitation, use Green-Ampt infiltration model.
Runoff	SCS Curve Method	SCS Curve Method - Green-Ampt infiltration model for "breakpoint" precipitation
Lateral drainage	Steady-state Boussinesq equation	None
Evapotranspiration	PET[a] from modified Penman equation Soil evaporation calculated from plant interception and snow accumulation Transpiration calculated from LAI[b] given by vegetative growth and decay model	PET[a] from modified Penman equation Actual evapotranspiration calculated as in HELP For "breakpoint precipitation, root extraction estimated, with root growth proportional to LAI[b]

[a]PET = Potential evapotranspiration.
[b]LAI = Leaf area index.

Note: Models selected from those previously applied to assessment of UMTRA Project or other DOE low-level waste disposal facilities.

Features as described in and/or inferred from model documentation.

Once an optimum combination of design parameters has been selected and the overall cover design has advanced to a relatively final condition, a water balance model may be used to assess the long-term performance of the proposed design. The proposed design parameters and the best available climate data may be used to run simulations of precipitation events and resultant cover performance.

Users' guides for the water balance models generally provide tables of default values for some parameters that may be unknown or difficult to estimate. For instance, a value is needed for the leaf area index, which describes the ratio of transpiring vegetative surface area relative to the ground surface area. This may be estimated from the tables in the users' guide, although first-hand observation of the "model plant community" (to be emulated by the vegetation community on the vegetative cover) will improve the estimate. As with all models, the user must apply water balance models with caution, ascribing a level of confidence in the results of the modeling that is proportional to the level of confidence in the input parameters.

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5.0 GEOLOGICAL STABILITY

5.1 GEOLOGY

5.1.1 Introduction

Geologic characterization of UMTRA Project sites is an integral part of the overall design effort. This characterization consists of a summary of the regional geologic setting, local geology, regional and local structures, quaternary geology of the site region, and the local distribution of surficial units. The in-depth geologic studies are presented in the site characterization section of the final RAP. The geologic studies are closely related to other aspects of the site characterization effort (e.g., groundwater hydrology analysis, derivation of design parameters for geotechnical analyses of slope stability and liquefaction potential, geomorphic seismic hazard studies, and assessment of the possible future impacts of mineral resource development).

5.1.2 Technical approach

The geologic characterization study for an UMTRA Project site includes all of the elements discussed below. Emphasis is placed on basic site-specific characterization efforts. Detailed investigation of specific geologic hazards (e.g., seismic or geomorphic hazard studies, analysis of future impact of mineral resource development) is performed concurrently with the geologic study and uses the data developed.

Compilation and analysis of previous work

All pertinent stratigraphic, lithologic, geophysical, mineral resource, tectonic, and soils mapping information and literature are obtained and reviewed. The literature review is aided by the use of a GeoRef data search to assure more complete coverage. Previous geologic data compiled by the UMTRA Project, including all previous studies and all on-site and near-site subsurface data, are obtained. Subsurface data are correlated to the available data on the local and regional geologic setting. A search for unpublished geologic data or studies in the site area is conducted. Personal communications with researchers and authors of published and unpublished reports on the local and regional geology are used whenever possible.

An initial geologic compilation made on regional and local base maps is prepared for use in subsequent characterization efforts. This includes a detailed geologic map of the site vicinity. Conclusions are made regarding the completeness and reliability of the available information. Any apparent deficiencies will be identified as early as possible in the characterization process.

Additional studies will be recommended where significant discrepancies or deficiencies in the data exist.

Ground reconnaissance and mapping

A surface geologic map of the area is compiled that covers approximately a one-kilometer radius of the site to show significant geomorphic or bedrock features. The map is refined during detailed reconnaissance. Features such as formation contacts, local structural data (folds, faults and joints systems, orientations of bedding, and the like), and descriptions of exposed units are verified. The mapping effort includes exposed bedrock and surficial units. Special attention is given to units in the immediate vicinity of and beneath the final location of the pile. To the extent possible, subsurface data will be interpreted in the light of surface geology.

In addition to the surface geologic map, subsurface cross sections through the site area, especially beneath the pile, are prepared. This is done using both previously published data and logs of exploratory boreholes, test pits, and trenches advanced in the site area during the UMTRA Project site investigation.

Field descriptions and in-place conditions of contaminated materials and any other artificial fill are carefully recorded. Particular attention is paid to the potential impacts of past, present, or future human activities and adverse forces of nature on site geologic conditions.

Any other conditions representing potential geologic hazards are carefully noted. These could include evidence of subsidence, landslides, slope creep, frost heave, expansive or collapsing soils, areas of flooding or rapid erosion, evidence of active faulting, and so forth. Specific hazards will be addressed in studies following the initial geologic site characterization (e.g., seismic and geomorphic hazard studies; analysis of potential future human impacts on the site area). The approach to seismic and geomorphic studies is presented in Sections 5.4 and 5.2, respectively.

Photogeologic interpretation of remote sensing imagery

A complete representative suite of remote sensing imagery (LANDSAT or ERTS and NASA high-altitude photographs) is obtained for the site region. This imagery is carefully examined to determine the significance of regional geologic features. These features may include regional structural trends in bedrock, large-scale surficial processes, volcanic trends, migrating dune fields, and economically important resources. Any previously unrecognized or anomalous features or trends, migrating dune fields, and economically important resources are identified for further study.

5.1.3 Geologic site characterization report

The results of the geologic site characterization effort will include a detailed summary of the scope of work performed, a complete listing of all sources reviewed, and the presentation of representative maps, stratigraphic columns, cross sections of the site area, and a summary discussion of regional and local geology; in particular, Quaternary or surficial geology. A detailed discussion of the specific points discussed within the context of the overall site report follows.

Regional bedrock setting

A regional bedrock geologic map is compiled from published and unpublished sources. This is accompanied by discussions of the distribution, thickness, age, lithology and stratigraphy of bedrock formations, abundance of natural exposure, landform expressions of various units, and specific discussion of the distribution and age of volcanic units. The regional structural setting is discussed, including regional stratigraphic attitudes, the distribution of folds and faults, zones of uplift or subsidence, and a discussion of the structural history. The presence or absence of evaporites in the stratigraphy is noted. The distribution of surficial units and the regional geomorphic history are discussed in detail. Elements of this discussion include regional and local surficial geologic maps, a soils map of the site area, and discussions of regional surficial geologic processes.

Site geology

A detailed bedrock and surficial geologic map of the area within an approximate one-kilometer radius of the site (the area covered may vary depending on the complexity of the geology within the study area and the scale necessary to show sufficient detail), geologic cross sections using surface mapping and borehole or geophysical data, and a graphical description of pile foundation conditions are prepared. The maps are accompanied by a discussion relating the local geology to the regional setting, and discussions of the thickness, distribution, structural features, weathering, competency, and surficial expression of the local geologic units. Detailed discussions of each unit (including color, grain size distribution, cementation, and landform expression) are included. The report details structural features such as faults, folds, bedding orientations, and zones of intense fracturing or high permeability. Areas of artificial fill, tailings, windblown materials, subsidence, or landslide features, and evidence of slope creep, frost heave, and expansive, collapsing, or erosive soils will be noted. Human structures or potential future human activities that could affect site stability will be noted and discussed.

5.2 GEOMORPHOLOGY

5.2.1 Introduction

The purposes of the geomorphic hazard assessment are (1) to identify the geomorphic processes that affect the site; (2) to estimate the probability of their occurrence; and (3) to evaluate the possible magnitude of their effects during the life of the stabilized pile. The general approach used to fulfill these purposes involves three steps: (1) identification of past geomorphic processes and estimation of their rates from the geomorphic and stratigraphic records (postglacial time, roughly 10,000 years); (2) identification of present geomorphic processes and estimation of their rates from historic records and field observations (typically less than 80 years); and (3) prediction of future geomorphic processes and rates with appropriate allowances for various uncertainties associated with such processes. This process involves the integration of data at varying scales of space (regional to single-point) and time (thousands of years to instantaneous).

Hazard assessments must be primarily qualitative to semi-quantitative. Although quantitative models have been developed for many geomorphic processes, these models have limited applicability because they were developed for a specific range of conditions, or because the data required are unavailable and cannot be obtained economically from cost and benefit considerations for the UMTRA Project.

The scope of each geomorphic study depends on the hazards identified and the magnitude of their potential impact on the site. To reduce effort to the minimum acceptable level, a critical path approach is used. In such an approach, site suitability is assessed with respect to the most critical hazards before time is spent investigating lesser hazards. This approach can be complicated by the fact that some processes, such as mass wasting, are episodic, and their probability of occurrence is difficult to assess. At some sites with several significant hazards, considerable effort may be required to determine which is the most critical. Nevertheless, the level of effort required will vary between sites. Some sites may be clearly suitable, and others clearly unsuitable, based upon a relatively small amount of work at sites having significant geomorphic hazards. Detailed efforts will typically be required at sites having significant geomorphic hazards.

The scope of the investigation also depends, to some extent, on the type and quantity of available information. This information can be in the form of previous work or preserved in the local geology. The quantity and quality of data can vary considerably among sites. The best available database developed using an economically feasible program will be used for geomorphic evaluation.

For the UMTRA Project, results of the geomorphic studies are used directly in site selection and remedial action design. The geomorphic studies also interrelate with other studies as follows:

- o Identification of flood hazards.
  - Establishment of valley cross sections and identification of materials (bedrock, colluvium) for flood modeling.
  - Assessment of the realism of the proposed peak depth, width, and discharge of the design flood by comparison with stratigraphic and geomorphic evidence.
  - Assessment of the potential for channel avulsion during the design flood.
  - Assessment of the impacts of erosion and deposition of sediment during flood events.
- o Geotechnical studies.
  - Prediction of the distribution of subsurface materials from information about their origin.
  - Determination of the stratigraphy of surficial deposits from test pits, borings, and natural exposures.
- o Seismic and tectonic studies. Provision of geomorphic evidence of neotectonic activity.
- o Selection and sizing of materials for riprap and erosion control. Consideration of deposits of desert pavement, talus, and stream gravel that have demonstrated resistance to weathering conditions in the local environment.

Two reports have discussed the most current methods for identifying and assessing geomorphic hazards. Schumm and Chorley (1983) provide a theoretical discussion of geomorphic processes that may affect a tailings site, including references to recent literature sources that illustrate various methods of assessment. Nelson et al. (1983) offer a handbook approach to the most probable hazards, including specific methods for assessment, engineering procedures for mitigation, and confidence levels for hazard predictions over periods of 200, 500, and 1000 years. The following summaries of procedures for assessing the most common critical hazards are adapted from their reports.

Schumm and Chorley (1983) have identified 28 geomorphic processes that may create hazards for tailings sites. The hazards are grouped by location within the fluvial system (drainage networks, slopes, rivers, piedmont, and coastal plain), and by process (erosion, deposition, pattern change, and metamorphosis). Their

tabulation serves as a checklist to assist in identifying potential hazards although, typically, only a few of the hazards will be of concern at many sites.

Because most sites are in small tributary valleys or near major rivers, the geomorphic hazards that are most common are river channel changes, gully intrusion, slope erosion, and mass wasting.

5.2.2 General approach for geomorphic hazard evaluation

To the extent possible, and commensurate with the nature of suspected geomorphic hazards, the data enumerated below are collected and interpreted, or the stated actions taken.

- o Aerial photographs and maps.
  - Sequential photographs for a period of decades.
  - Plat maps made by the General Land Office in the late 19th or early 20th centuries.
  - Early and current topographic maps.
  - Early city maps prepared by city councils, utility companies, and insurance companies.
- o Regional data on geology, geomorphology, hydrology, soils, and climate.
  - Published geologic maps and literature.
  - Unpublished geologic data from public and private agencies, universities, or researchers active in the region.
  - Soil surveys.
  - Repeat first-order geodetic surveys that may provide information on active uplift or subsidence.
  - Hydrologic data for gauging stations.
  - Climatic data for weather stations and airports.
  - Studies of trends in historic weather records.
  - Paleoclimatic data and reconstructions.
- o Site-specific data on geology, geomorphology, hydrology, climate, soils, and potential land-use changes.

- Files of Federal, state, and local agencies.

- Published geologic maps and data.

- Research stations maintained by universities or local companies.

- Conversations with local residents.

- Written records and old photographs from newspaper offices and historical societies.

o Preliminary evaluation and identification of objectives for field studies.

o Field studies.

- Aerial reconnaissance.

- Ground inspection of site and vicinity.

Geomorphic hazard assessments include the surrounding region, as well as the actual site, for several reasons. Processes that occur locally, such as mass wasting, may be better expressed in nearby areas. Processes now occurring beyond the boundaries of the site may eventually extend into the site (e.g., aggradation by back-filling or downfilling, gully erosion, knickpoint migration, and disturbances due to changes in land use). Finally, in the absence of detailed information about geomorphic processes within the site, knowledge of the processes occurring on a regional scale can be helpful in assessing the types and rates of local processes.

5.2.3 Standard methods for assessing common hazards

River hazards

Hazards from channel erosion, aggradation, and lateral shifting are difficult to evaluate for several reasons. First, the behavior of a river at a site depends not only on the stability of the particular reach, but also on the stability of upstream and downstream reaches. Furthermore, episodic natural disturbances (e.g., floods, droughts, earthquakes, landslides, forest fires, and hurricanes) may have a major effect on river behavior. Finally, human changes in the drainage basin, stream-channel, and discharge (such as altered vegetation, surface materials, and landforms; channelization; and water diversion or impoundment in reservoirs) may also have significant effects. The main steps in the evaluation are as follows:

o Collection and review of available data.

- Topographic, geologic, and soil maps.

- Aerial photographs.

- Hydrologic data, particularly river stage and discharge records.

- Land use plans.

o Preliminary analysis of the data.

- Late Pleistocene and Holocene stratigraphic units that indicate long-term trends in river behavior.

- Present channel pattern.

- Identification of potential sites for field investigation.

o Field investigation.

- Aerial reconnaissance extending at least 20 miles upstream and downstream from the site. To document present conditions photographically, identify features that could affect the river at the site (knickpoints, aggradation by downfilling or backfilling, avulsions, changes in land use upstream from the site), observe typical mechanisms of channel pattern evolution, and identify specific sites for further examination.

- Site inspection to determine channel morphology, bank erosion, sediment characteristics (banks and bed), and vegetation characteristics.

- Verification and possible dating of Holocene deposits.

o Historical studies.

- Changes in channel cross sections at bridges.

- Changes in gauge height at constant discharge.

- Changes in frequency of overbank flooding.

- Age of vegetation in floodplain.

Gully erosion

Gullies can form in a site where none previously existed, or can extend into a site by headward erosion. Two principal methods exist for addressing potential gully formation in previously ungullied areas. Both require data on valley-floor slope and drainage basin area for gullied and ungullied basins near the site.

- Empirical method. Valley-floor slope is plotted against the drainage basin area to determine the threshold slope for gully initiation.

- Tractive force method. Values of a tractive force indicator are calculated from regression equations and are plotted on the diagram; the values provide further information about the relative stability of the ungullied basins.

Although these methods are the best available, they have certain limitations. Artificial concentration of runoff by disturbance of the land surface (either human or animal) can make valley floors more susceptible to gullying than would be predicted. Therefore, the methods may be unreliable in areas of past or future ground disturbance. Second, Nelson et al. (1983) state that gully initiation by the PMP should be considered; however, both methods reflect normal historic precipitation patterns.

For basins within existing gully systems, rates of headward migration may be measured from successive aerial photographs or estimated from conversation with local residents. However, future migration rates may differ because of changes in land use, or (less probably) baselevel or tectonic uplift rate. No models or techniques exist to predict the magnitude of gully erosion once it does occur; therefore, prevention of gullies or avoidance of gullied areas is critical to ensure the longevity of the stabilized pile.

Mass movements

The following should be performed to identify and evaluate mass movements:

- Identification of existing mass movements, if present, from their characteristic geomorphic expression.

- Analysis of the movement's contribution to instability, including relative relief, slope aspect, angle and configuration, soil thickness, clay content, weak or closely jointed rock, and orientation of joints and bedding planes.

- Assessment of potential instability near the site, based on the presence of contributing factors.

In many areas, large mass movements occurred during the moist periods of the Pleistocene epoch, and are relic features. Thus, the age of existing mass movements should be assessed from their freshness, or by using relative dating techniques.

Slope erosion

Rates of erosion on relatively short slopes in tributary basins may be evaluated as follows:

- Observations of filling, stability of soil and colluvium, and stripping of soil from tree roots.
- Comparison with measured or estimated rates for comparable conditions.
- Evaluations of rates of erosional retreat of major escarpments.
- Reconstruction based on geomorphic history. (For example, if the width of a canyon and the time when cutting began are known, an average rate of scarp retreat can be calculated.)
- Estimations of the age of talus remnants that formerly were graded to the scarp.

Effects of tectonism and climatic or base level change

The effects of changes in tectonic activity, climate, and base-level are evaluated by considering the associated variations in runoff, discharge, relief, and sediment yield. Published regional studies are especially helpful. In some areas, artificially induced changes in vegetation may indicate the kinds of changes in slope and channel behavior that would accompany a shift to moister or drier conditions. Schumm and Chorley (1983) mention several studies of river adjustment to tectonic activity; however, more recently, Ouchi (1985) has identified diagnostic channel pattern changes from flume experiments.

5.3 SUBSURFACE INVESTIGATION

5.3.1 Introduction

The purpose of geological characterization of UMTRA Project sites and site regions is to characterize processing and disposal site subsurface conditions, foundation soils, bedrock stratigraphy, and proposed borrow sources. The stratigraphy and physical properties of materials composing the stratigraphic units are characterized. Stratigraphy is determined by using information logged in boreholes and test pits. Geophysical surveys may also be used to define stratigraphy. Material properties are determined by field and laboratory tests. The nature and extent of investigations will vary from site to site. This section describes exploration methods and tests used for disposal sites and borrow areas. Groundwater site characterization, interrelated with geological site characterization, is described in Section 8.1.

Detailed procedures used in conducting the field investigations and laboratory tests are consistent with currently accepted practice in the United States.

The programs outlined in this section are the minimum efforts considered necessary to define site characteristics. Each site characterization program is designed to fit the data needs and characteristics of the individual site. If necessary, multiple or phased field and laboratory investigation programs are conducted in order to obtain the required data in a timely and cost-effective manner.

5.3.2 Archived data

In order to assess the data needed at a specific site and to avoid duplication of effort, the available data for the particular site are reviewed. The review includes a review of available information on existing boreholes and test pits, site and regional geology, laboratory test data, and other applicable data which may influence site characterization. In particular, as much information as is available about the geology of the site is reviewed before planning a site characterization program. These and other data are presented in a summary of site characterization efforts and are an integral part of the Comparative Analysis of Disposal Site Alternatives Report and the RAP.

5.3.3 Alternative site selection

Alternative site selection is conducted for UMTRA Project sites in order to identify alternative sites for disposal of contaminated materials if stabilization in place is technically unsuitable or too expensive. Alternative site selection studies and the process of complying with the National Environmental Policy Act (NEPA) result in the identification of the preferred alternative. In order to provide the preliminary subsurface information necessary to evaluate alternate sites, one to three conventional soil or rock borings are completed at the processing site and alternate disposal sites. Testing and sampling consists of standard penetration tests (SPTs) done at five-foot or other suitable intervals through soils deposits; rock cores are obtained in bedrock. Borehole depths and spacings are determined on a site-specific basis; temporary standpipes or permanently installed monitor wells may be installed as appropriate to measure groundwater levels.

5.3.4 Disposal site characterization

Field studies

Disposal area. Borings are required in order to determine the foundation soil and bedrock characteristics at a disposal site. The density of borings is approximately one for every three acres. A sufficient area is covered to allow repositioning of the pile within the general area of interest. Shelby tube, split barrel (2.5-inch diameter), and SPT samples are collected to classify the soils,

correlate data, and test in the laboratory. Groundwater levels are determined at the time of drilling; generally, piezometers are not installed unless groundwater studies (Section 8.1) fail to identify static groundwater levels. Where applicable, field packer tests may be conducted in order to determine in situ hydraulic conductivity in bedrock.

While the approximate number of borings is indicated above, the location and depth of borings depend upon site conditions. A grid pattern may be desirable at one location, but inappropriate at another. The layout and position of holes should be defined for each site in order to define site-specific subsurface conditions. Additional borings may be required if unusual or variable site conditions are encountered.

Laboratory tests

Laboratory tests are performed on disturbed and undisturbed soil samples. Table 5.1 lists laboratory tests that may be performed.

5.3.5 Borrow area sites

General

Borrow areas include sources of soil, sand, gravel, and rock and are identified by performing a borrow assessment. This assessment is performed by geologists or geotechnical engineers and consists of a review of pertinent data and site visits. Local commercial sources and individual suppliers are contacted in order to obtain information on the availability of local borrow sources. Other sources of useful information include the SCS, U.S. Forest Service, state and local highway departments, and the like. Existing borrow sources for which a sufficient amount of geotechnical data are available may be suitable for use, therefore reducing the amount of characterization required.

The suitability and required quantities of borrow materials as well as the distances of the borrow sources from the site are considered in selecting candidate borrow sources for investigation.

Radon cover preliminary study

Field program. Following the borrow source assessment, a limited number of areas are investigated by excavating eight to 12 test pits at each area. The test pits are spaced to provide representative coverage and to define the limits of suitable borrow material. Both large and small bulk samples are obtained in order to perform classification and material properties tests. A field log of each test pit is compiled and refined later based on laboratory test data. Water levels are recorded if water is

Table 5.1 Laboratory tests

Sieve analysis without hydrometer (ASTM C136)
Sieve analysis with hydrometer (ASTM D422)
Atterberg limits (ASTM D4318)
Moisture content (ASTM D2216)
Moisture density (ASTM D698)
Moisture density (ASTM D1557)
Capillary moisture relationships (ASTM D3152 and ASTM D2325)
Specific gravity (ASTM D854)
Triaxial permeability (EM1110-2-1906)
Three point sets Triaxial (R) (Army Corps of Engineers EM1110-2-1906)
Three point sets Triaxial (Q) (Army Corps of Engineers EM1110-2-1906)
Three point direct shear test (CD) (ASTM D3080)
Three point direct shear test (CU)
Three point direct shear test (UU)
Dry density
One-dimensional consolidation (ASTM D2435)
Crumb tests (ASTM Proceedings STP623)
Pinhole (ASTM Proceedings STP623)
Double hydrometer (ASTM D422)
Aggregate specific gravity and absorption (ASTM C127 or C128)
Sulfate soundness (sodium sulfate method) (ASTM C88--course aggregate only)
Los Angeles abrasion (ASTM C131 or C535)

Other tests that may be periodically requested include:

Unconfined compression (ASTM D2166)
Relative density (ASTM D2453 and D4254)
Percent passing No. 200 sieve
Expansion, shrinkage, and uplift (ASTM D3877)
Falling head permeability conducted in association with consolidation tests (per load increment)
Shrinkage limits (ASTM D427)
Petrographic analysis of rock samples (ASTM C295)
Partially saturated hydraulic conductivity
Rock core permeability
Three point sets California Bearing Ratio (ASTM D1883)
Constant head permeability (Army Corps of Engineers EM1110-2-1906)
Falling head permeability (Army Corps of Engineers EM1110-2-1906)
Indirect tensile strength (Brazilian disc) of rock (ISRM Method)
Schmidt impact hammer
Sonic velocity

encountered. The limits of suitable borrow areas are mapped during the field studies with the quantity of material available being compared to the quantity needed. A sufficient volume of borrow materials should be identified to provide approximately 1.5 to 2.5 times the volume of materials required by the in-place construction to make allowance for unsuitable soils, shrinkage, and other uncertainties.

Laboratory tests. From visual examination of the soil samples and a review of test pit logs, the most suitable borrow area is selected and samples from this area are tested in the laboratory for index and engineering properties. More than one area may be tested if the most suitable source cannot be identified prior to testing. Selected samples from the field program are tested for their physical and mechanical properties, strength, compressibility, hydraulic conductivity, capillary moisture, radon diffusion, and erodability. Depending on the nature of the borrow source, individual or mixed samples are tested.

Rock erosion protection preliminary study

Field program. Following the borrow assessment, one or more areas are investigated in order to define the limits and quality of rock borrow material. For sand and gravel sites, a minimum of six to eight test pits are excavated at each area. Both large and small bulk samples are obtained in order to perform classification and material properties tests. A field log of each test pit is prepared. For quarries with exposed bedrock, samples are obtained from rock outcrop areas. Schmidt hammer tests may be used on rock outcrops for preliminary field evaluation of rock quality.

Laboratory tests. Using visual examination of sand, gravel, or rock obtained from the field program and reviewing the test pit logs, the most suitable borrow area is selected for further testing. If this cannot be done, several areas may be tested. Samples from the test blasts and/or pits are tested for acceptable durability and soundness as outlined in Section 4.2.1, Erosion protection.

Borrow source final selection

Field program. After evaluating the field and laboratory test results from the preliminary study, a final field investigation is performed to verify the quantity and quality of available borrow materials (for the radon cover and erosion protection materials). The nature of this program depends upon the borrow site's characteristics. It may involve core drilling as close as 100 feet on center, test blasting, and/or the excavation of more test pits, until the presence of sufficient quantities of acceptable quality material are verified. Water levels should be recorded. Samples or cores are obtained approximately on five-foot intervals. In-place

density tests may be performed on soils in order to evaluate site-specific shrinkage or expansive factors needed during construction.

Laboratory testing program. A laboratory testing program consisting of gradation, Atterberg limits, moisture and density determinations, and other tests, as appropriate, selected from Table 5.1 will be performed in order to verify the correlation of the desirable material types in soils. For rock borrow sites, a petrographic analysis of rock thin sections will be conducted as a verification of suitable material types. Additional radon diffusion and emanation coefficient tests and capillary moisture tests will be performed on soils to determine the parameters required for the final design of the radon barrier (see Section 10.0, Alternate Site Selection).

5.4 SEISMIC

5.4.1 Introduction

As part of the design of remedial works at UMTRA Project sites, studies are conducted to determine the seismic hazard. These evaluations result in a seismotectonic characterization of each site and provide a set of earthquake design parameters. These parameters include the design earthquake magnitude; the on-site peak horizontal ground acceleration; the distances to and lengths of capable faults; and the types of capable faults and associated displacement. During the seismic investigation, the potential for on-site fault rupture is also analyzed.

Based on the findings of the seismotectonic characterization (Sections 5.4.2 and 5.4.3), further earthquake engineering analyses are completed. These analyses may include the development of additional parameters that are dependent on the local subsurface conditions. Section 5.4.4 describes the development of site-specific engineering design parameters.

5.4.2 Criteria and definitions

The following are the standards and definitions applied when evaluating the seismic hazard at UMTRA Project sites.

- Design life. As specified by the EPA Promulgated Standards for Remedial Actions at Inactive Uranium Processing Sites (40 CFR 192), the controls implemented at UMTRA Project sites are to be effective for up to 1000 years, to the extent reasonably achievable and, in any case, for at least 200 years. For the purpose of the seismic hazard evaluation, a 1000-year design life is adopted.

- Design earthquake. For UMTRA Project sites, the magnitude(s) of the earthquake(s) that produces the largest on-site peak horizontal acceleration and that produces the most severe effects upon the site is the design earthquake. This earthquake could be either a floating earthquake or an earthquake whose magnitude is derived from a relationship between fault length and maximum magnitude. The latter case is applied for a verified or assumed capable fault of known rupture length.

- Floating earthquake (FE). An FE is an earthquake within a specific seismotectonic province that is not associated with a known tectonic structure. Before assigning the FE magnitude, the earthquake history and tectonic character of the province are analyzed.

- Capable fault. A capable fault is a fault that has exhibited one or more of the following characteristics:

  - Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

  - Macroseismicity (magnitude 3.5 or greater) determined with instruments of sufficient precision to demonstrate a direct relationship with the fault.

  - A structural relationship to a capable fault such that movement on one fault could be reasonably expected to cause movement on the other.

  The definition of a capable fault is essentially the one adopted by the NRC for siting nuclear power plants (10 CFR 100, Appendix A, 1975).

- Acceleration. Acceleration is the mean of the peaks of the two orthogonal horizontal components of an accelerogram record. The exact term used is "peak horizontal acceleration" (PHA). The accelerations are determined from the constrained attenuation relationship based on distance and magnitude as developed by Campbell (1981). The mean-plus-one standard deviation (84th percentile) value is adopted. This value is considered a nonamplified PHA.

- Surface acceleration. Surface acceleration is the site acceleration adjusted for the site soil attenuation or amplification effects.

- Duration of strong earthquake ground motion. For the purposes of UMTRA Project studies, duration is defined, after Krinitzsky and Chang (1977), as the bracketed time interval

in which the acceleration is greater than 0.05g. The methodology of Krinitzsky and Chang (1977) is applied in estimating the duration of strong ground motion at a particular site.

- Magnitude and intensity. Magnitude is the base-10 logarithm of amplitude of the largest deflection observed on a torsion seismograph 100 kilometers (km) from the epicenter (Richter, 1958). This local magnitude value may not be the same as the body-wave and surface-wave magnitudes derived from measurements at teleseismic distances. Unless specified otherwise, Richter magnitude values for values less than 6.5 are used in UMTRA Project seismic hazard evaluations.

  Intensity is the index of the effects of any earthquake on the human population and structures. The most commonly applied scale is the 1931 Modified Mercalli (MM) Intensity Scale, which will be used in UMTRA Project studies.

  Because pre-instrumental earthquake records are reported in intensity and more recent instrumental records are in magnitude, there may be a need to relate these values. The relationship developed by Gutenburg and Richter (1956) is used:

  $$M = 1 + 2/3\ I_0$$

  Where M = magnitude in the Richter scale and I_0 = Modified Mercalli intensity in the epicentral area.

- Maximum earthquake (or maximum-magnitude earthquake). The term Maximum Earthquake (ME) was defined by Krinitzsky and and Chang (1977) as "the largest earthquake that is reasonably expected" on a given structure or within a given area. That definition is applied in UMTRA Project seismic hazard studies. No recurrence interval is specified for such an event.

5.4.3 Technical approach

The following actions are taken to provide an adequate basis for selecting the design earthquake, deriving the initial on-site peak horizontal acceleration value, and analyzing the potential for on-site fault rupture.

All pertinent data about geology, geophysics, geomorphology, soils, and rock are acquired and interpreted. These data may be presented in existing maps that delineate faults in the region of the site, and published discussions pertaining to the regional seismotectonic setting. If deemed necessary, computerized databases are employed to obtain pertinent information.

Seismic studies completed for large structures such as major dams, power plants, or other large industrial facilities are acquired and analyzed. These studies could include ones for completed facilities.

The regional study area is selected by calculating the distance at which the largest magnitude earthquake possible for a region, as determined by Algermissen et al. (1982), produces the minimum accepted (for the UMTRA Project) on-site design acceleration (0.10g). All further characterization work is then limited to this region.

Instrumentally and historically recorded earthquake files are examined. An epicentral map showing the geographic distribution of known earthquakes within the study area is compiled. The National Oceanic and Atmospheric Administration (NOAA) and all earthquake data files, epicentral listings from state-maintained seismic nets, and available microseismic data are obtained and evaluated.

For each seismotectonic province within the study area, the earthquake record for the province is analyzed and the maximum recorded earthquake for each province is identified. For outlying provinces, the maximum earthquake is identified. This is based on published studies of the region completed by other investigators.

Applying methods discussed by Glass and Slemmons (1978), a selected suite of remote sensing images and conventional aerial photographs at suitable scales is analyzed. All photogeologic lineaments or geomorphic features indicative of an active seismic setting are plotted. Specific attention is paid to fault traces identified by previous investigators. To assess the potential for on-site fault rupture, the photogeologic analysis fully encompasses an area within a five km radius of the site. The extent of the remaining coverage analyzed depends upon the location of known faults, the level of effort in previous regional studies, and an appraisal of the tectonic setting. Normally, strip coverage within a 65 km radius of the site is analyzed, along with other more remote areas containing long faults that may be the source of the design earthquake.

The potential effects of the maximum earthquake for each remote seismotectonic province within the study area are analyzed. Within the province of the site, the floating earthquake is placed 15 km from the site. For the other outlying provinces, the maximum earthquake is placed at the closest distance along the boundary of each province to the site. The on-site peak horizontal ground accelerations produced by these earthquakes are derived. The attenuation relationship of Campbell (1981) is used unless a relationship more suitable for a particular region is established. Joyner and Boore (1981) and Campbell (1982) give examples of other acceptable relationships. The relationship of Campbell (1981) will be constrained and be the mean-plus-one standard deviation value (84th percentile). The largest acceleration is used to identify an area for subsequent

investigations and which potentially capable faults within that area require further study.

Based upon the previous review of available data and the photogeologic analysis, faults within the region are assessed as a source of earthquakes capable of producing on-site accelerations in excess of the largest value derived from the FE analysis. The relationship between fault rupture length and earthquake magnitude given by Slemmons et al. (1982) and/or Bonilla et al. (1984) is used. Acceptable attenuation relationships previously discussed are applied. Fault systems which could produce accelerations less than that of the largest value derived from the FE analysis are not further analyzed. Any faults that appear to be capable of producing high accelerations are examined as discussed below.

Ground and/or aerial reconnaissance studies are performed to determine whether there are capable faults in the study area. All aerial reconnaissance missions are completed under low-sun-angle conditions. To assess on-site fault rupture potential, the area within a five km radius of the site receives special attention. Suitable geomorphic techniques or fault study trenches as appropriate are applied to determine whether faults are capable. The correlation between faulting and macroseismic activity is considered.

The findings of the work discussed above are compiled into a map or series of maps which depict the distribution of capable faults and known earthquake epicenters. A detailed discussion of each seismotectonic setting is developed. If specific seismogenic sources can be identified, a maximum magnitude for each fault system is estimated using the fault/rupture length versus magnitude relationships developed by Slemmons et al. (1982) or Bonilla et al. (1984).

The earthquake magnitude based on the seismogenic source that produces the largest on-site acceleration is selected as the magnitude of the design earthquake. This magnitude could be that of the FE or one estimated from the rupture length of a capable fault. The largest on-site acceleration is selected. For use in liquefaction analysis, a larger magnitude earthquake (which produces less than the largest acceleration but has a longer significant duration and would result in more severe effects upon the site) may also be presented.

The findings of the seismic studies discussed above are included in the environmental assessments or the site characterization sections of remedial action plans. These reports include data on the earthquake history, a description of the tectonic setting, fault and epicenter maps, and the analyses of the design earthquake acceleration, and duration. They also address the potential for on-site fault rupture.

5.4.4 Seismic design

Once the peak site acceleration (fifty percentile) has been determined for a site using methods outlined in the previous sections of this chapter, the impact of stratigraphy upon the acceleration is evaluated. The site is classified as having deep or shallow soils. Based upon this classification, modification to the site acceleration is as follows.

For shallow soil sites having less than 30 feet of overburden above bedrock, the site surface acceleration used in liquefaction and slope stability analyses is considered to be the same as the acceleration derived from the seismic study.

Deep soil sites require adjustment to the on-site acceleration derived from the seismotectonic site characterization. The acceleration must be modified for attenuation or amplification through the soil in order to derive the surface acceleration used as input into liquefaction and slope stability analyses.

Regardless of the depth of site overburden, the site soil characteristics and the potential hazard of earthquake-induced damages are assessed. For sites having a factor of safety greater than 1.0 for seismic stability and 1.5 for liquefaction analysis, curves developed by Seed and Idriss (1982) are used to determine soil effects upon acceleration. If either of the factors of safety is less than that given above, derivation of the detailed site amplification is warranted to determine the site surface acceleration.

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6.0 GEOTECHNICAL STABILITY

6.1 PROCESSING SITE CHARACTERIZATION

6.1.1 Field studies

The nature and material properties of the tailings piles must be determined in order to decide the stabilization option, e.g., if stabilization in place can be accomplished without recompacting or otherwise consolidating the pile. In addition, the behavior and stratigraphy of the foundation soils must be determined in order to assess the stability of the pile. An initial exploratory program is performed, consisting of a series of piezocone penetration tests similar to the static cone penetration test described in the ASTM D3441 performed at a minimum density of one per acre to cover the tailings pile. Each test penetrates the entire depth of the pile and extends into the foundation soils until stiff or dense soils are encountered. Data from these probes are used to (1) define the stratigraphy of the pile (i.e., locate significant layers, zones, and pockets of slimes within the embankment); (2) determine the rate of dissipation of induced pore pressures (the rate of pore water pressure dissipation is used to estimate the material's hydraulic conductivity and consolidation parameters); (3) obtain the penetration resistance of the tailings and hence their strength and bearing capacity; and (4) determine the groundwater level.

The stratigraphy interpreted from the piezocone data is considered in determining the location of additional boreholes drilled in the second phase of field work. These boreholes are drilled to obtain undisturbed and disturbed samples for laboratory tests and to verify the stratigraphy defined by the piezocone data. Sufficient boreholes are drilled to verify/interpret the information from the piezocone investigation. An appropriate sample interval is selected to provide sufficient Shelby tube (ASTM D1587), split barrel (ASTM D3550), and/or SPT (ASTM D1586) samples of each material type. The Shelby tube and ring-lined split barrel samples provide undisturbed samples for laboratory tests. The SPTs provide a basis for correlating data collected with other published or unpublished data and are used along with the piezocone data in liquefaction analysis. Groundwater levels at the time of drilling are determined, but piezometers are installed only if the groundwater program (Section 8.1) fails to define site-specific groundwater conditions. These borings extend approximately 20 feet below the tailings/natural soil interface; however, the final depth depends on the stratigraphy encountered. At least one of the boreholes is extended 20 feet into bedrock or up to 250 feet below the tailings/soil interface if foundation stratigraphy and material properties permit.

On piles where a piezocone investigation may not be economical (usually piles of less than 20 acres in areal extent), boreholes conducted on a similar grid as described above will be advanced.

Continuous sampling, using standard sampling techniques, is performed throughout the tailings.

Borehole sampling is also conducted adjacent to the piles in order to identify the variability of the near-pile foundation soils. Test pits are excavated on the pile to obtain representative sand, sand-slime, and slime tailings samples for laboratory tests. Test data are used to determine the geotechnical properties of the tailings in place as well as when placed as fill.

After the evaluation of the first two phases of drilling, additional field work (including borings) may be required to define and characterize further specific soil layers, zones of weakness, and the like.

6.1.2 Laboratory tests

When the first phase of on-site drilling is complete, the field data and samples are examined by the site geotechnical engineer or engineering geologist and a laboratory testing program is specified. Laboratory testing of undisturbed and SPT samples for correlating material properties is undertaken. Table 5.1 lists and describes laboratory tests which may be assigned. In particular, strength (triaxial compression), compressibility (one-dimensional consolidation), permeability, capillary moisture, and other tests may be conducted on the undisturbed or remolded soil samples. The results of this testing may be correlated with the piezocone data.

If the design earthquake and the site soil conditions (loose to medium-dense, saturated sand, and silt tailings) dictate, a limited number of dynamic soil tests, such as Cyclic Triaxial Tests and Resonant Column Tests, will be performed.

6.2 SLOPE STABILITY

6.2.1 Introduction

In order to assess the long-term stability of the tailings piles, the long-term static and earthquake loading conditions are determined. Natural slopes that may affect the long-term performance of the embankment are also analyzed for static and earthquake loading conditions. In addition, short-term static and seismic loading of the embankment slopes and construction slopes must be analyzed to assess the suitability of the proposed designs.

6.2.2 Methods

Conventional slope stability analyses are performed for UMTRA Project sites. Methods of analyses used include circular and non-circular limiting equilibrium analyses, wedge analyses, and infinite

slope analyses. The method of analysis used depends on the actual site and soil conditions. Various, validated computer programs are used.

Seismic conditions are usually analyzed by the pseudo-static approach. For the pseudo-static analysis, a horizontal seismic coefficient (k) based on the peak value of the derived site surface acceleration of the design earthquake is selected. For seismic analysis of the slopes under construction and at the end of construction, analysis will be performed using a k equal to one-half of the site peak surface acceleration. For long-term stability, the minimum value of k used at any site is 0.10. If two-thirds of the site peak surface acceleration is greater than 0.10, the greater value is adopted for k. This value is reduced to two-thirds of the peak in order to provide a mean value for input into the long-term stability analysis.

6.2.3 Analysis

Selection of cross section

The selection of cross section(s) to be analyzed is based on engineering judgment and a review of the site characterization data. Several cross sections based on site stratigraphy and the proposed pile configuration may be evaluated. Alternatively, a composite cross section (a combination of the highest embankment section and the most critical layering configuration) may be used. Typical criteria considered in developing profiles include:

- Embankment and foundation stratigraphy.
- Proposed slope configuration (typically five horizontal to one vertical for the tailings embankment).
- Presence and location of weak soil layers.
- Material properties for soil layers.
- Seepage, groundwater, and surface water conditions.
- Use of special materials or layers within the cover, tailings, and the like.
- Special topographic features associated with high risks.

Data reduction

Existing and new test data are evaluated to determine input parameters for use in stability analyses. The analyses consider available site specific data. The derivation of strength parameters is discussed and is presented in the RAP. A summary of soil properties, including supportive data, sources, density, moisture content, triaxial compression, direct shear, cone penetrometer, and standard penetration test data, is usually provided in the RAP. When possible, published data and standard references are reviewed to verify the parameters selected (Vick, 1983; NAVFAC, 1982; Lambe and Whitman, 1969).

Table 6.1 lists the preferred method of analysis for the different situations likely to occur at piles where remedial action work is undertaken.

Conditions analyzed

Slope stability analyses are performed on major cuts and fills associated with the tailings pile, appurtenant earth structures (both temporary and permanent), and surrounding natural slopes that may affect or be affected by construction of the embankment. Table 6.2 presents the criteria used for judging acceptable slopes analyzed using conventional slope stability analyses.

Mitigative measures for other conditions not typically encountered at UMTRA Project sites, but which may arise in the design of appurtenant structures, will be designed to satisfy commonly accepted minimum factors of safety (e.g., earth dams may require sudden drawdown or partial pool analyses as recommended

Table 6.1 Choice of total stress versus effective stress method of stability analysis

Situation	Preferred Method
1. End-of-construction with saturated soil; construction period short compared to consolidation time	S_u - analysis with $\phi = 0$ and $c = S_u$
2. Long-term stability	$\bar{c}, \bar{\phi}$ - analysis with pore pressures given by equilibrium groundwater[a]
3. End-of-construction with partially saturated soil; construction period short compared to consolidation time	Either method: c, ϕ, from unconsolidated undrained tests for c, plus estimated pore pressures

[a]A special case may exist where low-permeability clay soils would fail under undrained conditions, even over the long run. Such a condition may be present in high percentage bentonite layers used in covers.

Note: ϕ = friction angle (total stress), i.e., undrained conditions.
c = cohesion (total stress), i.e., undrained conditions.
$\bar{\phi}$ = friction angle (effective stress), i.e., drained conditions.
$\bar{c}$ = cohesion (effective stress), i.e., drained conditions.
S_u = undrained shear strength.

Table 6.2 Guidelines for minimum acceptable safety factors in slope stability analysis

Situation	Minimum acceptable factor for safety
During construction static stability	1.3
End of construction static stability	1.3
End of construction seismic stability[a]	1.0
Long-term static stability	1.5
Long-term static with flood stability (including rapid drawdown)	1.2
Long-term seismic stability[a]	1.0

[a]See Section 5.4.4 for a discussion of seismic design coefficients.

by COE, 1970). For slopes subjected to design accelerations greater than 0.30g (k greater than 0.20) other dynamic analyses should be used in order to assess stability if the factor of safety is determined to be near the minimum by less rigorous analysis. Slopes not meeting the minimum safety factors are appropriately redesigned in order to meet these standards.

6.3 SETTLEMENT

6.3.1 Introduction

Settlement of the reconstructed piles at UMTRA Project sites is predicted in order to evaluate long-term stability. Settlement can occur within the reclaimed embankment and in the foundation soils upon which the embankment is constructed. The absolute and differential settlement depend on the distribution of different types of materials, the compressibility of each soil type, and the stresses on specific soil layers. Settlement, especially differential settlement, can lead to surface water runoff flow concentrations that could erode the pile cover and/or lead to cracking of the radon cover.

Tailings consist of interlayered and interfingered sand and slime stringers, lenses, and layers that range from several microns to several feet thick. Material size varies both vertically and horizontally due to shifting and braiding of the discharge flow over

previously deposited tailings. A tailings pile is a heterogeneous deposit of tailings sands (less than 30 percent passing the No. 200 sieve), tailings slimes (greater than 70 percent passing the No. 200 sieve), and tailings sand-slimes (greater than 30 percent but less than 70 percent passing the No. 200 sieve). The tailing sands are typically found on a "beach" close to the discharge points and around the perimeter of the piles. Slimes settle in the decant pond, which is usually distant from the discharge points. The sand-slimes mixture is generally found between the sand and the slimes. The position of the sand and slimes may vary widely as a result of spigotting from different discharge points. Layers of sand tailings may be deposited over layers of slimes and vice versa. Slimes lenses may be close to the beach due to localized pooling.

For settlement analyses, several simplified soil profiles have to be developed. Large areas of sand, slime, and sand-slimes mixtures (including interlayered sands and slimes as sand-slimes mixtures) are identified for use in analyzing settlement of the tailings. Such assumptions are considered appropriate for the design requirements of UMTRA Project piles. Section 6.1 describes the minimum level of effort required to characterize the tailings deposit.

If the tailings pile is relocated, the absolute and differential settlement of the embankment is reduced since the tailings are compacted. Differential settlement may occur because a uniform distribution of material types may not be achieved.

6.3.2 Data collection

Data collection begins with characterization of the tailings pile and the foundation soils at the tailings site. Areas of sands, slimes, and sand-slimes mixtures within the tailings are defined. Zones of soft soil are delineated in the foundation. The groundwater table is defined, as are zones of partially saturated soils above the water table.

Materials compressibility is determined using SPT data, the piezocone penetrometer (including pore pressure decay), and tests on samples from Shelby tubes or ring-lined, split-barrel samplers. Consolidation tests may be performed on saturated soil, or soil at its natural moisture content. The decision of which moisture content to use is based on the location of the sample in relation to the water table and the degree of saturation of the strata from which the sample was obtained.

6.3.3 Analyses

The level of effort expended on settlement analyses is dependent upon the perceived risk for a particular site. The following

types of settlement may occur at a pile (embankment and foundation):

- o Instantaneous settlement.
- o Short-term settlement (primary consolidation).
- o Long-term settlement (primary and secondary consolidation).

Not all types of settlement require detailed analyses. For example, experience dictates that long-term settlement of recompacted embankments placed over a foundation with uniform conditions will not significantly affect pile integrity.

The method of analysis depends on the material type, the data collected for that material, and the condition of the material in place. Calculations based on elastic analyses are used for nonplastic soils; consolidation theory, as described by Lambe and Whitman (1969), is used for clays and clayey materials. Other methods of analysis such as those based on finite strain may be used if appropriate. Some theories that may be used to calculate settlements:

- o Elastic theories as presented in Lambe and Whitman (1969) and NAVFAC DM-7.1 (1982).
- o Conventional consolidation theory as presented in Lambe and Whitman (1969) and Duncan and Buchignani (1976).
- o Multilayered analyses using conventional consolidation theory as presented by Gray (1946).
- o Finite strain settlement techniques as developed by Schiffman et al. (1984).
- o Cone penetration techniques as presented by Robertson and Campanella (1984) and Schmertmann (1978).
- o Analysis of secondary consolidation as presented by Holtz and Kovacs (1981).

Where appropriate, total combined settlement (excluding instantaneous settlement) is plotted as a surface contour map in order to evaluate differential settlement, cover cracking, and flow concentrations. Cover cracking is evaluated using the approach described by Lee and Shen (1969).

6.3.4 Final condition

The size of the tailings embankment, the complexity of the subsurface stratigraphy both within the tailings pile and foundation soils, and the limited data from which to derive design parameters make the prediction of total and differential settlements inexact. In order to reduce the uncertainty and raise the reliability of

long-term stabilization, several construction and design features may be required:

- Monitor the embankment settlement to note when settlement is complete. Place the radon cover material only when settlement is complete. This will lessen the chance of the cover cracking due to differential settlement.

- Monitor for completion of settlement after placement, but before final grading, of the radon cover. Grading after settlement lessens the chance of unanticipated flow concentrations due to storm water runoff.

- Adopt an appropriate construction sequence so that areas with the largest settlement potential are built first.

- Place cover material at two to three percent above the optimum moisture content. This makes the material more pliable and less likely to crack during settlement.

- Use construction techniques such as preloading to reduce the time in which settlement occurs.

- Limit the size, quantity, and distribution of demolition materials within the embankment.

Experience with early UMTRA Project sites where tailings were relocated indicates that mixing during excavation, hauling, and placement results in a uniformly mixed compacted embankment, thus minimizing the potential for differential settlement and eliminating the need for special design and construction considerations.

6.4 LIQUEFACTION POTENTIAL

6.4.1 Introduction

In order to evaluate the long-term stability of piles at UMTRA Project sites, the liquefaction potential of the pile and foundation soils under design earthquake conditions is assessed (see Section 5.4 for definition of the design earthquake). The liquefaction potential of a site is determined by the soil properties and condition, depositional history, depth to groundwater, and characteristics of the earthquake motion to which it is subjected.

For the soils typically encountered at UMTRA Project sites, liquefaction and/or cyclic mobility can occur in saturated, cohesionless soils (sands and silts) or low plasticity, clayey soils due to the cyclic loading usually caused by earthquake-induced ground motions. Liquefaction occurs when the effective stress in the soil is reduced to zero by the earthquake-induced buildup of pore water pressure. When this occurs, the shear strength of the soil decreases and the soil becomes essentially a viscous fluid.

Alternatively, cyclic mobility occurs in denser soils. After the earthquake, pore pressures reduce, resulting in an increase in the shear strength.

The most important factors used to assess the liquefaction or cyclic mobility potential at a site are (1) the ratio of earthquake-induced shear stresses in the soil to the vertical effective stress, (2) the relative density, (D_r), (3) the degree of saturation, and (4) clay content of the soil or tailings mass.

There is a practical maximum earthquake-induced ground acceleration, and thus a maximum shear stress, that can be produced in a soil or tailings mass by large earthquakes. This means that as the soil or tailings mass gets deeper, the ratio of the maximum possible shear stress to the effective stress decreases. This generally precludes liquefaction at depths greater than approximately 50 feet below ground surface.

Most researchers agree that there is a D_r above which liquefaction cannot occur. Liquefaction or partial liquefaction can occur in soils with a D_r of less than 70 percent of standard Proctor density. Generally, above a D_r of 70 percent, liquefaction associated with complete strength loss cannot occur.

6.4.2 Analysis

General

Because most of the UMTRA Project sites involve unsaturated tailings piles, the potential for liquefaction failure is very small. Each site is evaluated using site-specific material characteristics.

Analysis

The method of analysis used to assess liquefaction potential is that developed by Seed and Idriss (1982). The analysis assumes that no liquefaction will occur above the water table. This assumption may not be valid if there is an extensive saturated zone above the water table. Such cases will be analyzed for liquefaction. The method further assumes that only sands, silty sands, and low plasticity silts or clayey soils are capable of liquefying.

The Seed and Idriss simplified method is based on an empirical correlation of documented cases of liquefaction, measured earthquake Richter magnitudes (M), maximum horizontal ground acceleration at the site, and the SPT blow count (determined according to ASTM D1586) or the cone penetration resistance (Robertson and Campanella, 1984) of the soil prior to liquefaction.

In order to determine the design horizontal ground acceleration at the site, the acceleration in the bedrock below the site is determined. This is done by establishing the design earthquake and the distance to the causative fault. The bedrock acceleration is established from an attenuation curve developed in the seismic studies (Section 5.4). Since this motion will either be attenuated or amplified by the foundation soils at the site, the appropriate curve, as presented in the paper by Seed and Idriss, is used to estimate the design horizontal ground acceleration at the surface of the site or tailings pile. It is necessary to ignore the effects of the embankment slopes in the analysis. This acceleration is used to determine the shear stresses developed by the earthquake in the various soil layers. The shear stresses developed by the earthquake are compared to the shear stress required to cause liquefaction in a particular layer.

The shear stress required to cause liquefaction is found from a family of curves (Seed and Idriss, 1982), which relates the given earthquake magnitudes and the corrected SPT blow count or cone penetration resistance appropriate to the layer. These curves enable full account to be taken of the soil's or tailings' grain-size distribution. Appropriate strength curves should be used based on the fines content (minus 200 sieve fraction) of the soil layer being analyzed.

Seed and Idriss (1982) state that a factor of safety against liquefaction in a given soil or tailings layer may be calculated by dividing the shear stress required to cause liquefaction in the layer by the shear stress generated in that layer by the design earthquake. They state that a factor of safety between 1.25 and 1.5 should be taken as the minimum.

In addition to analyzing potential liquefaction, the consequences of failure are evaluated. Typically, the minimum factor of safety considered acceptable for UMTRA Project sites is 1.5. Should the consequences of failure be found minor (i.e., localized swamping and cracking of the cover), the existance of a liquefaction potential may be considered acceptable for design.

If site-specific conditions are such that the failure produces flow off the site rather than deformation and the simplified analysis produces safety factors below 1.5, more detailed site-specific analyses using measured dynamic soil parameters and the like should be undertaken.

6.5 FROST PROTECTION

6.5.1 Introduction

Hydraulic conductivity or permeability under saturated conditions has been shown to increase by as much as two orders of magnitude in compacted clay materials subjected to freeze-thaw cycles

(DOE, 1988). Other researchers including Kinosita (1978), Goelé (1980), and Everett (1961) have shown conclusively that volume changes can occur upon freezing in unsaturated soils. Thus, an analysis of site-specific frost penetration into an UMTRA Project disposal pile cover system is required for design. Dominant factors controlling the frost depth are climatic parameters including the intensity and duration of freezing periods (Mitchell, 1976). Section 6.5.3 discusses the determination of site-specific climatic parameters based on daily maximum-minimum temperature data. Variation in physical properties of soil such as mineralogy, dry density, and moisture content may cause frost penetration to vary by a factor of two or more (Brown, 1964).

6.5.2 Definitions and criteria

The following are definitions and standards applied when evaluating the site-specific frost penetration at UMTRA Project disposal sites.

- Design Life. As specified by the EPA Standards for Remedial Actions at Inactive Uranium Processing Sites (40 CFR 192), the controls implemented at UMTRA Project disposal sites are to be effective for 1000 years, to the extent reasonably achievable and, in any case, for at least 200 years. For the purpose of frost depth penetration, a 200-year design life has been adopted (DOE, 1988).

- Design Frost Depth. For UMTRA Project sites, the design frost depth is the maximum distance measured downward from the surface into a moist soil medium with a temperature at or below the freezing point of water, causing the moisture within the soil to freeze.

- Climatic Parameters. The following weather factors used in determination of the intensity and duration of freezing periods.

  - Degree Day. "Degree day" is defined as the difference between the mean daily temperature and a base temperature taken at the freezing point of water multiplied by the duration of one day. A temperature of 32 degrees Fahrenheit is used as the base temperature.

  - Design Freeze Index. The magnitude of the cumulative degree day difference between the maximum and minimum points on the cumulative plot for one freezing season. A freezing season is one year in length beginning at an arbitrary date in the late spring or early summer.

- Mean Annual Temperature. The mean of the average maximum/minimum daily temperatures for one year's duration.

- Duration of Freeze. The number of days difference between the maximum and minimum points on a cumulative plot of degree days.

6.5.3 Technical approach

Determination of Climatic Parameters. The following procedures should be followed to determine the climatic parameters at any UMTRA Project disposal site. The first step is to obtain records of the daily maximum/minimum temperature data obtained at a weather station located at or near the proposed disposal site. Data are nationally available from:

National Climatic Data Center E/CC42
Attn: USER Services Branch
Federal Building
Asheville, North Carolina 28801-2696
(704) 259-0682

Often temperature data are available from state climatological centers; e.g., for sites located in Colorado data can be obtained from:

Colorado Climate Center
Colorado State University
Department of Atmospheric Science
Fort Collins, Colorado 80523
(303) 491-8545

These service centers can provide information concerning weather station locations in the area if a station is not present at the disposal site. A weather station should not be used unless a minimum of 20 years of complete temperature data has been compiled.

The most efficient method available to reduce the daily temperature data is through utilization of a micro-computer. Temperature data are available in sheet form or may be obtained on computer floppy disks. Reduction methods are presented in the Data Manipulation section, below. Data are commonly recorded on computer disks in a variety of formats. Supplemental information indicating latitude, longitude, and elevation of the recording station, time of readings, precipitation amounts, snowfall, and snow depths are commonly included. Only the temperature data are directly used in calculations, so it is necessary to separate the temperature data from supplemental data. The simplest method to perform this function is through a short computer code such as a BASIC code.

Data Manipulation

To reduce the data, proceed as follows. First, compute the mean daily temperature from the maximum and minimum daily temperatures. Next, compute the degree day for each day of record by subtracting the freezing temperature of water (32°F) from the mean daily temperature. Accumulate the degree days and plot the resulting summation for each day of the freezing season. It is necessary to begin the freezing season on a date in the late spring or early summer to assure that the plot of cumulative degree days will remain positive, within the first graphical quadrant.

The plot should be constructed to indicate the cumulative degree day versus the day number of the freezing season. The design freeze index is then obtained for the season by calculating the difference between the maxima and minima from the curved portion of the cumulative degree day plot. Similarly, the duration of freeze is obtained by taking the day number difference of the maxima and minima. Finally the mean annual daily temperature is computed by averaging all the mean daily temperatures for the entire freezing season. Table 6.3 provides example degree day calculations.

Statistical Analysis

To analyze the data, first list all three of the climatic parameters with their corresponding years of occurrence. Then rank the design freeze indices and duration of freezing period in descending order. The mean annual daily temperature is ranked in ascending order.

Plotting positions are then computed for the parameter values. If the number of occurrences for each parameter values is identical, only one set of plotting positions is necessary. However, if occurrences differ, a set of plotting positions for each parameter will need to be computed. The plotting position P(x) is found by dividing the rank number (m) by the total number of occurrences (n) plus 1.

$$P(x) = m/(n+1) \tag{25}$$

The inverse of P(x) is the recurrence interval for the parameter x not to be exceeded, on the average in time interval T, with T = 1/P(x) as the nonexceedance period. Thus, the exceedance recurrence interval is computed by

$$T = 1/(1-P(x)) \tag{26}$$

Plotting the variate (climatic parameter) versus its plotting position or nonexceedance period on extreme value Type I probability paper, or Gumbel paper, allows for the determination of the variate at a 200-year nonexceedance period. Graphical solutions involve

Table 6.3 Degree day calculations

Date		Date	Maximum daily	Minimum daily	Average daily	Degree day =	Cumulative
Month	Day	(number)	temp. (degree F)	temp. (degree F)	temp=Max+Min/2	avg. temp.-32	degree day
11	4	96	53	23	38	6	2185
11	5	97	48	19	33.5	1.5	2187
11	6	98	54	31	42.5	10.5	2197
11	7	99	60	31	45.5	13.5	2211
11	8	100	60	24	42	10	2221
11	9	101	67	26	46.5	14.5	2235
11	10	102	64	30	47	15	2250
11	11	103	52	39	45.5	13.5	2264
11	12	104	41	39	40	8	2272
11	13	105	45	23	34	2	2274
11	14	106	38	27	32.5	0.5	2274
11	15	107	38	16	27	-5	2269
11	16	108	44	-4	20	-12	2257
11	17	109	41	13	27	-5	2252
11	18	110	42	16	29	-3	2249
11	19	111	46	31	38.5	6.5	2256
11	20	112	54	32	43	11	2267
11	21	113	57	22	39.5	7.5	2274
11	22	114	48	23	35.5	3.5	2278
11	23	115	45	19	32	0	2278
11	24	116	46	13	29.5	-2.5	2275
11	25	117	37	10	23.5	-8.5	2267
11	26	118	40	13	26.5	-5.5	2261
11	27	119	44	10	27	-5	2256
11	28	120	35	0	17.5	-14.5	2242
11	29	121	25	-3	11	-21	2221
11	30	122	30	-7	11.5	-20.5	2200
12	1	123	38	-8	15	-17	2183
12	2	124	34	14	24	-8	2175
12	3	125	23	-19	2	-30	2145
12	4	126	35	6	20.5	-11.5	2134

plotting variates and their nonexceedance values on Gumbel paper. this paper is constructed such that data fitting a Gumbel probability distribution

$$F(x) = e^{\left(e^{-a(x-B)}\right)} \tag{27}$$

will plot as a straight line. Gumbel probability paper can be purchased or can be constructed following methods outlined in Ang and Tang (1975) and elsewhere.

Any of the following three methods can be used to determine the variate at the 200-year nonexceedance interval. An ocular "best fit" line can be drawn through the data from which the variate value at the 200-year nonexceedance period can be read. Or, the predicted climatic parameter value for a 200-year nonexceedance interval may be found by analytical methods. The Gumbel probability distribution can be solved for a specific nonexceedance period (Schultz, 1976). An equation in the form

$$X_{T(r)} = X' - 0.455x + 0.77975\ x \ln T_r \tag{28}$$

where

T_r = nonexceedance period.

$X_{T(r)}$ = variate at nonexceedance period.

X' = variate mean.

x = standard deviation of variate.

A Gumbel probability graph can be plotted showing both ocular and analytical methods for comparison. The analytical method provides probabilistic predictions using the Gumbel probability distribution of the observed data. To confirm how well the equation models the observed data, it is necessary to predict several values of the variate and plot this line with the observed data.

The last method allows a linear regression to be calculated for the variates and plotting positions. To perform a linear regression, the variate and plotting position need to be in an arithmetic scale. Conversion of the plotting position to an arithmetic scale is performed by computing the standard variate. The Gumbel distribution has been defined in Equation 28 as

$$F(x) = e^{\left(e^{-(x-B)}\right)}$$

Substituting s for (x-B) allows the Gumbel distribution to be written as:

$$F(x) = e^{\left(e^{-s}\right)} \tag{29}$$

Taking twice the logarithm yields

$$s = -\ln(-\ln F(x)) \tag{30}$$

so that the double logarithm and cartesian variate scales will produce a straight line probability distribution plot. Performing a linear regression on data in this form will yield an equation in the form

$$y = mx + b \tag{31}$$

where

m = slope of the regressed line.

b = y intercept.

The 200 year nonexceedance value standard variate is computed as

$$F(x) = 1-1/200 = 0.995$$

therefore,

$$s = -\ln(-\ln(0.995)) = 5.296.$$

Substitution of 5.296 for x in the regressed equation allows for a prediction of the 200-year nonexceedance parameter. Data used to present the ocular and analytical methods on Gumbel distribution paper are used to demonstrate the linear regression techniques.

The regressed equation will yield higher, more conservative values than the analytical method will. The regressed equation is more easily performed than the analytical solution. If the regressed equation correlation coefficient (r) is greater than or equal to 0.95, the difference in the predicted parameter values will not significantly affect the predicted frost penetration depth.

Potential Problems

Missing data will cause problems in the determination of the climatic parameters. Incomplete temperature data will bias the calculation of the standard variate. Statistical analysis of weather data for several sites in the western United States leads to the conclusion that the freeze index and the mean annual daily temperature act as independent variables. Climatic data should therefore be appropriately assessed. When determining the freeze index, temperatures missing from the freezing period will cause the

freeze index to be underestimated. It has been found that if temperatures for more than five percent of the duration of freezing days are missing, the associated freeze index is unreliable. Data missing from the nonfreezing period do not affect the freeze index. When calculating the mean annual daily temperature, temperatures missing during any portion of the year can cause the mean annual daily temperature to be underestimated. If more than 15 days of temperature data are missing from any given year, data from the year should not be used to calculate the mean annual daily temperature. Thus, this climatological data should be assessed independently for these two parameters.

Some disposal sites are located in areas where weather stations, hence daily temperature data, do not exist. However, often weather stations exist within the same micro-climate. A station in the same micro-climate should be within approximately 25 miles of the disposal site, possess similar weather conditions, and have the same general terrain and elevation as the disposal site. Under these conditions the climatic parameters should be determined for each station within the micro-climate. The three parameters can then be independently correlated to their station elevations. By knowing the elevation of the disposal site, each of the three climatic parameters can then be determined.

Occasionally, weather stations do not exist within the recommended 25 mile micro-climate radius of the disposal site. When this occurs, climatic parameters should be evaluated for all stations that do exist within the general region of the disposal site. An example of this situation is sites located in western and southwestern Colorado. Climatic parameters should be determined for all stations within the region, as well as the elevation and latitude of each station. A multiple regression analysis should then be performed using each of the climatic parameters as the dependent variables, with the elevation and latitude as independent variables. Regressed coefficients result from the analysis that is used to formulate an equation for each climatic parameter. These equations are functions of both elevation and latitude. Input of the disposal site elevation and latitude into these equations will allow for estimation of site-specific climatic parameters. Caution must be used with this method; if the correlation coefficient from the regressed equations does not equal or exceed 0.70 the equation may not adequately represent the observed data. When this occurs, judgment is required to estimate from the available data which weather station or stations most closely models the disposal site climate. Then the weather data from this station(s) are used.

6.5.4 Frost depth prediction

As fine-grained soils freeze, suction draws water toward the freezing front, which provides the mechanism for formation of ice lenses. This process is described in detail by Williams (1966). Suction also increases stresses within the soil matrix, causing

consolidation. Expansion of freezing water coupled with consolidation effects leads to randomly oriented crack formation. This phenomenon increases conductivities through fine-grained soils.

Frost penetration into a soil medium is the result of combined flows and/or fluxes of various physical gradients. Thermal properties are fundamental relationships common to all heat transfer problems. Both thermal properties and climatic parameters are accounted for in a frost depth prediction formula for multi-layered soil systems initially presented by Aldrich and Paynter (1953). After development of the formula it was discovered to be essentially identical to a formula originally published by W. P. Berggren (1943). However, Aldrich and Paynter's formula differs slightly and was thus named the Modified Berggren formula. Both the Modified Berggren formula and thermal conductivity relationships related to soil properties (Kersten, 1949) are combined in a digital solution by G. W. Aitken and R. L. Berg (1968). The digital solution was converted into a micro-computer program and compiled for the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL). This program is utilized to predict site-specific frost depth at UMTRA Project disposal sites.

Procedure

The calculation of the frost penetration depth requires the conversion of the air freezing index to the surface freezing index, and the selection of appropriate dry densities and moisture contents for the soil and rock layers affected. These parameters, along with the climatic parameters previously discussed, are required to calculate the frost penetration depth. The CRREL's Modified Berggren formula will be used to compute frost depth penetration at UMTRA Project disposal sites.

n-Factor

The n-Factor is a function of the surface material. Net solar radiation, conduction, and convective transfer of sensible heat from the air contribute to a warming of the ground surface, creating higher ground temperatures than those of the overlying air. It is necessary to convert the air freezing index to a surface index using the n-Factor. Values range from 0.5 for snow-free turf to 1.0 for a snow-covered surface. In the program, snow-free sand and gravel is assigned a value of 0.70. Snow-free conditions are conservatively assumed for UMTRA Project sites. While snow cover results in a higher n-Factor, sensitivity analysis shows that even a few inches of snow insulates the ground and reduces the frost penetration below that of bare soil. For graveled topslopes and cobble and gravel sideslopes, an n-Factor of 0.70 should be used. (Note that portland cement and asphalt pavements are assigned values of 0.75 and 0.70, respectively.) Bare soil values of 0.70 have been measured by the CRREL. Since some UMTRA Project piles will be designed to support

vegetation, an n-Factor of 0.60 will be used, which is midway between turf and bare soil. While the n-Factor is known to vary with latitude, wind, speed, cloud cover, and other climatic conditions, the values selected above are considered suitably conservative to apply to all of the UMTRA Project sites. Although not anticipated to occur due to the large size of the piles and gentle design slopes, a slight increase in the n-Factor of 0.05 to 0.10 should be used if the pile is continually shaded, as on steep north-facing slopes.

Soil Parameters

Soil parameters required as input into the design calculation, in addition to layer geometry, include dry density and moisture content. Placement conditions should be used as a basis for the analysis although sensitivity analyses should be performed to allow for material variation, especially in terms of moisture content. Placement conditions of the radon/infiltration barrier can be derived from the laboratory test data of the selected borrow source. Rock erosion protection, biointrusion barriers, bedding layers, and soil rooting media layers may not have been tested for the required parameters. Therefore, typical values from published literature may be used. Moisture contents of free-draining layers are assumed to remain low. In no case should the moisture content exceed that of saturation.

Verification

Weather data, including minimum and maximum temperatures, should be collected at each site during the first construction season. This data should be compared to that collected at the weather station(s) used to prepare the calculations for the design frost depth. Variations in the mean annual temperature, duration of freeze, and cumulative freeze index can be calculated. These variations can be used to adjust the climatic parameters used in the design frost depth calculation, thus accounting for localized climatic variations from the weather station to the site.

Sensitivity analyses should be performed to determine the effects of variations of the input parameters, including climatic data and soils material properties.

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7.0 RADON ATTENUATION AND SITE REMEDIATION

The proposed remedial action must comply with the EPA standards for control of residual radioactive materials, including standards for radon emissions and cleanup of land and buildings contaminated with residual radioactive materials. This section discusses the approaches used to demonstrate that radon emissions from the stabilized embankment are controlled by the proposed design and that the proposed design will provide reasonable assurance of compliance with the standards. This section also discusses the approaches used to determine the extent of contamination at the site and to demonstrate that the remediation of the site will provide reasonable assurance of compliance with the standards.

7.1 RADON ATTENUATION

The EPA identified a reduction of radon emissions from tailings piles as an objective in developing the standards for the control of tailings. They selected an emission limit as the primary form of the standard, with a concentration limit as an alternative form. These limits are an average emission (flux) of 20 picocuries per square meter per second (pCi/m^2s), and an average concentration above background of 0.5 picocurie per liter (pCi/l) at any location outside the disposal site boundary. Both radon standards are design standards in which compliance is determined on the basis of predicted rather than measured emission rates or concentrations. The standards require that the design "provide reasonable assurance that the releases of radon-222" will not exceed the limits.

The radon emissions are controlled by an earthen cover placed above all contaminated materials. This earthen cover also serves the purpose of reducing the infiltration of water into the stabilized embankment to assure compliance with the groundwater standards (see Section 8.0). By using average site-specific values or conservative generic values, the radon flux through the earthen cover can be modeled to show compliance with the design standard. The design is based on the following assumptions.

- A stabilized pile (embankment) can be constructed consisting of distinct layers of materials, such as in situ or relocated tailings, followed by windblown materials, and then radon barrier and erosion protection materials. Other layers, such as a biointrusion barrier, freeze/thaw protection, and so on, may be incorporated in the embankment.

- An average radon emanating fraction is determined for each distinct contaminated material, such as tailings or windblown material.

- An average radon diffusion coefficient is calculated for each distinct contaminated material and for the radon barrier materials.

- The radon barrier materials are adequately represented by samples obtained for geotechnical, emanating fraction, and diffusion coefficient analyses.

- Volume-weighted average values for porosity, bulk dry density, and radium-226 (Ra-226) concentration are adequate estimates for the layers in the stabilized pile.

- The long-term moisture contents for the stabilized pile and radon barrier, as predicted by engineering analyses, are conservative estimates of the long-term condition of the pile.

- The compaction and placement of the materials in the stabilized pile will be sufficient to inhibit differential settlement and cracking of the radon barrier.

7.1.1 Design of the radon barrier

The thickness of cover material required to limit radon flux to 20 pCi/m^2s is calculated using the computer code RAECOM (NRC, 1984). The mathematical model implemented in RAECOM describes one-dimensional steady state radon diffusion through a two-phase multi-layer system of porous media, representing the pile and its cover.

Multiple layers of contaminated materials and cover are allowed, with differences in physical, radiological, and diffusional properties represented by several layer-specific input parameters. Radon concentrations in both soil-air and soil-water phases are treated, as well as the exchange between phases. Boundary conditions are the radon flux into the bottom of the pile and the air concentration of radon at the surface of the pile. In addition, interface conditions are applied, requiring continuity of both flux and concentration in both phases at layer interfaces. The exact simultaneous solution to the coupled radon mass balance and flux equations for the two phases is performed using matrix algebra for the general n-layer case.

The seven input parameter values required for each layer of the tailings pile system modeled by RAECOM are:

- Layer thickness (cm).
- Dry bulk density (g/cm^3).
- Porosity (fractional).
- Moisture content (percent dry weight basis).
- Radon emanation (fractional).
- Radon diffusion coefficient (square centimeters per second, or cm^2/s).
- Ra-226 concentration (picocuries per gram, or pCi/g).

In addition to these parameters describing the layers of the stabilized pile, the RAECOM model requires input of the total number of layers in the pile and the layer to be optimized in meeting the specific flux limit (20 pCi/m^2s) at the surface. Also, the boundary

conditions for the radon diffusion must be specified for the top and bottom of the stabilized pile. The bottom boundary condition is always an incoming flux equal to zero pCi/m^2s. The top condition is the observed background radon concentration (in pCi/l) in the air near the site.

The subdivision of the contaminated material into layers should be developed from cross sections representative of the probable end-of-construction conditions. When appropriate, restrictions on the allowable sequence of material placement should be included in the construction specifications; however, in some cases, a thicker radon barrier would be less expensive than restrictions on the sequence of material placement and the design should incorporate the thicker barrier. The layering should reflect the most likely embankment configuration.

The mean, standard deviation, and the standard error are all important statistical values and should be calculated for each of the design parameters. Since the flux standard was written as an average over the disposal site, the mean values of the design parameters for each layer of pile or cover are appropriate to use in the radon barrier design. The uncertainty in each mean parameter is indicated by the standard error of the mean. Since the standard error is obtained by dividing the standard deviation by the square root of the number of measurements, the uncertainty in the design can be reduced by increasing the number of measurements.

The mean values must be unbiased estimates. The method of averaging depends to a degree on the source of the data. If the data were generated in an area-by-area characterization survey, then area- or volume-weighting is appropriate. If the data were generated from a random statistical sampling of the overall pile, then all samples have equal weight and simple arithmetic averaging is appropriate. The method used must be determined on a case-by-case basis. All design parameters, except moisture content, are average values; moisture content is conservatively estimated.

In order to limit the uncertainty of the design, it is necessary to reduce the uncertainty in the cover thickness due to the uncertainty in all the material properties. The number of samples necessary to accomplish this reduction in uncertainty is determined on a site-specific basis and depends on the cover material, predicted long-term moisture, and average values for material parameters and the variability of these values within the contaminated materials and radon barrier material. A detailed discussion and rationale for selecting the number of samples for measurement of the porosity, diffusion coefficient, radium concentration, and emanating fraction for the tailings was presented in a previous report (TAC, 1985c).

The basis for selecting values for each of the seven input parameters listed above is briefly discussed below.

Layer sequence and thickness. The proposed structure of a stabilized pile may consist of several layers. The typical layering of a relocated pile might be a layer composed of a mixture of the tailings with any existing pile cover plus the contaminated soil from beneath the pile; a layer of windblown, evaporation pond, and other contaminated materials; a compacted radon barrier cover; and a rock and gravel erosion protection cover. The layering sequence will be determined based upon the possible radon source from the specific materials. For a pile to be stabilized in place, the layering would be similar, except the in situ material would be represented by a series of layers with site-specific values. Layer thickness will be calculated using material volumes and embankment geometry.

Dry bulk density. The dry bulk densities of the materials and cover are dry densities measured by either laboratory or in situ methods. Laboratory methods, such as standard Proctor tests (ASTM D698), are used parimarily during the design phases and are measured on samples compacted to the design specification for relocated materials. In situ measurements, such as sand cone, are used for undisturbed materials and during placement of the materials in the embankment. In situ measurements will be corrected for moisture content to give dry densities.

Porosity. The materials' and cover's porosities are calculated from the dry bulk densities, using the specific gravity of the material, which is determined along with other geotechnical parameters. The equation used is:

$$\text{Porosity} = 1 - \frac{\text{(dry bulk density)}}{\text{(specific gravity x unit weight of water)}}$$

Moisture content. The moisture contents for the pile and cover are based on estimates of the long-term moisture content using site-specific data. This is discussed in detail in Section 7.1.3. The moisture contents used in radon barrier design are conservative estimates of the average long-term moisture content, where conservative implies the estimates are based on relatively dry conditions.

Radon emanation. Radon emanating fractions are measured over a range of moisture contents and Ra-226 concentrations. The overall average of these values for each major category of contaminated material is normally used in modeling the tailings pile, unless a correlation between Ra-226 concentration or moisture content and emanation is apparent. In this case, either an estimated value, based on the correlation, or a conservative value should be used.

The radon emanating fraction is determined by comparing the radon activity in a sealed sample when it is in equilibrium with Ra-226 to the radon activity trapped in the mineral grains. The first part is accomplished by allowing radon and radon daughters in an undried sample to ingrow in a sealed container and then analyzing

the sample for radon daughters using gamma spectroscopy. The second part is accomplished by releasing the radon in the pore spaces of a dried sample and reanalyzing the sample for radon daughters using gamma spectroscopy, after a minimum four-hour decay period. The difference between these two activities divided by the equilibrium radon activity indicates the radon emanation from the material.

Radon diffusion coefficient. Radon diffusion coefficients for contaminated and radon barrier materials are measured for samples from the site. Measurements are made with a moisture content at or near the long-term moisture estimates for the stabilized pile, as well as above and below the long-term estimate, to allow characterization of the diffusion coefficient as a function of moisture saturation.

The diffusion coefficients are measured either from samples representative of in situ materials or samples compacted in the laboratory to design specifications, as appropriate. If applicable, the samples are compacted wet of optimum moisture and then dried to test moisture. The sample is placed on a radon source and the time for radon to pass through the sample to a detector is measured. The diffusion coefficient is calculated from the breakthrough curve.

Radium-226 content. The Ra-226 concentrations are measured on samples taken from each area of the site. Windblown, evaporation pond, and mill site areas are normally characterized in addition to the tailings pile. During construction, samples will be collected in the upper 14 or more feet of the stabilized pile to determine the average Ra-226 concentrations. Radium-226 content measurements are made by gamma spectrometry for radon daughters on dried, equilibrated samples.

Ambient radon. The ambient radon concentration in air is the top-of-the-pile boundary condition for the RAECOM model and is based on background measurements near the site. In the absence of ambient measurements, regional values from the literature may be applied.

7.1.2 Data acquisition for radon barrier and contaminated materials

A generic sensitivity analysis was conducted to assess the impact of variability in the design parameters on the required radon barrier thickness (TAC, 1985b). Additionally, the effect on radon barrier thickness was assessed for changes in the Ra-226 concentration and in the emanation fraction of UMTRA Project piles (TAC, 1985c). From the information gained from these two studies, a characterization plan can be developed where resources for characterizing the contaminated and radon barrier materials can be allocated to minimize the uncertainty in the predicted radon flux from the disposal site.

The design parameters, in decreasing order of importance, are listed as follows:

- o Long-term moisture content of the radon barrier.
- o Radon diffusion coefficient for the radon barrier.
- o Concentration of Ra-226 in the contaminated materials.
- o Emanating fraction for radon from the contaminated materials.
- o Radon diffusion coefficient for the contaminated materials.
- o Porosity and density of the radon barrier and contaminated materials; moisture content of the contaminated materials.

Radon barrier. The uncertainty in the radon barrier thickness is dominated by the long-term moisture content of the radon barrier and the associated diffusion coefficient, which is a sensitive function of the moisture content (see Section 7.1.3 for discussion of the method for estimating long-term moisture).

The diffusion coefficient estimates used for preliminary radon barrier design are measured for several locally available materials. The number of measurements is limited to conserve funds for measurements on the final borrow materials. In addition, the preliminary cover measurements are made over a wide range of moisture contents; therefore, a diffusion coefficient value may be estimated for any long-term moisture content using a least squares fit to the data. The small number of preliminary measurements of cover diffusion coefficients may not allow the overall uncertainty of the radon barrier thickness to be reduced to an acceptable level.

Measurements made on the actual borrow materials should be sufficiently intensive to reduce the uncertainty in the required radon barrier thickness to a reasonable level. Based on a statistical study (TAC, 1985b), a minimum of 40 measurements of final radon barrier material would be appropriate in view of the cost of the measurements. These measurements would be concentrated in a small range of moisture contents close to the predicted long-term moisture content, with measurements made at or near the long-term moisture content as well as above and below the long-term content.

The cover design should be completed well before construction on a site begins. It will be necessary that measurements of the diffusion coefficient of the actual radon barrier material be made before the final design is approved. Once the actual borrow site has been selected, at least eight samples representative of the material will be taken. If special sieving or admixtures will be used in preparing the cover material, the samples should be prepared in the same manner. As the borrow source is excavated, additional samples may be taken. If possible, all early samples will be from test pits or stockpiled cover soil. The data from these samples will be used to assess the variability in the diffusion coefficient of the cover at a particular moisture content and compaction.

In general, a radon barrier of uniform thickness will be designed for the entire pile, instead of a barrier of variable thicknesses that can accommodate a variable source term. There are two approaches that may be used to determine the uniform thickness required to limit the radon flux to acceptable levels. For embankments where different sections or areas have drastically different materials, an area-weighted averaging may be used. A specific set of RAECOM input parameters is profiled for each pile section so that the surface radon flux from a cover thickness may be calculated for that section. Each flux is then weighted by the respective area for that pile section and averaged to determine the flux for the entire pile surface. This average flux is then compared with the EPA standards to determine if the uniform radon barrier thickness is adequate. If not, a new thickness is estimated and the entire process is repeated.

Pile sampling. The Ra-226 concentration, in conjunction with the emanating fraction, determines the radon source term available for diffusion. Therefore, the required radon barrier thickness is sensitive to the Ra-226 concentration and emanation fraction. However, since radon gas diffuses slowly through soils, only the upper portion, typically 10 to 20 feet, of the contaminated material significantly affects the required radon barrier thickness.

The Ra-226 concentrations are usually well characterized as a result of the efforts to determine the extent of the contamination (see Section 7.2.1). Typically, a minimum of 100 to 300 measurements are made of the Ra-226 concentration. Sites with several distinct areas or regions of contamination will require more extensive characterization, with a concurrent increase in the number of measurements. For each distinct contaminated material, an average concentration should be determined, as discussed in Section 7.1.4. If the material has a large inherent variability, additional samples may be necessary to reduce the error in the estimated average concentration.

Emanating fractions and diffusion coefficient measurements may be made on relatively pure samples of slimes and sands, as well as on samples with a mixture of sands and slimes. Since piles consist of sands and slimes as well as a mixture of the two, average values for the measurements are used in the design calculations. If a dependence of emanating fraction on moisture content is indicated, the averages at appropriate moisture contents are used. It is generally assumed that the off-pile contamination is due to tailings and that it has the same average emanating fraction. In cases where the off-pile contaminated volume is large or where different materials are involved, such as in ponds, additional emanating fraction and diffusion coefficient measurements are made on samples of the material. To assure that the average diffusion coefficient is representative of the true diffusion coefficient, a minimum of four samples from each distinct contaminated material will be tested at various moisture contents, except for material buried below 10 to 20

feet, which has been demonstrated to have minimal impact on the radon flux from the stabilized pile. These samples should also be analyzed for emanation fraction.

Inherent safety factors in the design approach. The cover design for the pile is intended to provide "reasonable assurance" that the average flux will not exceed 20 pCi/m^2s. Careful limiting of the uncertainties in parameter values and the use of conservative values for parameters where the uncertainties cannot be reduced are used to satisfy the requirement for reasonable assurance.

There are, in addition, some conservative assumptions implicit in the design approach that indicate the actual flux will be less than the estimated flux. Whenever the soil is very wet, frozen, or covered with snow, the radon is effectively blocked from escaping into the atmosphere. Depending on the period over which such conditions exist, there will be a reduction in the actual annual average flux as compared to the design flux.

In the design of the pile, no radon flux attenuation is attributed to the erosion protection and filter layers applied to the pile. There may be some decrease in the radon flux due to these layers; thus, a safety factor is present.

The only safety factor intentionally applied in the design of the radon barrier is the conservative moisture content, which is in agreement with the need for "reasonable assurance" expressed by the EPA. It is the intent of this discussion, however, to make clear that there are reasons to expect that the annual average flux would be lower than the design flux.

7.1.3 Long-term moisture content

The design of a cover system to meet the performance criteria established by the EPA includes a radon barrier consisting of select native soils that act to retard the diffusion of gas, allowing a substantial fraction to decay to solid products before it escapes into the atmosphere. The long-term moisture content of soils used in the construction of the cover system is of particular importance in determining the thickness of the radon barrier layer and is influenced by other layers in the design.

Several models and empirical solutions have been developed by many researchers to estimate a soil's water-retention characteristics and the equilibrium water content of a soil based on particle size distribution, density, consolidation properties, infiltration, evaporation, and evapotranspiration.

This section discusses the laboratory tests and empirical correlations that are being used on the UMTRA Project to calculate

and/or predict the moisture content versus suction and the long-term moisture content of soils used for the radon barrier and the contaminated materials.

Laboratory tests

Two laboratory tests are available for determining the capillary moisture relationship of a soil: ASTM D2325 for coarse- and medium-textured soils, and ASTM D3152 for fine-textured soils. Both of these tests provide a relationship between moisture content and suction (or negative pressure) that would result in a soil due to evaporation and evapotranspiration. The test ASTM D2325 is normally used to determine the capillary moisture relationship from 0.1 to 1.0 bar of suction, while ASTM D3125 is used to determine the capillary moisture relationship from 1.0 to 15 bars of suction (1.0 bar = 0.987 atmosphere = 14.5 pounds per square inch = 1020 cm of water).

The tests are routinely run on representative samples of borrow material that will be used in the radon barrier and on representative samples of contaminated material. These data are used to predict the unsaturated hydraulic conductivity of the pile soils and in the modeling of the long-term moisture content.

Empirical correlations

Several different empirical correlations have been evaluated to determine the moisture content of a soil as a function of the matric or suction potential that would be caused by evaporation, evapotranspiration, lateral flow, percolation, and the like. Most of the correlations evaluated were able to predict only the wilting point of the soil, which is the moisture content corresponding to a matric potential of -15 bars, hereafter referred to as the -15 bar moisture content (Richards and Weaver, 1943). However, three correlations, all using the physical properties of soil, have the capability of predicting the moisture content corresponding to a wide range (-0.04 to -15 bars) of soil matric potentials. These three solutions were developed by the following:

- Rawls et al. (1982).
- Brakensiek et al. (1982).
- Gupta and Larson (1979).

These relationships are based on the percent sand, silt, clay, and organic matter, the bulk density, and a set of regression coefficients that are multiplied by each of these parameters. These correlations all fit the following general equation:

$$\theta_p = a \times \text{sand } (\%) + b \times \text{silt } (\%) + c \times \text{clay } (\%) + d \times \text{organic matter } (\%) + e \times \text{bulk density} + f$$

where

θ_p = predicted volumetric water content.
a, b, c, d, e, f, = regression coefficients.

Bulk density = γ_d (1 + w)

where

γ_d = dry density.
w = moisture content (dry weight basis).

If bulk density is expressed in grams per cubic centimeter (g/c^3) and γ_d in pounds per cubic foot (PCF), units can be converted by using the relationship of 1 gm/c^3 = 62.4 PCF.

To convert the volumetric water content to moisture content on a dry weight basis (gravimetric moisture content), the following conversion is applied:

$$\theta_m = \theta_v \times \frac{\gamma_w}{\gamma_d}$$

where

θ_m = gravimetric moisture content.
θ_v = volumetric water content.
γ_d = dry unit weight of the soil.
γ_w = unit weight of water.

The results of these regression equations, compared against actual laboratory data, indicate the following:

- The Rawls et al. (1982) and Brakensiek et al. (1982) correlations are more suitable to sandy and silty material.
- The Gupta and Larson (1979) correlation is more suited to clayey soils.
- For soils that are well-graded with more than 10 percent clay, an average of the three correlations is best suited.
- For soils that are gap-graded with little or no silt and a low clay content, none of the correlations is suitable for predicting moisture content versus suction.

Another method which has been investigated for directly determining the long-term moisture content of a soil is the method suggested by Gee et al. (1984). However, this empirical correlation is based on the in situ measurement of site soils, has a very limited

database, and neither applies well to UMTRA Project sites nor correlates with laboratory test data.

Variations of the moisture content

For the purposes of radon barrier design, the methods described above will be used to make the best estimate of the radon barrier's long-term moisture content. In addition, the methods described, supplemented by data on the likely variations in the climate of the site and judgment of the physical processes involved, will be used to estimate the wettest and the driest (upper and lower bound) the radon barrier is likely to be for a period of several decades. For the purpose of design, as suggested by the EPA, several decades will be interpreted as approximately thirty years.

It is recognized that variations in the moisture content of the radon barrier can and will occur over the design life of the stabilized pile. The mean value of the moisture content will be used in calculating the infiltration through the radon barrier and the radon flux through the radon barrier. For the purposes of a conservative estimate of the radon flux and the amount of seepage of water through the radon barrier, it may be necessary to evaluate the upper and lower values of the long-term moisture content in order to evaluate the conservatism and reliability of an assumption. The extreme values of dry and wet, estimated as described above, may be used in the calculation of the extremes of infiltration and radon emanation. When this is done, the reasons for adopting extreme values of the moisture content of the radon barrier will be documented. The long-term moisture content will be used in calculating the thickness of the radon barrier and the amount of infiltration that will occur, and the extreme values will be used to determine the degree of conservatism associated with the design.

Conclusions

When determining the long-term moisture content of a particular soil, the following items are highly relevant: (1) the soil moisture characteristic curve, i.e., the plotting of moisture content versus matric potential (by either predicted, laboratory, or field test data); (2) the type of erosion protection layer to be placed on top of the radon barrier (will inhibit evaporation from the radon barrier); (3) the climatic environment (will affect the equilibrium moisture content); (4) the moisture content of the material at the time of emplacement; and (5) the optimum material when compacted to its specified dry density.

The amount of water retained by a soil depends primarily upon adsorption. Adsorption depends upon the specific surface of the soil materials, which is a function of particle size distribution of

the soil and consequently the pore size distribution. For example, a fine-textured soil, such as a clay with a large specific surface, has a great attraction for water. Hydroscopic water is held to the soil surface by adhesion and electrostatic forces. Soils with a higher specific surface will retain water more forcefully; clays have the highest specific surface area. Isomorphic substitution and interrupted structures result in a negative charge at the surface of clay particles. To balance this negative charge, clay particles attract dissolved cations present in the pore water. The water molecules adjacent to the negatively charged clay surface may orient themselves due to their polarity. At the hygroscopic limit, the tension is 30 bars and much of the water is held so tightly that it is essentially nonliquid and moves mostly in the vapor phase. A water content corresponding to a moisture potential between 15 and 30 bars is called capillary water, which is removed too slowly by plants to prevent wilting (Buckman and Brady, 1969). Fifteen bars is the tension at which most plants will undergo permanent wilting. Soils feel dry at hygroscopic potentials (greater than 30 bars suction) but feel moist at capillary potentials (less than 30 bars suction).

Compaction, in turn, will decrease the pore size distribution so that a soil may hold more water at any given matric potential. At a constant gravimetric moisture content, the degree of saturation will increase under compaction due to the decreasing void ratio. The degree of increase in saturation ratio will be very much a function of the initial void ratio and compression index of the soil. Low initial void ratios (which means a high saturation for a given moisture content) are very often incompatible with high compression indices, so that dramatic increases of saturation ratios under a pressure of 15 bars is unlikely under those circumstances. Materials will be placed at or above optimum moisture contents, so that 50 percent saturation should be attainable after compaction and is considered the lower limit of saturation for determination of the long-term moisture content of the radon barrier.

If the 15 bar moisture content of the compacted radon barrier material is below the moisture content of the in situ borrow materials, then the 15 bar moisture content should be used. If the opposite occurs, then it generally can be concluded that the tested 15 bar moisture value is probably not correct. Therefore, the material would be retested or the in situ moisture content would be used for design purposes.

7.1.4 Statistical and sensitivity analysis

The EPA standards require that the radon barrier design provide "reasonable assurance" that the radon emissions do not exceed an average flux of 20 pCi/m^2s. Additionally, prudent engineering design, when based on limited data, requires the consideration of the intrinsic variability in the data and its associated design

impact. These considerations are necessary for the UMTRA Project since many of the sites have constraints, such as limits on the final volume of the stabilized embankment and amount of cover material available. Therefore, ensuring the constructibility of the prescribed radon barrier requires an analysis of the potential variations in the estimated mean values of critical parameters.

To achieve this reasonable assurance, during pre-construction design stages the limited characterization data collected for the sites shall be analyzed using standard statistical techniques and the impact of the uncertainty in the data shall be determined by using sensitivity analysis. Since the tailings and cover materials cannot be exhaustively characterized due to cost considerations, the true values for the average Ra-226 concentrations, emanating fractions, and diffusion coefficients must be estimated from limited data sets. Inherent in this approach is an uncertainty in the estimated true mean value for each critical design parameter, which leads to an overall uncertainty in the required cover thickness. By evaluating this overall uncertainty, reasonable assurance of compliance with the standards can be demonstrated or the need for additional characterization can be determined.

For predicted radon barrier thicknesses less than six inches, no sensitivity analysis is required because the minimum constructable thickness is eighteen inches. If the thickness of the radon barrier required for radon control (estimated by using the mean values for the parameter) is more than six inches, then the combined uncertainty in the cover thickness design due to the uncertainty in all of the parameters shall be limited to 40 percent of the cover thickness required by the mean values. The uncertainty in a parameter is expressed as the standard error of the mean (SEM). The combined uncertainty is estimated by performing a single radon barrier thickness calculation using the mean + SEM for all parameters, where the conservative sign is used for each parameter, and this "worst case" thickness is compared to the thickness based on mean values of the parameters. The limit on the uncertainty for any single parameter shall not be specified, but rather shall be the combined effect for all parameters. If the combined uncertainty exceeds the limit, then the effects of the uncertainties for the individual parameters will be investigated to determine which parameter(s) needs further characterization. If the sensitivity analysis indicates additional characterization is necessary, further characterization will be performed to ensure compliance with the limit in the combined uncertainty. This limit will apply to all pre-construction designs so that the final design for construction will comply with the limit.

Diffusion coefficient. A long-term moisture content and associated diffusion coefficient will be developed for both the radon barrier material and the upper 14 feet, or more, of contaminated materials. A 15-bar capillary moisture value should be measured for each sample and used as the long-term moisture content unless a more accurate or conservative value is available (see Section 7.1.3). Diffusion coefficient tests for each sample, at a minimum of five moisture contents (at least two above and two below the long-term moisture value), will be used to define the diffusion coefficient-moisture saturation curve for each sample. The resulting data should be fit using a data-fitting technique to determine the long-term moisture estimate for each sample. Since the long-term moisture estimate is a critical parameter, the measurement of 15-bar capillary moisture and diffusion coefficient should be made on aliquots from the same sample.

The mean value ($\bar{x}$) of the diffusion coefficient for the radon barrier material and every appropriate contaminated material shall be determined by the simple arithmetic average of the diffusion coefficients obtained for all samples of the respective materials at the specified moisture saturation. The SEM is determined by dividing the standard deviation (s) by the square root of the number of samples (n) for that material.

$$\bar{x} = (\mathrm{sum}(x_i))/n$$

$$s = \mathrm{sqrt}((\mathrm{sum}(x_i - \bar{x})^2)/(n - 1))$$

$$\mathrm{SEM} = s/\mathrm{sqrt}(n)$$

where

x_i is the diffusion coefficient for each individual sample.

All data should be included in the calculations unless documented evidence exists to indicate laboratory or sample selection error. Since the materials at the UMTRA Project sites are not homogeneous, apparent outliers, i.e., apparently anomalous data, may be representative values. The laboratory may be asked to review the results or perform repeat tests for suspect data to determine if the experimental procedure may have caused the discrepancy.

Radium-226 concentration. The average Ra-226 concentration in each disposal layer, borehole vicinity, or other specified area should be determined from laboratory analysis of multiple samples and from in situ measurements. The samples will be acquired from specific locations, usually from boreholes or surface areas. If the spatial distribution of the sample locations is uniform and the thicknesses of all samples are equivalent, then the average concentration and the SEM for each layer should be calculated using the equations presented above where x_i would be the number of samples.

However, when the samples are not of equal thicknesses of the material or the sample locations are not representative of equal areas, a weighted average and SEM should be determined. For instance, Bendix Field Engineering Corporation uses six-inch, 12-inch, and 24-inch samples and the Remedial Action Contractor (RAC) uses these and other sample lengths. Since varying thicknesses and areas are representative of varying volumes of material, the average concentrations associated with variable volumes should not be simply averaged linearly.

The volume associated with each sample would be determined by multiplying the thickness of the sample by the area associated with that sample location. That is,

$$v_i = t_i \times a_i$$

where

v_i = the volume associated with sample i.
t_i = the thickness of sample i.
a_i = the area associated with the sample location for sample i.

The weighted average concentration and SEM would be determined using the following equations:

$$\bar{c} = (\mathrm{sum}(v_i \times c_i))/(\mathrm{sum}(v_i))$$

$$\mathrm{SEM} = \mathrm{sqrt}[(\mathrm{sum}((v_i \times c_i - \bar{v} \times \bar{c})^2))/(\bar{v}^2 \times n \times (n - 1))]$$

where

n = number of samples.

c_i = concentration associated with sample i.

v_i = volume associated with sample i.

$\bar{v}$ = average of volumes v_i, calculated as the simple arithmatic average.

Notice that if all of the samples have the same thickness (i.e., t_i is constant) or if the spatial distribution of the sample locations is uniform (i.e., a_i is constant), the constant values factor out of the equation. In either of these cases, the weighting would be by area or thickness, respectively, instead of volume.

The Ra-226 concentration within the piles is known to vary significantly due to the variations in the ore and processes used. Although some results may appear to be outliers, this inherent variability typically means the values are representative of the true

concentrations. Therefore, apparent outliers should not be excluded unless laboratory or in situ measurement error is documented.

Emanating fraction. The average emanating fraction should be determined by either simple averaging, as with the diffusion coefficient, or by volume weighting, as with the Ra-226 concentration. Volume weighting should be used only when large amounts of distinctly identifiable materials occur. Normally, simple averaging will be adequate. The SEM should be determined based on which averaging method was used. As discussed above, all data shall be used in the calculation.

7.1.5 Approach for radon monitoring around UMTRA Project sites

Monitoring of radon-222 (Rn-222) concentrations in the ambient air at UMTRA Project sites is performed before, during, and after construction. Approximately one year prior to the planned remedial action construction, screening level measurements are made using alpha-track detectors. During construction, both alpha-track detectors and continuous-flow Lucas cell instruments are used. For six months to one year following the end of construction, alpha-track detectors are used to document the reduction in ambient radon concentration from the stabilization effort.

During the pre-remedial action monitoring period, there are two purposes for collecting the ambient radon concentration data: (1) to determine the ambient values at the site boundary, which includes the influence of the radon release from the site itself; and (2) to confirm the overall pattern of radon concentration in vicinity of the site. Radon monitoring will be used to assist in the most effective placement of the monitors to be used during remedial action construction. The monitors used during construction allow site personnel to plan the construction activity to maintain the radon concentration off the site at levels less than 3.0 pCi/l above background. Also, monitors will be used to limit worker exposures to less than 30 pCi/l on the site. The "real time" data from these monitors also provide evidence to the local concerned public that the construction operation is not releasing dangerous amounts of radon to the environment. After construction is complete, measurements of the ambient levels at the site boundary are made in order to demonstrate that radon concentrations are in compliance with the 0.5 pCi/l above background radon standard.

To allow virtually real-time control over construction operations during remedial action, continuous radon monitors are placed at three to five locations around each site. Weekly averages of the hourly reported concentrations are used to determine trends in the ambient radon concentration. If the weekly average rises to 3.0 pCi/l above background level, construction activities are curtailed and steps are taken to reduce the radon release rate by moistening and covering exposed tailings. In addition to the continuous monitors, passive integrating detectors are used during the

construction phase to document radon concentrations at certain sensitive receptor sites. Monitoring locations typically include schools, hospitals, and other population sites or public facilities. Alpha-track detectors are typically exposed for several months, and two detectors are exposed at each sampling station to assess sampling variability.

After construction is complete, measurements of the ambient radon levels at the site boundary are made in order to demonstrate the reduction in levels resulting from the remedial action. These measurements are made at the same locations monitored during the preconstruction stage. Alpha-track detectors are used in the same fashion as described above.

7.2 PROCESSING SITE REMEDIATION

The EPA specified the standards for removing the contaminated material and the allowable levels of residual radioactivity. The standards are summarized in Section 7.2.2. To accomplish the required remedial action, the extent of contaminated material must first be determined. To determine if the remedial action provides reasonable assurance that the standards are met, verification activities must be performed. These are discussed in the following sections.

7.2.1 Site characterization design

This section presents the rationale for obtaining the data necessary to define the extent of the contamination at a site. For the piles or portions of piles that are to be moved from their present location, the depth of contaminated material below the pile that must be excavated in order to meet the soil contamination limits must also be determined. That depth and the vertical and areal extent of the off-pile contaminated materials are collectively referred to as the "limits of contamination." Associated with this is a volume of contaminated material. In some cases, due to the type of excavation equipment, conditions at the site, or the physical contours of the contaminated material, additional volumes of uncontaminated material may have to be removed. In such cases, volumes for excavation will be based on "limits of excavation" giving a corresponding excavation volume.

Data acquisition for defining the limits of contamination

This section presents the rationale for obtaining data to define the extent of contamination and is primarily based on a previously published paper (TAC, 1985a).

Certain considerations are made prior to designing a radiological data acquisition plan for each of the 24 inactive mill tailings sites. Firstly, it is recognized that large scrapers and other

earthmoving equipment will be used to excavate and transport off-pile material to the disposal site. Since excavation lifts of less than four to eight inches are not practical and the excavation length is normally a minimum of 75 feet, the use of large equipment limits the density of data necessary to define the limits of contamination to approximately a 50-foot grid and six-inch incremental depths. For areas with relatively constant contamination levels and depths, data from grid points a few hundred feet apart are adequate.

The second consideration in planning a radiological site characterization survey is the typical physical dimensions or areal size of the contaminated volume. The spacing of measurements should be somewhat smaller than the size of the contamination deposits that are to be detected, in order to ensure the deposits are sufficiently and frequently sampled. A review of the use of a processing site, including old photographs, provides an indication of the degree of disturbance of the site. At some processing sites, the mill and ore storage areas were significantly recontoured during the life of the facility. Extensive regrading of these areas normally results in contaminant dispersal with depth, possibly over small areas. Therefore, a sampling density dependent on the degree of variability is desirable if a high degree of accuracy in quantifying the volume of contaminated material is desired.

A third consideration is the accuracy desired in defining the location and volume of contaminated material prior to the remedial action. For the UMTRA Project, the goal is to define the extent and volume of off-pile contaminated materials to be excavated to within roughly 20 percent. Reliance on radiological monitoring during excavation subsequently ensures that EPA standards are met.

The considerations presented above are general. Site-specific considerations, normally related to cost or particular conditions of the site, can significantly alter the radiological characterization approach. Detailed definition of the contamination may reduce overexcavation and is particularly justified in situations where the material may be transported for long distances to an alternate disposal site. If the excavated area will require expensive restoration, or if smaller earthmoving equipment is used, detailed definition of the contamination may also be cost-effective.

Elements of radiological site characterization

Site grid and land survey. A site coordinate system is first established using reference elevations and state plane coordinates. All data to be collected for engineering designs are reported relative to the site coordinate system and are provided on a magnetic data tape in a format compatible with the UMTRA Project Technical Information Management System. Land topography on two-foot contours is digitized and also placed in the Technical Information Management

System. Overlay maps are computer-developed to aid in interpretation of data for limits of contamination. These data and maps are provided to the RAC for final design use.

Borehole drilling and logging. For areas of known or suspected deeply buried contamination, holes are augered at five-foot increments and downhole-logging with a gamma scintillometer (sodium iodide) is performed through the hollow-stem auger. In cases where rotary drilling is necessary, the hole may require casing prior to downhole logging. The downhole-logging instrumentation is calibrated to pads of known Ra-226 concentrations in order to derive a Ra-226 measurement (in pCi/g). Split-barrel samples are typically collected from a percentage of the boreholes to analyze for Ra-226 by gamma spectroscopy and for thorium-230 (Th-230) and natural uranium by radiochemical separation and alpha spectroscopy. Lithologic logging is done on split-barrel samples according to the Unified Soil Classification System (USCS), and visual soil classification is recorded on standard logging forms. A land survey to obtain the horizontal coordinates and elevations of all boreholes is done concurrently with the radiological survey.

If adequate data are not available, a drilling study is done to determine the depth of contaminated soil beneath the tailings pile. Split-barrel samples are collected and analyzed for Ra-226 concentrations. Selected sub-interface samples are also analyzed for Th-230 and heavy metals. Data from some sites indicate that some non-radiological contaminants (e.g., arsenic, selenium, vanadium, and molybdenum) migrate to greater depths beneath the tailings than does Ra-226. The tasks described in this section are performed by specialty subcontractors under the TAC's direct supervision. The RAC is provided with the data, documents, and reports for use in the final design.

Gamma exposure rate measurements. Gamma exposure rate surveys are often used to define the approximate boundaries of large areas where contamination lies near the surface, such as areas contaminated by wind or water dispersion from a tailings pile. For a gridded area off the pile and away from known contamination, gamma exposure rate measurements are made at each grid point three feet above the surface and at ground level. If the ground level measurement is higher, then localized surface or near-surface contamination is suspected.

Along each grid line, a traverse is made with gamma measurements recorded at three feet above the surface and at ground level to determine anomalous hot spots and the approximate boundary of off-pile contamination in relation to the 5.0 pCi/g above background Ra-226 standard. A scintillometer reading of five to 10 microroentgens per hour (microR/h) above ambient levels is used as a guide to estimate the 5.0 pCi/g Ra-226 perimeter.

The gamma survey is carried out to near-background levels to ensure that the areal extent of all windblown contamination has

been determined. Locations with elevated gamma exposure rates are recorded and marked for subsequent soil sampling. Significant anomalous areas are investigated further and the areal extent is defined by four gamma measurements along the perimeter of the anomalous area and one along the traverse line. Gamma traverse measurements are also done along suspected areas (e.g., drainages, railroad and highway beds, and tops of bluffs). Potential sources of contamination such as old equipment or junk piles are scanned for gamma and alpha radiation.

Gamma surveys are conducted using a scintillometer capable of detecting 5.0 microR/h and calibrated against a pressurized ionization chamber in the field. Daily source checks are done to ensure proper operation of each instrument.

Ra-226 concentration determination by soil sampling and in situ measurements. Certain areas of the site are normally expected to be contaminated only in the top foot of soil. These areas lend themselves to soil sampling and analysis rather than borehole logging. A grid is constructed and surface soil samples are taken at not less than 50 percent of the grid locations in order to acquire an unbiased estimate of magnitude and distribution of contamination. Grid spacing is determined on an area-by-area basis depending on contaminant variability as discussed earlier. Soil samples are analyzed for Ra-226, potassium-40 and thorium-232 in the laboratory by gamma spectroscopy, following drying and preparation of the sample. At grid points where a surface soil sample is taken, an in situ "delta" measurement is made at a depth of six inches.

A delta measurement is made with a collimated scintillometer (sodium iodide) calibrated to provide an estimate of localized Ra-226 concentration in the field. Soil gamma emissions are counted with and without an absorber placed between the soil and the collimated scintillometer. The difference in count rates indicates the gamma emissions from beneath the detector. The equipment is calibrated on pads which have known Ra-226 concentrations in order to derive a Ra-226 measurement in pCi/g.

The delta measurement is primarily used as a guide for determining soil sample locations to define areal boundaries and depths of contamination better. The delta measurement is also useful at locations in high gamma-shine areas, such as near a tailings pile, where other field measurement techniques are not usable. If the delta measurement at a depth of six inches indicates levels near 5.0 pCi/g Ra-226, a soil sample is taken at the interval from six to 12 inches, followed by a delta measurement at a depth of 12 inches. This procedure continues until the delta measurement decreases to below 5.0 pCi/g Ra-226 or a delta measurement has been taken at a depth of 18 inches. An in situ measurement equal to or less than 5.0 pCi/g Ra-226 normally provides statistical confidence that the actual concentration is less than the 15 pCi/g limit for subsurface

contamination. If the 18-inch delta measurement indicates levels above 5.0 pCi/g Ra-226, a borehole is drilled at the location and downhole-logged to determine the depth of contamination. Biased soil samples and delta measurements are taken to determine contamination levels to a depth of 18 inches at anomalous locations as detected by gamma exposure rate measurements. The purpose of these measurements is to determine if contamination levels below the surface meet the EPA standard of 15 pCi/g Ra-226.

In areas where gamma exposure rates diminish to less than 10 microR/h above background, biased surface delta measurements and soil samples are taken to define the 5.0 pCi/g Ra-226 perimeter better. In this case, staggered delta measurements are taken in order to determine additional soil sample locations along the estimated 5.0 pCi/g Ra-226 perimeter line. Subsequent gamma spectroscopy analyses of soil samples provide a measure of the accuracy and precision of in situ measurements. The purpose of these measurements is to determine the extent of surface contamination exceeding the EPA standard of 5.0 pCi/g Ra-226 in the first six inches of soil.

A percentage of the soil samples over a range of activities is analyzed for Th-230 and natural uranium in order to compare the concentration to that of Ra-226. In some cases, excavation criteria are based on uranium or Th-230 rather than Ra-226. One particular example of this is where a preferential separation of Th-230 from Ra-226 in raffinate ponds occurred. Thus, the limits of contamination in these ponds is dependent on Th-230, rather than the Ra-226 concentration. The percentage of samples, as well as the location of samples analyzed for Th-230 and uranium, is determined after reviewing the history of the site and the chemistry used in processing the ore.

Building surveys. For building surveys, measurements are taken for surface alpha contamination (removable and total), gamma ray exposure rate, and radon daughter concentration. Two different plans exist for surveying buildings; one plan is for structures to be demolished, and another is for structures to be decontaminated. A limited survey is done indoors and around the exterior of structures that have no salvage value. Surface alpha contamination levels are measured in these buildings in areas suspected of being contaminated in order to obtain a measure of the degree of potential hazard to workers during the demolition period. The gamma exposure rate at three feet above the surface in the center of each room is recorded. For structures with salvage value, more extensive surface alpha and gamma exposure rate surveys are done on a grid of approximately 10 to 20 feet to determine areas where decontamination is necessary. In addition, biased alpha contamination sampling is done at locations likely to be contaminated (e.g., flat ledges or other dust-collection points) with the sampling frequency determined from variability of alpha readings. If elevated surface alpha or gamma levels are indicated near large quantities of loose materials, the

surface is swept and a sample is taken to be analyzed by gamma spectroscopy. For unrestricted release of buildings, gamma exposure shall not exceed 20 milliroentgens per hour (mR/h) above background as stated in 40 CFR 192. Radon daughter concentration (RDC) measurements are made to ensure compliance with the EPA indoor RDC standard of 0.02 working level (WL). If the building was constructed during or subsequent to milling operations, boreholes may be drilled through the flooring, especially near anomalously high gamma exposure rate readings, to detect substructure contamination.

Uncertainties in volumes of excavation

Constraints on site characterization efforts and site characterization sampling designs affect the ability to define both limits of contamination and limits of excavation. Current site characterization designs have two basic components: (1) identifying the boundaries of areas; and (2) estimating depths and material volumes. The boundary investigation is primarily "deterministic" in that it attempts to define, on a given spatial resolution, where a concentration boundary falls. The depth of contamination investigation is more "statistical" in nature; it uses "systematic sampling with random start" (stratified in regular intervals from the surface down) to obtain an estimate of the average depth of material in an area. The site characterization of contamination depth is seldom conducted on a spatial interval sufficient to precisely define the pattern of contaminant depth changes in an area.

Precise determination of the required depth of excavation at any point may be done either during characterization surveys or during excavation through real-time excavation monitoring. For the UMTRA Project, it has been determined that site characterization is intended to define the limits of contamination (both horizontal and with depth) sufficiently for the purposes of engineering design (both preliminary and final). A target value is to estimate the volume within 20 percent.

Thus, site characterization is to provide a contamination boundary and average depth of contamination in a particular area. Excavation control measurements are expected to guide the actual excavation depth in any particular location to give a volume comparable to the volume based on the average depth. The benefit is a considerable reduction in the cost of site characterization surveys.

Conservative overestimation of contaminated volumes has been preferred for most sites to date. Conservative features that have been applied include:

- Where limits are defined using in situ measurements of Ra-226, concentrations of 2.0 pCi/g and 5.0 pCi/g have been used as cutoff values rather than 5.0 pCi/g and 15 pCi/g at

some sites. This is intended to allow for uncertainties of in situ measurements.

- Excavation depths are sometimes increased by six inches beyond the estimated required depth. This is sometimes done when a distinct contamination depth can be defined to allow for mechanical mixing during excavation.

- Excavation depths are set deeper than what would be a real average depth in areas where the contamination extends to variable depths. This accounts for the presence of unidentified areas of deeper contamination, and gives some buffer for mechanical mixing.

These conservative volume estimation methods were found to be necessary based on experience with actual excavations in order to obtain a reasonable estimate of what will actually be excavated rather than the precise contaminated volume.

7.2.2 Standards for remedial action

The Uranium Mill Tailings Radiation Control Act of 1978 (PL95-604) gave the responsibility of developing standards for remedial action to the EPA. Section 108 of PL95-604 states that the DOE shall "select and perform remedial actions at the designated processing sites and disposal sites in accordance with the general standards" prescribed by the EPA. The EPA standards (40 CFR 192) state:

> Section 108 of the Act requires the Secretary of Energy to select and perform remedial actions with the concurrence of the Nuclear Regulatory Commission and the full participation of any State that pays part of the cost, and in consultation, as appropriate, with affected Indian Tribes and the Secretary of the Interior. These parties, in their respective roles under Section 108, are referred to hereafter as 'the implementing agencies.'
>
> The implementing agencies shall establish methods and procedures to provide 'reasonable assurance' that the provisions of Subparts A and B are satisfied. This should be done primarily through use of analytical models, in the case of Subpart A, and for Subpart B through measurements performed within the accuracy of currently available types of field and sampling procedures. These methods and procedures may be varied to suit conditions at specific sites.

Subpart A deals with the control of residual radioactive materials and establishes standards for the longevity of control and for the release of radon-222 to the atmosphere.

Subpart B establishes standards for cleanup of land and buildings. The standards applicable to the project are:

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

A. the concentration of Radium-226 in land averaged over an area of 100 square meters shall not exceed the background level by more than --

(1) 5.0 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15-cm-thick layers of soil more than 15 cm below the surface.

B. in any occupied or habitable building --

(1) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) the level of gamma radiation shall not exceed the background level by more than 20 microR/h.

In addition to the EPA standards for buildings, removable surface alpha contamination and the total non-removable alpha contamination shall not exceed the surface contamination guidelines for personnel and equipment in the UMTRA Project Environmental, Health, and Safety Plan (DOE, 1989). The limits will ensure that potential airborne radionuclide concentrations will not exceed 10 CFR 20 Appendix B standards and that physical contact with the surfaces by occupants of the structures will not result in a measurable radiation exposure. These guidelines also apply to equipment released from the site.

As indicated earlier, the standards suggest that the implementing agencies determine what methods and procedures will be used to provide "reasonable assurance" that the standards are met. Reasonable assurance implies that a site-specific analysis is appropriate where the cost of demonstrating compliance with the standards is to be weighed against the health risks or other impacts associated with leaving areas which slightly exceed the standards.

Within Subpart C are the criteria for applying supplemental standards. Six specific circumstances are listed when supplemental

standards can be applied in lieu of the standards in Subparts A and B. If one of these criteria apply, the remedial action plan will document and justify the application of supplemental standards.

7.2.3 Verification of remedial action

The EPA standards require that the remedial actions provide reasonable assurance of compliance. To demonstrate this, the implementing agencies have approved procedures to use. The procedures can be grouped into four categories: excavation control, final verification of soil, Ra-226 concentrations, and final verification of building decontamination.

Excavation control monitoring

The purpose of excavation control monitoring is to guide excavation through the use of radiological measurements. It is designed to ensure that the 5.0 pCi/g (surface) and 15 pCi/g (subsurface) standards are met. In addition, it minimizes the amount of material that is excavated while meeting the standards. Properly performed excavation control monitoring simultaneously ensures that neither under-excavation nor excessive over-excavation occurs.

Excavation will be monitored by qualified technicians relying principally on gamma field measurements employing hand-held instruments such as gamma-scintillation detectors. This technique will be used only where measurements are not seriously impaired by interference from nearby deposits of contaminated materials. In areas where significant interference exists, alternate monitoring techniques will be used. These techniques may include use of a shielded probe gamma-scintillation instrument (operated in a gross count mode or in a delta mode) or the immediate gamma counting of soil samples in the on site laboratory. In all cases, these techniques will be routinely calibrated by comparison of the field measurements to soil samples analyzed in the laboratory and reported on a fully equilibrated dry-weight basis. Because the standards are based upon average areas of 100 square meters (m^2), the excavation control monitoring will be performed on areas of this characteristic size as well.

Elevated gamma-ray radiation fields, if present, will preclude exclusive use of in situ monitoring devices to estimate the surface radionuclide concentrations in soil on or immediately adjacent to the tailings pile. When in situ measurements cannot be performed, the suggested method for analysis is to take individual or composite samples of soil, seal by canning, and immediately count the sample by gamma ray spectrometry. Errors associated with this approach will be reduced by taking several samples 30 days prior to starting work to determine calibration factors. These samples will be

counted, dried, pulverized, and screened with recanning for subsequent analysis. They will be counted later after the Ra-226 daughters reach equilibrium. Analyses of these prepared samples can then be compared to standards. Several samples will be collected weekly during the remedial action and analyzed to provide a measure of the variation of the calibration factor.

Final radiological verification survey for land

The final radiological survey will be based on 100 m^2 areas, with a nine-plug composite sample used to obtain a measure of the average Ra-226 concentration in an area. The sample, composited from nine 15-cm-deep samples of approximately equal mass, will be canned and analyzed using gamma spectrometry after a minimum twenty-day equilibration period. Other sampling protocols or verification techniques may be used if shown to characterize the mean concentration adequately and if approved in advance by the UMTRA Project Office and implementing agencies. The Ra-226 measurement will be reported on a dry-weight basis. For measurements based on gamma spectrometry of Ra-226 daughters, full equilibrium will be assured. It is expected that at least preliminary measurement results will be obtained prior to backfilling. The error limits for Ra-226 verification measurement techniques must be better than plus or minus 30 percent of the mean concentration, at the 95 percent confidence level.

Final radiological verification survey for buildings

The typical plan requires that gamma surveys will be conducted using an instrument capable of detecting two microR/h above background. Buildings will be scanned while holding the instrument at three feet above the floor. Maximum, minimum, and average exposure rates will be recorded for each room of the buildings. All areas where the exposure rates exceed 20 microR/h above background will be noted for additional remedial action.

Alpha detection instruments will be used to monitor surface contamination. A statistically defensible survey technique will be used. The following describes one such technique. A grid system will be constructed for each room of a structure that has been decontaminated. The grid size will be adjusted such that a minimum of 30 grid points will be defined by using grid lines not more than 30 feet nor less than three feet apart. Measurements will be made at each grid point and other areas of special radiological interest such as floor drains or areas that were the most highly contaminated. Contamination may be averaged over 10-square-foot areas and compared with the allowable limits. In cases where the total contamination is greater than the limits for removal, measurements for assessing the removable contamination levels will be made.

Radon daughter concentration measurements will be taken in areas of the building, or in any building associated with the milling activities, where previous data indicated elevated radon daughter concentrations. An annual average radon daughter concentration will be determined for all structures to assure that they meet the standard.

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8.0 WATER RESOURCES PROTECTION

The EPA standards and their proposed revisions pertaining to water resources protection at inactive uranium processing facilities (EPA, 1983, revised in EPA, 1987) require site characterization of the hydrogeologic regime at and around each UMTRA Project site. The Uranium Mill Tailings Radiation Control Act of 1978 as amended stipulates that "proposed" standards apply until final standards are promulgated (Sec. 108(a)(3)). The DOE shall provide a demonstration of compliance with the EPA standards for groundwater protection at inactive uranium mill tailings sites as specified in 40 CFR 192 (Subparts A-C), draft revisions issued in March 1989 (EPA, 1989). This section should clearly outline the DOE's strategy for complying with the standards. It describes the general technical approaches for site characterization, how to develop the principal elements of the compliance strategy, and methods to evaluate whether the proposed remedial action will meet the EPA standards for water resources protection.

8.1 HYDROGEOLOGIC CHARACTERIZATION

8.1.1 Identification of hydrogeologic units

The DOE will conduct subsurface investigations at each former mill processing site and potential tailings disposal site to define the presence and extent of groundwater-bearing units. Information on all potentially affected aquifers and confining units should be provided and any unsaturated hydrogeologic units should be identified that may convey hazardous constituents released from residual radioactive material. Sufficient graphical and quantitative data and information should be presented to provide a defensible conceptual hydrogeologic model.

Initial site characterization will be performed under the approaches discussed in Sections 5.1 and 5.3, Geology and Subsurface investigation, respectively. After the regional and site geology have been identified, pertinent hydrostratigraphic units can be delineated and characterized. Initial methods to characterize the hydrogeology are as follows:

- Review existing data/literature. Such a review would include existing well and spring data (e.g., drillers' logs, geophysical logs, and water analyses from data sources such as the Federal agency databases WATSTORE (U.S. Geological Survey, or USGS), NASQUAN (USGS), NAWDEX (USGS), STORET (EPA), and NURE (USGS)), geologic and geohydrologic reports, maps, and surficial radiation surveys.

- Develop a preliminary conceptual model of groundwater flow within the immediate vicinity of the site, including identifying hydrogeologic features (e.g., hydrostratigraphic units) that may convey hazardous constituents (see Section 15.3.1, DOE, 1988).

- Inventory and describe existing water wells and springs within a two-mile radius of the site vicinity (see Section 16.3.1, DOE, 1988).

A drilling program can then be designed based on the available data to characterize the site geology and hydrogeology. In order to describe the hydrogeology of the disposal and processing sites fully, the following information on any potentially affected aquifers and confining units must be included: (1) geometry; (2) lateral extent; (3) thickness; (4) recharge and discharge zones; and (5) flow characteristics (e.g., fracture flow vs. porous media flow). In addition to saturated hydrogeologic units, unsaturated units having a potential effect on contaminant transport will also be characterized.

8.1.2 Hydrogeologic, hydraulic, and transport properties

Once the hydrogeology has been characterized, the hydraulic and transport properties of the potentially affected hydrogeologic units at the processing and disposal sites shall be determined. Hydraulic and transport properties include (1) hydraulic conductivities, (2) effective porosities, and (3) dispersivities. The DOE should also describe hydraulic gradients, groundwater flow directions, and average linear groundwater velocities for each potentially affected hydrogeologic unit. Material properties of the tailings and the disposal cell will be determined in the laboratory to evaluate long-term percent saturation in the radon barrier and the tailings; infiltration through the disposal cell cover and the tailings; and transient drainage from the tailings. These descriptions of hydrogeologic and material properties should consider the spatial and temporal distribution and possible heterogeneities and anisotropy of these properties as appropriate to support compliance demonstrations.

The DOE shall measure water level elevations in monitor wells to construct a map of the potentiometric surface for each potentially affected hydrogeologic unit. The elevations of the measuring reference points shall be surveyed. Water level elevations will be measured with sufficient frequency to establish seasonal fluctuations. The representative potentiometric surface shall be determined using groundwater elevations measured within a one month period. When seasonal water level fluctuations, stage height in a nearby body of surface water, or irrigation may influence the potentiometric surface, a map of the potentiometric surface should be provided for each seasonal condition. Groundwater elevation data and hydrostratigraphy will be used to determine which hydrogeologic units are unconfined or confined. Groundwater flow directions will be specified as flow lines that are orthogonal to potentiometric contours. The potential for upward or downward hydraulic gradients within a hydrogeologic unit or between hydrogeologic units should also be addressed (see Section 16.1.2, DOE, 1988).

A conceptual model of the hydrogeologic regime at the site should be devised and be used as a guide for testing hydrogeologic properties. The hydrogeology of the site will be integrated with regional hydrology to identify areas of recharge and discharge for each hydrogeologic unit and the possible degree of connection to surface water.

Aquifer parameters, including transmissivity and storage coefficient and aquifer boundary conditions, can be obtained by conducting aquifer pumping tests (see Section 16.1.5, DOE, 1988). Aquifer tests should be conducted in properly designed pumping wells, with observation wells spaced at appropriate intervals to record drawdown. The pumping rate shall be estimated using a step-drawdown test. The pumping test shall continue for sufficient time to exceed well storage effects in the pumping well, so that drawdown can be measured in observation wells, and so that potential aquifer boundary conditions can be observed. Following termination of pumping, recovery measurements shall be taken. Unconfined aquifer tests shall be analyzed for delayed drainage where fine grained sediments may contribute to this effect (Lohman, 1979). Unconfined and confined aquifer tests may be analyzed by either the Jacob-Cooper semi-log method or the Theis log-log method (Driscoll, 1986; Lohman, 1979). The hydraulic conductivity of the test section of aquifer can be calculated by dividing the transmissivity by the thickness of the aquifer tested.

In cases where the transmissivity of the formation is too low to run a pumping test or where there are no observation wells, falling-head slug withdrawal tests may be conducted to measure hydraulic conductivity. The methods of analysis of slug test data (Bouwer, 1978; Hvorslev, 1951) can be used to analyze slug test data for unconfined conditions. Methods of analysis described by Skibitske (1963), Cooper et al. (1967), and Ferris and Knowles (1963) can be used to analyze slug test data for confined conditions (see Section 16.1.3, DOE, 1988).

Down-hole packer tests can be performed to determine the hydraulic conductivity of specific intervals of formations that are unsaturated or saturated. Modified drill stem tests can be used to determine the vertical hydraulic conductivity of aquitards or confining layers (Section 16.1.4, DOE, 1988). Methods of analysis for these hydrogeologic tests are presented in the Ground Water Manual (BOR, 1977), the Earth Manual (USDI, 1980), and Lambe and Whitman (1969). Although falling head or constant head triaxial hydraulic conductivity tests can be performed in a laboratory, the tests may not be representative of field conditions because of macro-secondary permeability features or heterogeneities. Depending upon the hydrologic regime and the probability distribution of hydraulic conductivity, an appropriate method should be used to calculate an average hydraulic conductivity. These may include arithmetic, geometric, and harmonic means (Freeze and Cherry, 1979; Haan, 1977).

Porosities may be calculated from void ratios measured in the laboratory on core samples (Lohman, 1979) or estimated from literature for similar hydrogeologic units. Effective porosity, which includes only the pores or fractures that water flows through, must be estimated from porosities. Effective porosity can be measured directly as the specific yield obtained from unconfined aquifer tests (Lohman, 1979). In some cases, accurate measurements of effective porosity are not available and conservatively low effective porosities will be assumed when calculating average linear groundwater velocities.

The average linear groundwater velocity may be calculated using Darcy's law (Freeze and Cherry, 1979):

$$V = \frac{K\ i}{n_e}$$

where

V = average linear velocity (L/T).
K = hydraulic conductivity (L/T).
i = hydraulic gradient (L/L).
n_e = effective porosity (L^3/L^3).
where L = length units and T = time units.

Dispersivities may be measured in the field from tracer tests or calibrated by modeling the migration of existing contamination. Several reports have tabulated dispersivities for different hydrogeologic situations and related dispersivity to scale of the contamination migration problem (TVA, 1985). Estimation or calibration of dispersivity should account for the degree of heterogeneity within the hydrogeologic system.

Disposal cell and tailings hydraulic properties

To assess whether the remedial action will comply with the proposed EPA groundwater standards, it is necessary to quantify the hydraulic properties of the disposal cell and subsoils as they control the rate of infiltration into the disposal cell and the rate of seepage from the disposal cell. The percent saturation, capillary moisture curve, and saturated hydraulic conductivity must be obtained for the subsoils, tailings, contaminated site materials, and the radon barrier (see Section 16.1.7, DOE, 1988).

The saturated hydraulic conductivity of the radon barrier may be estimated from recompacted samples of material from the borrow source. The samples will be compacted to approximately the same

specifications as required for placement of the cover, as described in the RAP for each site (see Section 17.2.2, DOE, 1988). Contaminated materials will be tested in situ when they will not be disturbed during remedial actions, or at their design specifications when they are to be moved or placed. The saturated hydraulic conductivity will be measured in the laboratory using either constant-head or falling-head triaxial tests. The relation of hydraulic conductivity to moisture content may be calculated from capillary moisture curves using the modified Millington-Quirk method (Green and Cory, 1971), a method developed by Mualem (Van Genuchten, 1985), or other appropriate methods. In low hydraulic conductivity materials, it may be necessary to perform the measurement of the relation of hydraulic conductivity to moisture content directly in the laboratory (Constantz and Herkelath, 1984; Passioura, 1976).

The hydraulic gradient may be measured by tensiometers and heat dissipation probes, or estimated from moisture content profiles measured by time domain reflectometry or neutron moisture meter logging (DOE, 1989d) (see Section 16.1.7, DOE, 1988). Generally, a uniform moisture content or soil tension with depth in a homogenous material implies a hydraulic gradient of unity.

8.1.3 Geochemical environment

The DOE shall geochemically characterize background groundwater quality for each of the potentially affected aquifers at the the processing and disposal sites. Hazardous constituents in the tailings, evaporation ponds, and windblown material or other materials related to uranium processing at the site will be identified. The geochemistry and the distribution of hazardous constituents in each of the potentially affected aquifers at the processing site will be assessed. Geochemical properties of the subsoils at the disposal site will be characterized and aquifer geochemical characteristics that relate to contaminant migration will be quantified. The distribution of non-radiological hazardous constituents in soils below tailings that will be relocated, unlined evaporation ponds, and windblown material will be addressed in Section 9.0.

8.1.4 Characterizing water quality

Groundwater quality for all potentially affected aquifers at both the processing and disposal sites shall be determined. Initially, the tailings and groundwater samples will be screened for the chemical constituents listed in Table 8.1. To characterize a site for the organic hazardous constituents listed in Appendix I of 40 CFR 192, the DOE will analyze the list of Appendix IX of 40 CFR 264. Organic hazardous constituents listed in 40 CFR 264 (Appendix IX) may be deleted from further analyses if they were not used in the processing of uranium or are below laboratory detection limits in analyses of tailings after one period of sampling. Elemental

Table 8.1 Constituents and detection limits for water analysis[a]

Constituent	Laboratory method detection limit (mg/l)	Constituent	Laboratory method detection limit (mg/l)
Major Anions		Cyanide	0.01
Bicarbonate	1.0	Iron	0.03
Carbonate	1.0	Lead	0.01
Chloride	1.0	Manganese	0.01
Sulfate	0.1	Mercury	0.0002
Fluoride	0.1	Molybdenum	0.01
Nitrate	1.0	Nickel	0.04
Nitrite	0.1	Selenium	0.005
Nitrate and Nitrite	1.0	Silver	0.01
Phosphate	0.1 (as P)	Sulfide (as H_2S)	0.1
		Strontium	0.1
Major Cations		Thallium	0.01
Ammonium	0.1	Tin	0.005
Calcium	0.01	Uranium	0.003
Magnesium	0.001	Vanadium	0.01
Potassium	0.01	Zinc	0.005
Sodium	0.002	Total dissolved solids	10.0
Silica	2.0		
		Organic Hazardous Constituents[b] (mg/l)	
Minor and Trace Constituents[c]		Total organic carbon	1.0
Aluminum	0.1		
Antimony	0.003		
Arsenic	0.01	Radionuclide (pCi/l)	
Barium	0.1	Gross alpha[d]	1.0
Beryllium	0.01	Gross beta[d]	0.5
Boron	0.1	Lead-210	1.5
Bromide	0.1	Polonium-210	1.0
Cadmium	0.001	Radium-226	1.0
Chromium	0.01	Radium-228	1.0
Cobalt	0.05	Thorium-230	1.0
Copper	0.02		

[a]Field parameters including temperature, total alkalinity, pH, and specific conductance will be measured. Dissolved oxygen, Eh, and redox couples may be measured at specific work sites for further characterization. mg/l = milligrams per liter.

[b]Appendix IX of 40 CFR 264 will be analyzed to satisfy the requirements of organic analyses required in Appendix I of 40 CFR 192.

[c]Elemental concentrations will be analyzed to satisfy the requirements of 40 CFR 192.

[d]These analyses must be determined on samples with less than 500 mg/l total dissolved solids.

Note: Detection limits above are those specified to laboratories subcontracted to perform analyses for the UMTRA Project. These levels are considered reasonably achievable, and consistent with Project goals and regulatory requirements.

concentrations of minor and trace constituents will be analyzed to characterize a site for compounds listed in Appendix I of 40 CFR 192. Some inorganic constituents listed in Appendix I of 40 CFR 192 may also be deleted from the list to be analyzed after four sampling periods, if it can be demonstrated that they do not exceed laboratory detection limits in the tailings samples or are not related to uranium processing.

8.1.5 Background and baseline groundwater quality

Background groundwater quality is the groundwater quality from a hydrogeologic unit that would be expected at a site if contamination from the designated uranium processing facility had not occurred. Baseline water quality is defined as the representative water quality in a monitor well in which groundwater quality has been influenced by uranium processing activities at the site.

At designated processing sites where residual contamination currently exists, the DOE may propose background concentrations based on groundwater quality in upgradient locations or adjacent areas that have not been affected by uranium processing activities and on appropriate geochemical and hydrogeologic assessments of the processing site. At alternate disposal sites, the DOE will propose background concentrations based on groundwater quality characterization information.

Background groundwater sampling locations should not be sited hydraulically downgradient from any suspected contaminant source unless no other sampling locations are available or it can be demonstrated conclusively that these downgradient locations are sufficiently far removed to be unaffected by contamination. Furthermore, these locations should be outside the area of radial flow that was created by groundwater mounding during active tailings disposal.

At least one background monitoring well per geohydrologic unit should be provided. However, a minimum of three background monitoring locations is necessary to document the occurrence of limited use groundwater (Class III). Under some circumstances, the determination of background water quality can be augmented with historical water quality data or analyses of samples collected from existing wells and springs in the same hydrogeologic unit within the region (e.g., within the same basin or watershed) that has not been affected by uranium processing. Such data could expand the background data set, making it possible to characterize background concentrations using statistical parameters. Whenever possible, a minimum of four sampling rounds will be used to establish background.

Baseline water quality will be monitored at processing sites with groundwater contamination. Baseline water quality will be established for specific hazardous constituents for each monitor well to establish trends in water quality in the interim between remedial action and the implementation of groundwater restoration. A minimum of four sampling rounds are required to establish baseline water quality. However, baseline water quality will be continuously updated as it may change with time.

Field parameters and chemical and hazardous constituents to be analyzed in samples are presented in Table 8.1. After background water quality has been characterized for the complete list, the list of hazardous constituents may be modified, depending on site-specific conditions and the concentration limits proposed in the Remedial Action Plan.

As part of the procedures to validate the background and baseline water quality data, the cation/anion balance will be calculated and recorded for each sample result. An acceptable sample will have an error less than plus or minus five percent. If unacceptable sample results are reported, the samples will be reanalyzed to acceptable limits or additional samples will be collected and analyzed to acceptable limits. The use of split and known samples is described in the Albuquerque Operations Manual (DOE, 1988).

When there is only a limited number of data points, statistical analyses of water-quality data can support only qualitative or semi-quantitative interpretations. Statistical analyses of water-quality data at every site will include:

- o Arithmetic means, standard deviations, and coefficients of variation for each constituent for each monitor well.

- o Arithmetic means, standard deviations, and coefficients of variation for each constituent for each quarterly sampling set.

These statistical parameters will allow a semi-quantitative evaluation of the means and spatial and temporal variations of all the background and baseline water-quality constituents. The selection of a method to calculate mean background and the range of background depends on the statistical distribution of concentrations for each hazardous constituent. The calculation of background is necessary during preparation of the remedial action plan because it characterizes water quality at the sites relative to background and can be used to develop concentration limits for hazardous constituents. However, for verification of excursions during surveillance and maintenance, background concentrations will continuously be updated during the application of the statistical procedures described in Section 4.5 of "Guidance for UMTRA Project Surveillance and Maintenance" (DOE, 1989e).

If it can be demonstrated that the statistical distribution of background concentrations of hazardous constituents follows a normal distribution, then all of the samples from all of the background wells are from the same population and the arithmetic mean may be calculated. Several methods for determining the statistical distribution of background water quality are presented in EPA, 1989. The range of background may be interpreted as the 99 percent confidence interval (EPA, 1989). The number of samples (N) should exceed four. For regulatory purposes, the upper range of the 99 percent confidence interval is compared with the MCL to establish the groundwater protection standards. For Appendix I hazardous constituents with no MCLs, the upper range of the 99 percent confidence interval becomes the groundwater protection standard. Similar statistical procedures will be used to characterize baseline water quality.

In the special case, where the statistical distribution does not follow a normal probability distribution, other statistical analysis may be used to calculate mean and the range of background. These may include a log-normal transformation of the water quality data or a non-parametric procedure (EPA, 1989). However, in some cases the data are insufficient for statistical analysis and it may be more suitable to average concentrations for each well, and average the average concentrations of all the wells to calculate a mean background. This method of analysis is particularly applicable when there are a disproportionate number of samples from a few of the total number of background wells.

In determining the mean and range of background, obvious outliers related to cross contamination or laboratory analytical error should be eliminated from the data set so that the mean and range are realistic for the site. The analyis also should check for seasonal variation. A written explanation will be provided to document the reasons for omitting any suspect data. In cases where there is a relatively small percentage of analyses (15 percent or fewer) with values below the detection limit (DL), a value of DL/2 is substituted into the database and the statistical tests outlined above are conducted (EPA, 1989).

A schedule for sampling background and compliance monitor wells at each site will be outlined in the surveillance and maintenance plan. Generally, quarterly sampling will be conducted for the first year following the completion of remedial action at disposal sites, semiannually thereafter for two to six years, and annually there after. At processing sites where groundwater monitoring is required, baseline and background water quality should be monitored for four consecutive quarters and then on an annual basis following completion of the remedial action. However, this schedule may be modified depending on site-specific factors such as the rate of groundwater flow, the possibility of seasonal variations in water quality, and whether there is a potential for harm to human health or the environment. The results of the detection monitoring will be reported in an annual groundwater report that will become part of the site file and will be submitted to the NRC. In some cases, the

monitoring schedule may be revised to assess the effectiveness of groundwater restoration or to verify excursions of concentration limits.

Details of reporting and recordkeeping are included in "Guidance for UMTRA Project Surveillance and Maintenance" (DOE, 1988).

8.1.6 Contaminant sources

Potential sources of hazardous constituents at a processing site include tailings, evaporation ponds, windblown material, and ore storage yards. Subsoils below each of these sources may also contain hazardous constituents. Residual materials in the mill yard may contain characteristic hazardous wastes that are ancillary to the uranium milling process.

Characterization of contaminant sources should proceed with a description of the uranium mill process, such as whether an alkaline or acid leach was used and whether solvent extraction was employed. All hazardous constituents used in the process and that were potentially present in the raffinate and tailings pore fluids should be identified. The mill process should describe how fine the ore was ground and how the tailings were discharged (by cylcone separator, spigot, and the like).

Source descriptions should include evaluations of the physical and chemical processes that influence the long-term leaching and release of hazardous constituents. Chemical characteristics of the tailings can be evaluated by pore water sampling with lysimeters or well points, when the tailings are near or at saturation (see Section 16.1.6, DOE, 1988). When the tailings have insufficient moisture for pore fluid sampling, batch leach tests or solution extracts may be prepared to analyze chemical constituents of the tailings (see Section 16.1.8, DOE, 1988). Column leaching tests may also be used to estimate source concentrations (see Section 16, DOE, 1988). Generally column tests will provide a lower estimate of source concentrations than batch leach tests. Source concentrations calculated from batch and column tests should be adjusted to account for dilution of the original sample moisture by additional pore volumes during the test and compared with other source concentration data from lysimeters well points. Batch-leach tests and solution tests may overestimate concentrations in pore fluids when the analyses are converted from the concentration in solution to the concentration in the original actual moisture content of the sample. Concentrations in groundwater beneath the tailings may also be used to back-calculate source concentrations if the degree of geochemical attenuation is known.

In a typical tailings pile, there may be separation of sands and slimes. In most cases, pore water held in the slimes will contain higher concentrations of hazardous constituents. It is necessary to have several sampling locations within the tailings to

obtain a representative distribution of the geochemistry of pore fluids. Pore fluid samples should be collected near the bottom of the tailings where the greatest probability of saturation occurs, and where the fluids will be less likely to be influenced by precipitation and evaporation, or volatilization of organic constituents. A minimum of three sampling locations shall be selected in the tailings, and at least one sampling location shall be selected in each of the other potential sources of hazardous constituents.

In the case where concentrations of hazardous constituents in contaminant sources are to be back-calculated from concentrations in groundwater beneath the tailings, it is necessary to obtain accurate estimates of the relative volumetric flux of seepage from the tailings to the groundwater underflow beneath the tailings. The concentration in the contaminant source is then the unknown variable in a mixing volume that relates the mass rate of inflow in the aquifer to that of tailings seepage. The equation for back-calculating source concentrations is discussed in Section 8.3. It should be emphasized that back calculation of source concentrations is valid only for conservative constituents unless geochemical attenuation can be quantified.

Tailings pore fluid samples will be screened for all chemical constituents listed in Table 8.1. This screening shall be used to develop a list of hazardous constituents and concentration limits for the hazardous constituents in groundwater (see Sections 8.2.1 and 8.2.2). The screening includes all the chemical constituents that are reasonably expected to be in or derived from residual radioactive material to be stabilized at the disposal site, including the hazardous constituents listed in Appendix I of 40 CFR 192. Screening for organics may be discontinued if, after one sampling period, no organics related to uranium processing are above laboratory detection limits in pore fluids or groundwater. The list of inorganic parameters may also be adjusted if, after four sampling periods, they are below detection limits, the EPA MCLs, or background levels.

8.1.7 Geochemical characterization and the distribution of hazardous constituents in potentially affected aquifers

Each of the potentially affected aquifers at the processing site shall be geochemically characterized and the distribution of hazardous constituents described. For characterization purposes, samples will be collected from monitor wells or surface water features that are directly related to groundwater discharge (see Section 16.2.1, DOE, 1988). Existing water quality data from literature and samples from existing wells may also be used to supplement site water quality data. Generally, the monitoring program should be conducted to establish the areal extent and depth of contamination. The extent of migration of contaminants should be bounded by the field program.

Specific steps necessary to characterize the extent of groundwater contamination are:

- Design a preliminary drilling program based on prioritized data needs (see Section 14.0, DOE, 1988). Monitor well locations and completion depths will be selected to delineate the areal and vertical extent of the contamination. Emphasis will be on siting wells in strategic locations (e.g., near the contaminated materials or dwellings, rivers, drinking-water facilities, likely discharge points, and between such locations and the contaminated materials). Well siting decisions will also be based on a conceptual model of the hydrogeologic regime. When possible, wells will be located where they can be maintained during remedial construction activities.

- The drilling of monitor wells may be phased to allow for sampling after each phase so that new locations for monitor wells can be advantageously selected. Selection of well locations and drilling phases should be as flexible as possible to allow for evaluation and response to new subsurface information obtained from each borehole drilled.

The first boreholes drilled for monitor well installation will typically be downgradient of the contaminant source and completed in the uppermost aquifer. Drilling methods will be used that eliminate the potential for spreading contamination and maximize the capacity for obtaining representative samples (see Section 14, DOE, 1988). At sites underlain by significant groundwater resources that may have been contaminated by leachate, the project goal is to collect water-quality samples and water-level data from monitor wells on a quarterly basis for a period of approximately one year (see Section 16.2.1-3, DOE, 1988).

The inorganic chemical constituents listed in Table 8.1 will be analyzed during the first four periods of sampling. In addition, if organic hazardous constituents have been identified above laboratory detection limits in contaminant sources at the site and there is potential for contamination of the groundwater, a single set of samples will be collected for analysis of 40 CFR 192 (Appendix I) organic hazardous constituents at one or more wells completed immediately beneath and downgradient of the contaminant source and one upgradient well. If significant concentrations of Appendix I organic hazardous constituents are detected near the contaminant source, a more inclusive sampling program will be developed to determine the extent of migration of organic Appendix I constituents in groundwater. Under the present scope of work, it has been found that such compounds are not typical components of uranium-recovery wastes (NRC, 1987). However, it is desirable to collect these samples for organic Appendix I constituents to characterize the organic contamination at some sites. Chemical constituents for which no concentration limits are proposed may be deleted from the sampling program if their analysis no longer contributes to the geochemical characterization of the potentially affected aquifers.

To define the extent of the contaminant distributions, additional monitor wells will be sited at progressively greater distances from the contaminant sources until concentrations of contaminant indicators measured in the field (e.g., pH, specific conductance, and total alkalinity) approach their respective background levels or until a discharge boundary is reached. The majority of the monitor wells will be located within the contaminant distribution. Selected sites will have nests consisting of two or more monitor wells constructed close together and completed at different intervals to observe the distribution of hazardous constituents with depth in the aquifer. Selection of the completion intervals is based both on the conceptual flow models developed for the site hydrogeology and on field screening techniques used during drilling. Field screening techniques for locating contamination include monitoring groundwater for pH, specific conductance, and alkalinity. Whenever possible, the deepest monitor wells are to be completed in zones below any suspected contamination. Siting decisions for wells are to be expedited by compiling water-level maps and by evaluating other data as sample collection proceeds in the field.

If the first four periods of hydrologic data and water analyses from the monitor wells show conclusively that there is no potentially useful groundwater resource at a site, then additional water sampling may be suspended at that site.

As part of the site geochemical characterization, the distribution of contaminants in each potentially affected aquifer will be compared to the mean and the range of background water quality and the EPA MCLs. Levels of contamination related to uranium processing at the site may be distinguished from background water quality or other sources of contamination by interpretation of geochemical data with species biavariate plots, trilinear diagrams, or mixing diagrams. The areal distribution of hazardous constituents in affected aquifers will be presented and the depth of contamination will be represented on isopleth maps and water quality cross sections. When necessary to differentiate between background water quality and contaminated groundwater or to identify potential sources of interflow between aquifers or other potential sources of contamination, geochemical modeling may be used to perform speciation and mineral saturation index calculations, volumetric mixing calculations, alkalinity titration calculations, reaction path simulations, redox reactions, adsorption reactions, and other mass-balance calculations. Input parameters used for geochemical modeling will be based on site-specific conditions, which are technically defensible. These include field and laboratory measurements of Eh and pH or redox couples.

8.1.8 Geochemical processes that control contaminant migration

Geochemical characterization at the processing sites and disposal sites is bifurcated into what should be analyzed on a routine basis and what is necessary to make a geochemical demonstration for water resources protection. Routine geochemical analyses at the

processing sites and disposal sites are related to establishing background geochemistry and developing an understanding of contaminant migration through subsoils. Additional characterization at processing sites may be required as part of the water resources protection strategy for groundwater cleanup pursuant to 40 CFR 192, Subpart B. In some cases, additional geochemical characterization may be necessary to demonstrate that natural flushing or geochemical attenuation can reduce concentrations so that groundwater cleanup or corrective action is not necessary. At some disposal sites, where geochemical attenuation may be an integral part of the water resources protection strategy, an additional level of geochemical characterization is required.

Natural processes that influence contaminant migration through soils and aquifer materials include advection, mechanical dispersion, dilution, filtration of suspended or colloidal solids, biological decomposition of organic and inorganic compounds, ion exchange, specific adsorption, neutralization, physical adsorption, neutralization, precipitation of dissolved chemicals, ion sieving by dense clay layers (ultrafiltration), and decay of radioactive elements (Rai and Zackara, 1984; Bouwer, 1978). Geochemical interactions between the soil or aquifer matrix and the contaminants may attenuate concentrations of the contaminants along the flow path. Attenuation mechanisms may include neutralization of seepage from the tailings, precipitation of solid compounds, sorption of trace metals and toxic non-metals, and oxidation/reduction followed by mineral precipitation.

The neutralization capacity of the soil and aquifer material beneath an acidic mill tailings pile is the single most important chemical factor in determining the ability of geologic material to chemically attenuate the movement of contaminants (Shephard and Cherry, 1980). This neutralization is the main driving mechanism for mineral precipitation and for adsorption in these systems. The increase in solution pH that characterizes neutralization in this environment produces a condition in which the solubility of iron and aluminum oxyhydroxides decreases. These solids precipitate and scavenge other contaminant trace elements (uranium, manganese, arsenic, selenium, and molybdenum) from solution.

Because carbonate minerals are usually the primary source of neutralization in the soil and sediment, determination of the carbonate content of the solid can be used to substantiate direct measurements of the neutralization capacity of the subsurface materials. The carbonate content can also be used to evaluate trace element data anomalies due to solubilization of the precipitated solids, which are the result of the trace element's multivalent properties. The presence of even a small fraction of one percent of carbonate minerals is sufficient to provide considerable neutralization capability. For this reason, an analytical method that has a low detection limit will be chosen for determining the carbonate content of the soil and aquifer material.

- Approved and established standard operating procedures contained in the Albuquerque Operations Manual (DOE, 1988) will be used.

- Trained and knowledgeable personnel will perform collection, field measurements, submittal, and laboratory analyses of water samples.

- Routine and non-routine collected water samples will be submitted in sample lots that consist of nine water samples or less. A quintuplicate analysis will be performed on a randomly chosen sample and a simulated sample with known constituent concentrations to determine accuracy and precision, to establish confidence intervals, and to determine total error for each analysis.

- Routine and non-routine randomly chosen collected water samples will be submitted in duplicate and quintuplicate to determine accuracy and precision of analysis.

- Routine and non-routine specially prepared simulated groundwater samples will be submitted that contain known concentrations of constituents from Table 8.1, and specially prepared simulated groundwater sample "blanks" and "spikes" will be submitted to determine accuracy, to determine compliance with pre-established accuracy requirements, to determine if reanalysis is required, and to monitor procedure precision.

- Intra-laboratory simulated water sample "blanks" and "spikes" will be prepared and analyzed.

- Laboratory instruments or other equipment used for the detection, identification, and/or quantification of organic and inorganic pollutants will be properly and routinely calibrated, maintained, repaired (if necessary), and this will be verified by appropriate documents.

- Explicit constituent accuracy and precision requirements for Organic Hazardous Pollutants in 40 CFR 261, and implicit requirements for non-organics in the required detection limits of Table 8.1, will be complied with.

- Inter-laboratory comparison of water analysis studies (e.g., the EPA or other agencies) will be used to determine overall accuracy and precision.

- Analytical results will be evaluated (see Section 16.2.3, DOE, 1988) to determine the validity of the data.

In addition to laboratory analyses, field analyses of temperature, pH, specific conductance, and carbonate alkalinity will

be performed at each sampling location. Under certain conditions, Eh and specific redox couples may have to be measured in the field and in the laboratory.

Water use, value, and alternative supplies

The DOE shall describe existing and potential future water uses in the vicinity of the disposal and processing sites. The description should include water quality characteristics, availability and characteristics of alternative water sources, and institutional controls on water use. The description should also provide an inventory of existing and planned surface and groundwater uses that could be affected by existing groundwater contamination, cleanup activities, or potential contamination resulting from the disposal unit.

The DOE shall conduct surveys to prepare an inventory over an area that is sufficiently large to characterize water usage in the vicinity of the site, which is typically a one- to two-mile radius of the site. The inventory shall document the owner; location, type, and amount of use; source of supply; type of intake (for surface water users); well depth, screened interval, and hydrogeologic units (for groundwater users); and available water quality data.

The present value of water will be determined through a combination of interaction with state agencies and local water companies and a field survey. Available records on the proximity, withdrawal rates, uses, and sources of presently used water in areas that are not contaminated will be obtained from state, tribal, county, and municipal water administration offices.

Information on the value of water may be supplemented by a field survey of the area surrounding the site to gather information on undocumented water users. The cost of water regionally and locally can be estimated based on information from state water resource agencies, various Federal agencies, and local water boards. If local or regional costs are not available, nationwide estimates can be used. Water costs will be tabulated by use (i.e., agricultural, domestic, industrial) when this directly influences the cost.

The extrapolation of future values of water and predicted uses of regional water resources will be developed using information from Federal, state, tribal, county, and local planning commissions and possibly through consultation with a water resource economist. This extrapolation may include reviewing water use records for the last 50 years, and in some cases reviewing predictions of increases (or decreases) in use for the next 30 years. Subjective analyses may be necessary for population estimates because in some areas (e.g., remote rural areas) the population may not increase a measurable amount in the next 30 years. Projections of future water use will

The general approach to be followed in quantifying geochemical properties of soil and aquifer material for demonstrations pursuant to developing a water resources protection strategy is to perform laboratory batch and column leach tests using tailings material, soil, aquifer material, and a simulated solution representative of rain water or groundwater for a particular site. Batch tests will be performed initially to evaluate equilibrium conditions by mixing a known quantity of tailings or subsoil with deionized water or simulated groundwater and agitating the mixture for 72 hours (see Section 16.1.8, DOE, 1988). The solution will then be centrifuged, filtered, and analyzed for chemical constituents of interest. Column tests will be performed in a similar procedure, except that consecutive pore volumes of water will be passed through the column. Column tests may require a longer period of time to conduct than batch tests. Geochemical data from these tests will be used to postulate different water-rock interactions, e.g., precipitation/dissolution and adsorption/desorption phenomena. Geochemical modeling can be performed with these laboratory geochemical data. Attenuation mechanisms will be evaluated with regard to long-term effects on water quality.

To support geochemical attenuation demonstrations, geochemical descriptions will include mineralogical information on solid composition, particle size distribution fracture/joint density, buffering capacity, redox potential, adsorption coefficients, and other qualitative and quantitative information as appropriate. Potential reactions between hazardous constituents and biochemical attenuation may be quantified when applicable.

A detailed understanding of site-specific hydrogeological conditions is a prerequisite to meaningful modeling exercises.

8.1.9 Characterization methods

Characterization activities and methods shall be conducted according to the procedures described in Section 8.2 of the Albuquerque Operations Manual (DOE, 1988). Preparation and presentation of characterization data in the RAPs and NEPA documents will follow the stated procedures and formats.

Water analyses and quality control

Chemical constituents to be determined by analysis will be selected from Table 8.1 and analyzed with approved and established procedures as listed in 40 CFR 136.3 and 40 CFR 261. Definition of chemical background and contamination levels requires reliable water quality data. To ensure the data are reliable, quality control measures will be used at all sites and will include the following items:

- Approved and established standard operating analytical laboratory procedures listed in 40 CFR 136 or their equivalent will be used.

Attenuation mechanisms decrease aqueous concentrations of contaminants by absorbing the contaminants onto solids. If the contaminants in solution are immobilized by reaction with the sediment or rock, then future groundwater contamination problems may be minimal. However, if the solids (e.g., gypsum) are subject to further long-term reactions, they may cause contaminant levels to be above background and perhaps above water quality standards for a considerable period of time. Minerals that are precipitated may dissolve and adsorbed species may desorb when normal groundwater conditions are reestablished during groundwater restoration. Therefore, the response of the entire sediment/rock/water system to "pre-contamination" aquifer conditions will be qualitatively evaluated at UMTRA Project sites during groundwater clean up.

Contaminants adsorbed onto mineral surfaces may subsequently desorb and move again as dissolved species in the groundwater. The net effect of the adsorption/desorption process is to retard the rate of movement of the contaminant through the aquifer compared to the groundwater flow rate. Attempts have been made to quantify this retardation mechanism by measuring the distribution coefficient (K_d) of an element under laboratory or field conditions (Freeze and Cherry, 1979). This approach has met with limited success in predicting the movement of trace metals under the chemically complex conditions normally found in the subsurface. However, a qualitative estimate of the effect of adsorption on contaminant migration can be made by comparing the present distribution of a contaminant near a tailings pile with that of a non-sorbing tracer from the tailings solution that has moved in the aquifer at groundwater flow rates. By this method, a retardation factor can be determined directly for each contaminant that occurs at an elevated concentration in the groundwater. Distribution coefficients for desorbing contaminants are usually determined from experimental batch and column leach tests (see Section 16.1.8, DOE, 1988).

Several types of laboratory analyses can be used to produce a qualitative estimate of a material's ability to attenuate the migration of trace elements. These analyses include bulk mineralogy, detailed clay mineralogy, microsizing X-ray mineralogy of fines, fractions, ion exchange capacity and base neutralization capacity, hydrochloric acid soluble iron, hydrochloric acid soluble manganese, gypsum content, pyrite content, organic carbon and total carbon, clay content, soil pH, and percent calcium carbonate. To characterize geochemistry in the saturated zone further, Eh or specific redox couples that can be used to calculate Eh will be measured. Some of these analyses are redundant; however, they provide a check on the reliability of other measurements. These analyses will be performed, as necessary, to assess the attenuative properties of the soil along the assumed flow path at alternative disposal sites. In most cases, these analyses will not be performed at the processing sites because the spatial distribution of contaminants determined at the site will provide a better estimation of attenuation.

be qualified by the accuracy of the assumptions used in the projection. Most projection methods assume a continuation of past conditions, present conditions, or historical trends.

Although the regulations guiding the UMTRA Project require stabilization to control the contaminated materials for 1000 years to the extent reasonably achievable, or in any case for at least 200 years, it is felt that water use and resource value projections beyond 30 years are of limited validity. However, in order to meet the intent of the EPA standards, water use and value will be projected qualitatively over the time period in which contamination is expected to persist. The projected water use and value will be compared to existing conditions and reasonable projections as to changes in population and agricultural or industrial water usage. In the absence of obvious trends, the type of long-term water use will be assumed to be the same as the present use.

Evaluating the availability of alternate water supplies will include presently used alternate supplies, presently available but unused supplies, and supplies not presently available but which could be developed.

8.1.10 Surface water

Surface water sampling will be conducted to determine if seepage or runoff from the processing site is affecting surface water quality (see Section 16.2.1, DOE, 1988). The selection of surface water sampling locations will be predicated on a literature review of surface water data and professional papers, aerial photographs of the site, and site reconnaissance. Climatological data will be obtained from the NOAA and analyzed to determine the relation of seasonal precipitation to surface water occurrence or flow. Available surface water quality data will be obtained and reviewed to determine whether they can be used to augment water quality data to be collected in the vicinity of the site. Discharge records of streams will be obtained from the USGS and examined to ascertain the potential for water quality impacts resulting from a flood event causing a water table rise into the base of the pile, to determine seasonal periods of low flow in perennial streams, and to determine periods of seasonal discharge for intermittent streams. To identify sampling locations, a map will be drafted to show bogs, swamps, seeps, springs, ponds, lakes, and streams or other surface water features within a two-mile radius of the designated site.

8.1.11 Background surface water quality

Background sampling locations will be chosen upstream of the designated site in areas unaffected by uranium processing activities. Surface water should be collected as grab samples from either stream bank in a well-mixed zone. Water levels and discharge rates

of the stream will be determined at the time samples are collected. If surface water contamination is detected, a more comprehensive sampling schedule will be established.

Surface water samples will be collected from all potentially affected surface water features within a two-mile radius of the designated site. Surface water grab samples will be collected in locations that would be most likely to indicate surface water contamination and from the bank adjacent to the potential source of contamination. These samples will be collected during the same sampling period as the background samples are collected. Samples will be collected during low flow conditions as much as the UMTRA Project schedule will allow.

8.1.12 Sample analyses

Surface water samples will be analyzed for the parameters specified in Table 8.1 by approved and established procedures as listed in 40 CFR 136.3 and 40 CFR 264. Field measurements of temperature, total alkalinity, pH, Eh, and specific conductance will also be taken. Organic hazardous constituents will not be analyzed in surface water samples unless they have been detected in a screening of hazardous constituents in tailings or evaporation pond samples or might be present as a result of uranium processing activities. After initial screening for hazardous constituents has been completed, the chemical parameters to be analyzed may be adjusted.

Surface water quality data will be compiled and presented a format that is useful for interpreting the degree and extent of contamination. Relative locations of tailings piles, evaporation ponds, and windblown materials will be placed on a map with the sampling locations. Analyses of downstream samples will be compared to analyses of background samples collected during the same sampling period and also compared to the EPA groundwater standards.

8.2 GROUNDWATER PROTECTION STANDARDS

An aquifer is defined as a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs. The groundwater protection standards in 40 CFR 192.02(a)(3) apply to the uppermost aquifer hydraulically downgradient from the disposal unit. The uppermost aquifer means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically connected with this aquifer within the boundary of the site. Any saturated zone created by uranium recovery operations at designated processing sites should not be considered an aquifer unless the zone is, or potentially is, (1) hydraulically interconnected to a natural aquifer; (2) capable of discharge to surface water; or (3) reasonably accessible because of migration beyond the vertical projection of the boundary of land transferred to government ownership and care.

The regulations (40 CFR 192) do not specifically consider lower aquifers hydraulically connected to the uppermost aquifer. However, the DOE has specified in this document that all potentially affected aquifers will be characterized. In some cases, lower aquifers and the uppermost aquifer may be redefined as one aquifer if they are hydraulically connected. If lower aquifers are connected in such a way that there are only water quality influences and the potentiometric influences are minimal, the lower aquifers may be considered separate aquifers with potential points of exposure. Evaluation of the point of exposure would entail comparison of predicted or observed water quality with the EPA groundwater standards and performing a risk assessment to evaluate the effects on human health and the environment.

Groundwater protection standards consist of three components: (1) a list of hazardous constituents; (2) a corresponding list of concentration limits for the constituents; and (3) a point of compliance. These components will be identified in the remedial action plan and are discussed below.

8.2.1 Hazardous constituents

Hazardous constituents will be identified that are likely to be in, or derived from, residual radioactive material at the disposal site. These will be identified by characterization of the composition of residual radioactive material, groundwater quality data, description of the processes and reagents used in processing uranium, and assessment of what constituents are reasonably expected to be in or derived from residual radioactive material. Hazardous constituents, with MCLs, are listed in Table 1 of 40 CFR 192.02(a)(3)(i) and are presented in Table 8.2 here. Other hazardous constituents with no MCLs are listed in Appendix I of 40 CFR 192 and are summarized in Table 8.1.

8.2.2 Concentration limits

For each hazardous constituent identified there will be a concentration limit proposed to be met at the point of compliance. The limit constitutes a maximum concentration of the hazardous constituent that may not be exceeded in groundwater in the uppermost aquifer hydraulically downgradient from the disposal cell. The concentration limits may be established as either background concentrations, maximum concentration limits, or alternate concentration limits. The selection of the concentration limit for each hazardous constituent is described below.

Table 8.2 Maximum concentration limits for hazardous constituents [40 CFR 192.02(a)(3) Table 1]

Constituent	Maximum concentration[a]
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Endrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4, 4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5, 8-dimethanonaphthalene)	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2,2′-bis (p-methoxyphenylethane))	0.1
Toxaphene ($C_{10}H_{10}Cl_6$, Technical chlorinated camphene, 67 to 69 percent chlorine)	0.005
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.01
Benzene (Cyclohexatriene)	0.005
Vinyl chloride (Ethene, chloro-)	0.002
Tetrachloromethane (Carbon tetrachloride)	0.005
1,2-Dichloroethane (Ethylene dichloride)	0.005
Trichloroethene (Trichloroethylene)	0.005
1,1-Dichloroethylene (Ethene, 1,1-dichloro-)	0.007
1,1,1-Trichloroethane (Methyl chloroform)	0.20
p-Dichlorobenzene (Benzene, 1,4-dichloro-)	0.075
Nitrate (as N)	10
Molybdenum	0.1
Combined radium-226 and radium-228	5 pCi/l
Combined uranium-234 and uranium-238	30 pCi/l
Gross-alpha particle activity (excluding radon and uranium)	15 pCi/l

[a]Milligrams per liter unless stated otherwise.

In the case where groundwater in the uppermost aquifer is limited use (Class III), it may not be necessary to propose a concentration limit because supplemental standards may be applied. This depends upon site-specific conditions and the NRC's interpretation of the groundwater standards. The application of supplemental standards is discussed further in Section 8.8.

Background concentrations

The limits for hazardous constituent concentrations in groundwater in the uppermost aquifer may be established as the background concentration of each constituent. At a disposal site to which tailings are relocated, background concentration is the concentration naturally present at the site. The proposed background concentration limits will be based on groundwater quality characterization information collected as part of the disposal site monitoring program. At designated processing sites where residual radioactive material will be stabilized on the site, background concentration is the concentration that would be expected in groundwater in the uppermost aquifer if contamination had not occurred at the site. The background concentrations will be based on groundwater quality characterized in adjacent areas that have not been affected by uranium recovery operations and on appropriate geochemical and hydrogeologic assessments of the processing site. For each proposed background concentration limit, sufficient information to demonstrate that the specified background concentration is representative of background groundwater quality is required. Such demonstrations should consider both temporal and spatial variability of groundwater quality based on analyses of site-specific groundwater monitoring data. Additional discussion on background water quality is provided in Section 8.1.5. The upper range of the 99 percent confidence interval may be used to establish the concentration limits for Appendix I hazardous constituents with no maximum concentration limits (EPA, 1989).

Maximum concentration limits

Maximum concentration limits (MCLs) specified by the EPA may be established as the concentration limits for hazardous constituents in groundwater in the uppermost aquifer. These limits are listed in Table 8.2 and do not need to be justified. If an MCL has not been established for a particular hazardous constituent, a background limit or an alternate concentration limit (ACL) (see Section 8.8.1) for that constituent should be proposed. If the upper range of the 99 percent confidence interval for background exceeds the MCL, then the upper range of the confidence interval should be proposed as the concentration limit for the hazardous constituent.

Alternate concentration limits

Alternate concentration limits may be established as the concentration limits for the hazardous constituents in groundwater in the uppermost aquifer. For each proposed ACL, it should be demonstrated (1) that the hazardous constituent will not pose a substantial present or potential hazard to human health or the environment as long as the ACL is not exceeded and (2) that the ACL is as low as reasonably achievable. Information needs for ACL applications are described in DOE's draft regulatory alternatives document (1989a).

8.2.3 Point of compliance

A point of compliance (POC) for each disposal site will be proposed. The POC is a vertical surface that extends downward into the uppermost aquifer along the hydraulically downgradient limit of the disposal area. In general, the POC concept is implemented by installing a series of monitor wells along this surface. The area covered by the disposal cell will include both the contaminated materials and the components of the engineered system that contains the materials. The location of the POC should be as close to the disposal area as practical and provide access for monitoring groundwater quality without disturbing engineered components intended for long-term isolation of the residual radioactive material. Included in the POC discussion should be a demonstration that groundwater monitoring at the POC will provide an early warning of the release of hazardous constituents to the uppermost aquifer. The UMTRA Project sites where remedial actions were completed before the promulgation of the draft EPA groundwater protection standards will not have a POC. However, groundwater protection and monitoring at these sites will assure protection of human health and the environment.

In the special case of the application for supplemental standards, it may not be necessary to specify a POC. However, it may be required to assess environmental harm or effects on human health as specified under 40 CFR 192.21.

8.3 PERFORMANCE ASSESSMENT

This section describes the steps necessary to demonstrate that the performance of the disposal unit complies with the groundwater protection standards for disposal. This demonstration would show that the estimated concentration of each hazardous constituent in groundwater in the uppermost aquifer at the POC is less than or equal to the concentration limit for that constituent. In the case where the compliance strategy is to establish supplemental standards, the demonstration would show no adverse affect on the existing water quality and no additional risk to human health or the environment.

may be used for this. Similarly, other documented and verified models can also be used for this purpose (DOE, 1988). By inputting the concentration of the contaminant source in the tailings it will be possible to simulate the distribution of hazardous constituents in the cross section beneath the tailings in the uppermost aquifer. The depth of contamination will be dependent on the vertical dispersivity, which may be obtained from the modeling literature for similar materials and adjusted to consider the scale of the problem and the degree of heterogeneity.

In analyzing conditions in which the aquifer has a lower bound and contaminants are fully mixed, the concentration of hazardous constituents in groundwater at the POC may be evaluated by a comparison of mass-rate of inflow of the contaminant source and groundwater underflow using the following equation (Hem, 1985):

$$C_f = \frac{C_1Q_1 + C_2Q_2}{Q_1 + Q_2}$$

where

C_f = final concentration in groundwater.
C_1 = concentration of solute in diluting groundwater.
Q_1 = volume of diluting groundwater.
C_2 = concentration of solute in leachate from tailings.
Q_2 = volume leachate from tailings.

The MOC model or another suitable or documented model may also be used to simulate contaminant concentration distributions in a plan view of the disposal site. The thickness of the aquifer that is modeled may be determined by cross-sectional modeling beneath the disposal unit or by characterization data that have identified a basal stratigraphic unit with lower hydraulic conductivity.

The modeling may be performed so that the input and output are in the form of normalized concentration ratios. In this manner, all hazardous constituents that have the potential to exceed concentration limits in groundwater can be assessed.

$$\text{Resultant concentration} = \frac{\text{Normalized predicted concentration X source concentration}}{\text{Normalized input concentration}}$$

The resultant concentration is then added to background concentrations and compared to the concentration limit or may be used for analysis in the application for supplemental standards or ACLs.

8.4 CLOSURE PERFORMANCE ASSESSMENT

To assure compliance with the closure performance standard in 40 CFR 192.02(a)(4), the design must be shown to be low maintenance and the long-term performance of the disposal cell must be demonstrated. Included in the discussion will be a demonstration that the proposed remedial action will perform as designed for the duration of the 200 to 1000 year design life. This demonstration will be based on the design criteria and design methods presented in Sections 4.0, 5.0, and 6.0 to ensure geological and geotechnical stability. Discussions will include the use of natural materials in the design and failure scenarios related to the design; i.e., protection against erosion, infiltration, and biointrusion.

To demonstrate the ways in which the proposed design minimizes the need for active maintenance, emphasis should be placed on (1) the use of natural, durable materials; (2) shaping the pile to resist natural forces such as water and wind erosion; and (3) minimizing infiltration by design features of the cover. As discussed in those sections referenced above, all materials selected meet NRC requirements applicable to the UMTRA Project, are as durable as is reasonably achievable, and are placed to promote their long-term performance in the absence of maintenance. Specifically, the pile components will be designed such that:

- The radon barrier of compacted soil is protected by the overlying filter, riprap, or soil and vegetation layers, which resist erosion, frost, and biointrusion.

- The sand filter, drain, and bedding layer is designed to be clean and durable. It is designed to avoid plugging by piping of soil particles, and is protected from erosion by the overlying rock layer.

- Rock erosion protection is constructed of durable rock, sized to resist runoff resulting from a PMP or PMF. Soil/vegetated covers are also composed of natural, durable materials with sufficient thickness and material properties so as to withstand long-term and maximum precipitation events.

It should also be emphasized that the piles will be designed with accepted factors of safety to prevent slope, settlement, and deformation failures. Therefore, maintenance requirements will be minimal. The remedial action designs also incorporate seismic, liquefaction potential, and geomorphological considerations.

8.5 GROUNDWATER PERFORMANCE MONITORING

The groundwater monitoring plan will include an assessment of the monitoring locations related to the POC, the constituents to be analyzed, and the sampling intervals. If appropriate, alternative methods to monitor the performance of the disposal cell will also be discussed. This may entail monitoring the performance of the cover as an infiltration barrier

A conceptual model should be developed that identifies critical elements of the performance assessment. These include:

- o Identifying hazardous constituents with concentration limits that may have potential influence on groundwater quality.
- o Providing a description of the water resource protection strategy. This may be meeting MCLs or background limits, or applying for supplemental standards or ACLs.
- o Identifying the uppermost aquifer.
- o Establishing a POC.
- o Defining concentration limits for hazardous constituents.

8.3.1 Seepage from the disposal cell

Assessing the amount of seepage from the disposal cell is the first step in conducting a performance assessment. Seepage from the disposal cell will initially be controlled by transient drainage of water within the tailings or water added during construction. The transient drainage rate will eventually approach the long-term seepage rate through the cover of the disposal cell.

To calculate the seepage flux through a rock-covered UMTRA Project disposal cell, it is necessary to define the relationship of hydraulic conductivity to moisture content for the radon barrier (see Section 8.1.2). The initial seepage flux through the cover typically is equal to the unsaturated hydraulic conductivity of the radon barrier at the observed moisture content (at placement) times a gradient of unity (DOE, 1989c). To what extent the seepage flux through the cover changes as a function of time depends on the boundary conditions imposed on the radon barrier (climatic conditions or tailings moisture contents). Generally, the moisture contents of the radon barriers have been found not to change substantially from the placement moisture content during the period of observation in UMTRA Project rock-covered disposal cells (DOE, 1989c). Because the boundary conditions are not known for every site, it may only be possible to avoid expensive construction and monitoring of cover test plots by extrapolating boundary conditions from other UMTRA Project sites with similar design and climate. These boundary conditions can be used with the material properties to calculate a seepage flux through the radon barrier.

Seepage rates through vegetative covers and checklist covers can be evaluated using the models HELP (Shroeder et al., 1984) and CREAMS (USDA, 1980). This modeling is performed to optimize the thickness of the rooting medium to enhance evapotranspiration and to minimize the seepage rate from the bottom of the cover soil layer (Section 4.2). In some checklist covers, an infiltration barrier consisting of a bentonite mat has been included in the cover design to provide a performance standard seepage rate of 2×10^{-9} cm/s.

The seepage rate, as a function of time, may be calculated through the application of a numerical model of unsaturated flow. The model would consider steady state seepage through the radon barrier as the upper boundary condition. Model input parameters would include material properties of the tailings and subsoils and material relationships of hydraulic conductivity as a function of moisture content and initial moisture content. The bottom of the disposal cell may be treated as a distinct layer or a boundary condition. Unsaturated models suitable for this application include WORM3 (Van Genuchten, 1987), TRUST (Reisenauer et al., 1982), UNSAT 1 (Van Genuchten, 1978), and UNSAT 2 (Davis and Neumann, 1983). However, other models may be considered for this application if they are properly documented and verified (DOE, 1988).

If the tailings are relocated as part of the remedial action, it may be possible to place the tailings at a moisture content that will produce the same steady state flux as that occurring through the radon barrier. Analysis of transient drainage in this case is not necessary, and the long-term steady state seepage from the disposal cell can be used in evaluating the performance of the disposal cell in regards to the EPA groundwater standards.

In some cases, the water resources protection strategy may involve demonstrating that seepage will not reach groundwater within the 1000-year design life of the disposal cell. Seepage can be simulated numerically by modeling the propagation of moisture through the subsoils below the tailings when transient drainage is a consideration. However, if transient drainage is not a consideration, or the range of moisture contents in the soils below the disposal cell can be conservatively bounded, the travel time may be calculated analytically by dividing the distance to groundwater by the Darcian flux and multiplying by the percent saturation and the porosity.

8.3.2 Concentrations of hazardous constituents in groundwater

The water resources protection strategy requires an assessment of potential hazardous constituents in groundwater. In most cases this involves modeling the distribution of hazardous constituents in the uppermost aquifer at the POC to determine if concentration limits will be exceeded. When the remedial action involves an application for supplemental standards or ACLs, modeling may be required to evaluate concentrations of hazardous constituents in groundwater to demonstrate that there is no excessive harm to the environment or human health.

For hydrogeologic situations where there is a relatively uniform potentiometric surface beneath the disposal cell, it may be possible to model the most critical flow path numerically in a cross section beneath the center of the pile. The two-dimensional finite difference solute transport model MOC (Konikow and Bredehoft, 1978)

or the rate of seepage through the tailings and subsoils. Various methods could be used depending upon site conditions, but might include (1) installation of neutron access tubes for neutron logging of the cover and tailings or subsoils at regular time intervals; (2) monitoring using Time Domain Reflectometry (TDR) to measure average moisture conditions within the radon barrier; (3) using heat dissipation probes to monitor moisture content within the tailings; or (4) implementing a chemical tracer (e.g., potasium bromide) in the top of the pile to monitor moisture propagation through the filter layer into the radon barrier. Figure 8.1 illustrates unsaturated monitoring methods for different disposal cell units.

Included in performance monitoring is the demonstration that implementation is feasible at the site. This can be divided into monitoring of disposal cell moisture and the unsaturated zone beneath the cell or groundwater at the POC, as appropriate. The site-specific locations and information required will be presented in the Surveillance and Maintenance (S&M) Plan for each site; but the general approach for monitoring must be shown to be suitable for assuring long-term compliance. The pattern and depths of monitor wells will be dependent on the site hydrogeology and hydrostratigraphic units as well as the compliance strategy.

The performance monitoring frequency for UMTRA Project disposal sites completed before the EPA issued the draft groundwater protection standards was as follows: Compliance wells were to be sampled quarterly for the first year following completion of the remedial action activities, and semiannually thereafter until the end of the performance monitoring period. Monitoring frequencies are described in the "Guidance for UMTRA Project Surveillance and Maintenance" (DOE, 1989e). The monitoring frequency may be adjusted to account for site-specific factors such as the rate of groundwater flow and the potential for harm to human health and the environment. In the event a potential excursion is detected, resampling may be conducted to verify the excursion and sampling activities will return to the original schedule until such time as the situation is clarified.

The constituents to be analyzed in the monitoring program will be based on the compliance strategy and performance assessment. In addition to the selected hazardous constituents, major anions and cations together with the standard suite of field parameters will also be analyzed in order to assess the performance of the disposal cell completely. If there is a natural variability in the proposed concentration limits for the hazardous constituents at a site, this variability must be considered when defining excursions. Determination of background variability should be updated as more background water quality data become available. After the site has been characterized for four sampling periods, the list of hazardous constituents may be modified to include only those hazardous constituents for which concentration limits have been developed.

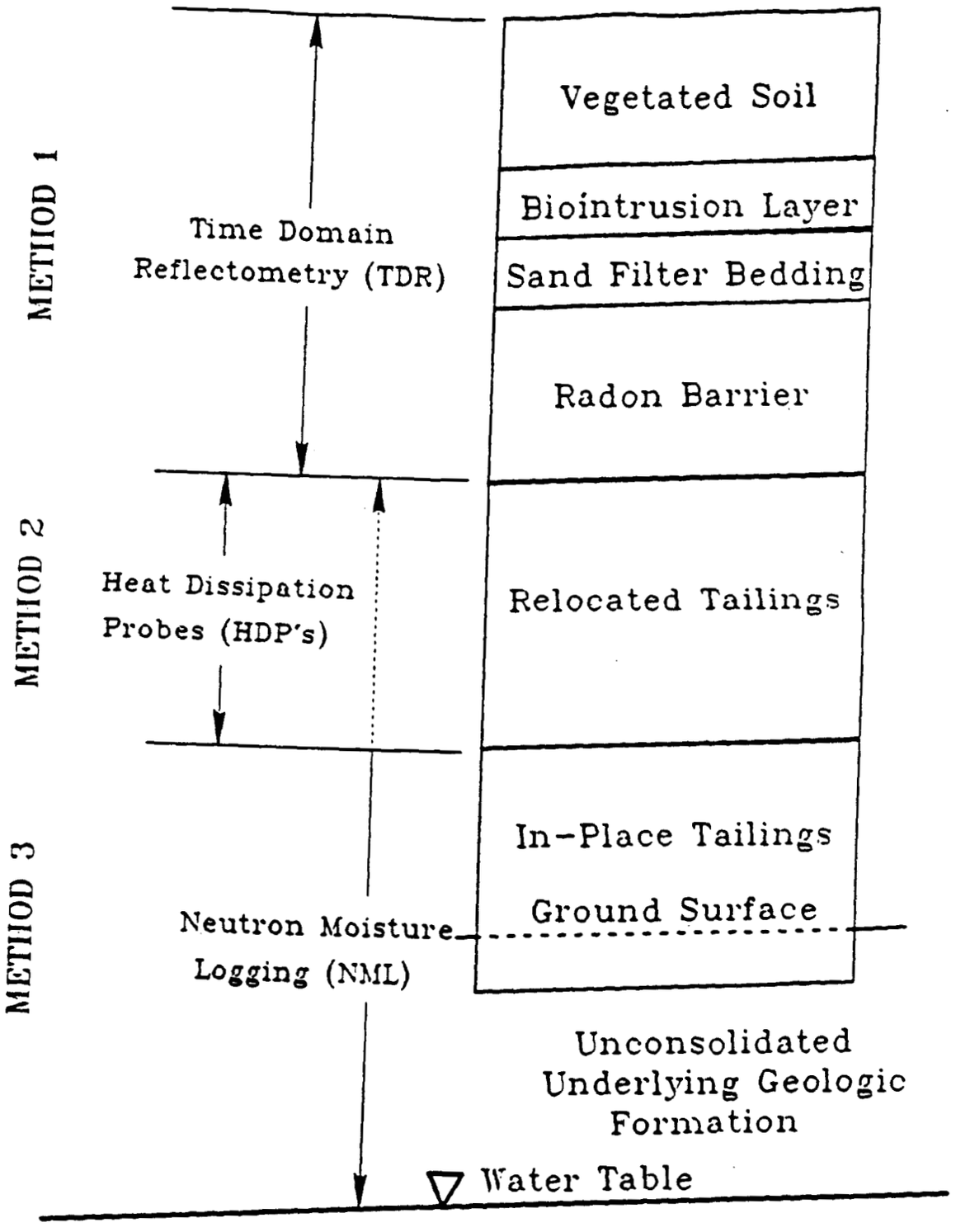

FIGURE 8.1
UNSATURATED ZONE MONITORING METHODS

8.6 CORRECTIVE ACTION PLAN

In conjunction with performance monitoring, it is necessary to provide an evaluation of alternative corrective actions that could be implemented if the disposal monitoring program indicates that a disposal unit is not performing adequately. Reasonable failure scenarios of the disposal unit should be considered and it will be necessary to demonstrate that corrective actions could be implemented no later than 18 months after finding an exceedance of the groundwater protection standard. Because of design considerations, including factors of safety in the disposal cell design, there are no "reasonable" failure scenarios that would be related to structural instability of the stabilized pile. Most failure scenarios would be related to an increased moisture flux through the disposal cell and subsequent corrective actions would reduce this flux.

To formulate the corrective action plan, possible failure scenarios leading to an exceedance of the standards would have to be developed. Also, an assessment of the temporal nature of the exceedance should be discussed (e.g., if drainage from the pile is transient or if equilibrium conditions have been reached). Then remedial actions to correct the failure mechanism leading to the exceedance can be described. A risk analysis should be performed based on the potential impacts of higher fluxes through the cell using the updated monitoring data. If there are no associated risks to human health or the environment, ACLs may be proposed for the identified constituents and no corrective action would be required. In other situations, it may be possible to apply for supplemental standards and no corrective action would be necessary.

8.7 GROUNDWATER CLEANUP

Cleanup of contaminated groundwater is required under the conditions of Subparts B and C of the EPA groundwater standards (40 CFR 192) but will be deferred until the final groundwater standards are promulgated. However, it must meanwhile be demonstrated that disposal can proceed independently of cleanup. It must also be shown that the proposed disposal activities at the designated processing sites do not preclude or preempt future cleanup activities. The need for and extent of aquifer restoration at each site will be determined based on the extent of existing contamination, the potential for current or future use of the aquifer for drinking water supplies, and the technical practicability of restoring the aquifer from an engineering perspective.

Analogous to the groundwater protection standard for disposal sites, the groundwater cleanup standard will specify hazardous constituents and corresponding concentration limits. The groundwater cleanup standard for processing sites should be generally consistent with the groundwater standard at sites where residual materials are being stabilized on the site.

Possible hazardous constituents present in tailings, contaminated groundwater, and soils contaminated by releases from the tailings and other materials will be identified. These constituents should satisfy one of the following criteria:

- o They should be reasonably expected to be in or derived from tailings material at the designated processing site.
- o They should be present in groundwater in the uppermost aquifer at the designated processing site as detected in groundwater monitoring programs.
- o They should be listed in Table I 40 CFR 192.02(a)(3)(i), or listed in Appendix I of 40 CFR 192.

In addition to site-specific characterization data, information such as descriptions of the milling process will also be used in the assessment of which hazardous constituents are expected to be in or derived from residual radioactive material at the processing site.

Similar to the concentration limits established under the groundwater protection standard, cleanup concentration limits for each hazardous constituent will be defined. These limits may be proposed as background limits, MCLs or ACLs as described in Section 8.2.2. The selection of numerical values for the concentration limits will be justified.

8.7.1 Cleanup demonstration

A demonstration that the remedial activities can proceed independently of cleanup ("decoupling") and that they will not interfere either spatially or temporally with aquifer restoration activities is required. It must also be shown that existing contamination and any future contamination resulting from disposal activities can be distinguished and appropriate corrective actions can be taken to control any contamination resulting from disposal activities. For this demonstration, possible extraction well locations, pumping rates, and zones of drawdown need to be identified and assessed to ensure that subpile contaminated groundwater can be accessed for aquifer restoration. Possible time constraints also need to be identified, such as the drainage time of in situ or construction water. If drainage times are long, the remediation period might have to be extended.

Another requirement for decoupling is demonstration that groundwater restoration activities will not compromise the integrity of the stabilized pile. In order to show this, the following steps need to be taken: (1) identify potential restoration scenarios; (2) assess each scenario or action with respect to engineering concerns; (3) quantify engineering impacts of each activity and determine the limit that would adversely affect the disposal cell; and (4) ensure that these limits will not be exceeded and restoration of the groundwater can be performed.

8.7.2 Restoration methods

Active restoration methods need to be identified for each site but generally fit in one of two categories: (1) above-ground treatment methods, wherein the contaminated water is removed from the aquifer, treated, and either disposed of, used, or reinjected into the aquifer; and (2) in situ methods, such as the addition of chemical or biological agents to fix contamination in place. An aquifer restoration program at a site may involve one or more of the restoration methods discussed below.

Extraction methods

Contaminated groundwater can be extracted from wells or trenches. The use of trenches is limited to relatively shallow contamination and is particularly useful in materials with a low hydraulic conductivity. Wells may be used for groundwater extraction when the hydraulic conductivity of the water-bearing materials is sufficiently high, or when the contamination is relatively deep.

Treatment methods

The need for treatment prior to discharge or reinjection into an aquifer depends upon the concentrations of contaminants in the extracted groundwater and the applicability of regulations on the discharge of effluent to surface water and groundwater. Chemical treatment methods include chemical precipitation, coagulation, ion exchange, flocculation, neutralization, sorption, and reverse osmosis. Contaminated groundwater can also be evaporated in evaporation ponds. Biological treatment can be used to transform nitrate to elemental nitrogen and oxygen. The preferred treatment methods depend on the specific mix of contaminants, the concentration of the contaminants, the general water quality, the volumetric flow of the treatment stream, and the available area for treatment facilities.

In addition to above-ground treatment, two in situ treatment methods are possible. These are chemical injection and the use of permeable treatment beds or walls. In situ treatment by chemical injection can be used to mobilize contaminants so that contaminants can be removed expeditiously from the subsurface. Other chemicals can be injected to precipitate the hazardous constituents and leave them in a stable phase. Permeable treatment beds are subsurface structures installed below the water table that provide an artificial chemical barrier for contaminants in the groundwater. Following removal of the contaminants onto the barrier, the treatment bed materials can be removed from the subsurface.

Discharge of treated water

Following the extraction and treatment of contaminated water, it will be discharged. Options for discharge include (1) discharge to surface water; (2) infiltration to groundwater through ponds or infiltration galleries; or (3) injection in shallow or deep wells. Appropriate permits will be obtained for the discharge option selected.

Natural flushing

Natural flushing is a passive restoration method whereby contaminants in groundwater are dispersed or removed with time by the natural flow of groundwater. Under the proposed EPA standards, 40 CFR 192, Subpart B, passive restoration may be permitted if it can be demonstrated that natural flushing can occur within a period of 100 years or less and where groundwater is not now, and is not projected to be, used for a community water supply (or other substantial use) within this period.

Natural flushing may be employed at the processing sites as the sole method for aquifer restoration, or it may be used in conjunction with any of the active restoration methods described above. The efficacy of natural flushing will be determined during the performance assessment of the proposed remedial action.

8.8 ALTERNATE GROUNDWATER COMPLIANCE APPROACHES

One of the three primary components of the groundwater protection standards is the specification of a concentration limit for each hazardous constituent at the POC. These concentration limits can be designated in one of three ways: (1) background levels, (2) MCLs, or (3) ACLs. Under certain prescribed conditions, supplemental standards can be invoked as an alternative. Site conditions, coupled with the disposal cell design, control which approach is used to meet the groundwater protection standards. The criteria for designating MCLs and background levels as the concentration limits at the POC are discussed in detail in Section 8.2, Concentration Limits. This section describes the criteria for using ACLs at the POC or invoking supplemental standards as the groundwater compliance approach.

8.8.1 Alternate concentration limits

As stated in Section 8.2, ACLs may be obtained if the hazardous constituents of concern do not pose a present or potential threat to human health or the environment, as long as the ACL is not exceeded and it is as low as reasonably achievable (ALARA).

In order to demonstrate that an ACL is protective of human health and the environment, 20 criteria are to be considered. These are:

I. Potential adverse effect on groundwater quality, considering:

1. The physical and chemical characteristics of the waste in the processing site or the depository site, including its potential for migration.

2. The hydrogeological characteristics of the site and the surrounding land.

3. The quantity of groundwater and the direction of groundwater flow.

4. The proximity and withdrawal rates of groundwater users.

5. The current and future uses of groundwater in the area.

6. The existing quality of groundwater, including other sources of contamination and their cumulative impact on groundwater quality.

7. The potential for health risks caused by human exposure to waste constituents.

8. The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents.

9. The persistence and permanence of the potential adverse effects.

10. The presence of underground sources of drinking water and exempted aquifers identified under 40 CFR 144.7.

II. Potential adverse effects on hydraulically connected surface water quality, considering:

1. The volume, physical, and chemical characteristics of the waste in the processing site or depository site.

2. The hydrogeological characteristics of the site and surrounding land.

3. The quantity and quality of groundwater and the direction of groundwater flow.

4. The patterns of rainfall in the region.

5. The proximity of the processing site or depository site to surface waters.

6. The current and future uses of surface waters in the area and any water quality standards established for those surface waters.

7. The existing quality of the surface water, including other sources of contamination and the cumulative impact on surface water quality.

8. The potential for health risks caused by human exposure to waste constituents.

9. The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents.

10. The persistence and permanence of the potential adverse effects.

The information needs and procedures for obtaining ACLs are contained in a DOE document on ACLs (DOE, 1989a). This document is essentially a Technical Approach Document for obtaining ACLs and supplemental standards. It details the various components that will need to go into ACL demonstrations for the UMTRA Project. These include discussions of land and water use, environmental considerations, hydrologic information, risk assessments, and corrective action assessments to address the ALARA concept.

The level of detail for any ACL application will be dependent on site-specific factors such as the complexity of the hydrologic system, water use, and proximity of people to a site; each ACL request will be unique. An ACL can be requested for both disposal (Subpart A) and aquifer restoration (Subpart B). Geochemical attenuation of hazardous constituents will generally require evaluation for disposal site ACLs.

8.8.2 Supplemental standards

The proposed EPA groundwater standards allow for the application of supplemental standards (40 CFR 192.21). Supplemental standards can be obtained if any of the following conditions are met:

- The remedial actions would present a substantial risk to workers or the public (40 CFR 192.21 (a)).
- Aquifer restoration would cause excessive environmental harm (40 CFR 192.21 (b)).
- There is no known remedial action (40 CFR 192.21 (e)).

- Aquifer restoration is technically impracticable (40 CFR 192.21 (f)).

- The groundwater is defined as a limited use groundwater (40 CFR 192.21 (g)).

A limited use groundwater is not a current or potential source of drinking water due to one or more of the following criteria (40 CFR 192.11 (e)):

- The concentration of total dissolved solids is greater than 10,000 milligrams/liter, or

- Widespread, ambient contamination not due to activities from the UMTRA Project site, that cannot be cleaned up using methods reasonably employed by public water supply systems, exists, or

- The quantity of water available is less than 150 gallons per day.

Supplemental standards must come as close to meeting the otherwise applicable standard (e.g., concentration limits) as is reasonably achievable (40 CFR 192.22 (a)). Human health and the environment must be protected when the excessive environmental harm, limited use groundwater, or technical impracticability criteria apply (40 CFR 192.22 (d)).

The DOE has prepared a policy and procedures document on Class III (limited use) waters (DOE, 1989b), which outlines the various steps in determining if groundwaters are limited use. The information and discussion required for a supplemental standard request are similar to those for an ACL, although the level of detail may be different. The DOE report on ACLs and supplemental standards discusses the various factors to be considered in a supplemental standard determination based on limited use.

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9.0 NONRADIOLOGICAL HAZARDOUS CONSTITUENTS IN SOILS

This section provides a methodology for establishing target soil cleanup levels at UMTRA Project sites to insure the protection of public health and the environment from post remediation releases. This methodology is designed to provide protection from both short- and long-term exposures to residual levels of nonradiological hazardous constituents in soils. All of the potential routes of human exposure should be accounted for using a quantitative exposure assessment of remedial actions at UMTRA Project sites. In addition, it must be demonstrated that residual levels of hazardous constituents in soils will allow compliance with the groundwater cleanup standards of 40 CFR 192.

The methodology for a quantitative exposure analysis involves four steps:

1. Identify and evaluate all potentially important exposure pathways where soil concentrations may result in exposure levels.

2. Characterize the existing levels of soil contamination.

3. Relate exposure levels to existing health criteria.

4. Incorporate these data and derived relationships to identify the level of soil contamination at which significant adverse health effects occur.

The EPA has described this methodology in detail in the preliminary draft Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites (EPA, 1988). Recognizing that soil cleanup at UMTRA Project sites should be consistent with the RCRA, the DOE has developed the model DECHEM (DOE, 1989) for quantitative exposure pathway analysis for human exposure to selected hazardous constituents. Further discussion of DECHEM is provided in Section 9.4. The DECHEM model is not used for evaluating compliance with the groundwater cleanup standards. An independent, more detailed hydrologic assessment will be used to determine compliance with the groundwater cleanup standards.

Both current and potential future land use patterns at UMTRA Project sites should be considered in identifying the potentially exposed populations and the likely pathways of human exposure. The exposure pathway analysis should also consider the mode of chemical release and the transport factors. Pathways that result in potentially high exposures of contaminants to humans and the environment should be emphasized in the analysis. Each exposure pathway consists of four elements: (1) a source of chemical releases to the environment, (2) a mechanism for chemical release and an environmental transport medium, (3) a point of potential human contact with the chemical, and (4) a human exposure mechanism (e.g., inhalation or ingestion) at the exposure point.

9.1 IDENTIFICATION OF POTENTIAL EXPOSURE PATHWAYS

Residual concentrations of nonradiological hazardous constituents in soils may pose a health risk to humans through the following pathways of intake:

- Ingestion of contaminated soil.
- Inhalation of volatilized contaminants contained in the air.
- Inhalation of airborne contaminated particulates.
- Absorption of contaminants through the skin as a result of contact with contaminated soil.
- Consumption of contaminated water.
- Ingestion of food containing bioaccumulated contaminants.
- Ingestion of large airborne particulates that lodge in the upper respiratory tract.

In addition to addressing the potential risk to humans, pathways to other species may need to be evaluated. Methods for performing an ecological risk assessment are contained in the draft Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites (EPA, 1988) and are summarized in Section 9.5.

9.2 HAZARDOUS CONSTITUENT CHARACTERIZATION

The current cleanup standard for uranium mill tailings is based upon the activity of Ra-226 in contaminated materials. When sufficient material has been removed that the radium activity in the remaining soil is less than or equal to 15 pCi/g at sites where backfill material is to be emplaced or 5.0 pCi/g on the surface, the site is considered "clean." At this time it has not been established that, by cleaning to the Ra-226 standard, the nonradiological, inorganic, and organic hazardous constituents will be removed to safe levels as well. This uncertainty requires that additional measures be taken to characterize individual UMTRA Project sites and to evaluate the effect of leaving specified concentrations of these hazardous constituents in place. Because there are no final EPA hazardous constituent standards for sediments or soils, it is incumbent upon the UMTRA Project to evaluate the potential risk to human health and the environment caused by leaving specific levels of these contaminants in place and to judge the potential affect of these residual contaminants upon their respective concentrations in groundwater.

Residual nonradiological hazardous constituents in soils at UMTRA Project processing sites may represent a risk to human health and the environment. At UMTRA Project sites, heavy metals and the metalloids represent the majority of the nonradiological hazardous constituents. The metalloids

that are typically associated with uranium processing are arsenic (As) and selenium (Se). Heavy metals that are most prevalent are lead (Pb), molybdenum (Mo), uranium (U), and vanadium (V). Because of its radioactivity, uranium must be managed as both a radioactive and a hazardous constituent. Other heavy metals that are important at individual UMTRA Project sites are cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), and zinc (Zn). All of these elements were present in the original ores as either individual minerals or trace elements within the sulfide minerals and have been released either as a result of uranium processing or subsequent chemical weathering. There is a possibility that other inorganic and organic hazardous constituents listed in Appendix I of 40 CFR 192.02(3)(i) (Table 8.2) may be detected in soils at some UMTRA Project sites.

In order to characterize the site to perform a quantitative risk assessment and evaluate whether residual levels of nonradiological hazardous constituents are sufficiently low as to allow compliance with the groundwater cleanup standards, it may be necessary to determine the three-dimensional distribution of nonradiological hazardous constituents in soils beneath tailings piles, evaporation ponds, mill yards, and areas of deposition of windblown materials. It also may be necessary to characterize the mineral phases upon or within which these contaminants reside. The mineral hazardous constituent relationship is important because certain chemical forms cause the hazardous constituents to become immobile and, thus, to represent little or no risk to human health or the environment; in such cases, significant remediation costs can be avoided.

An important goal of hazardous constituent characterization is to determine whether the hazardous constituents are all concentrated above the 15 pCi/g Ra-226 concentration depth. This situation would allow the removal of all the nonradiological hazardous constituents along with the Ra-226.

The first step in identifying potentially hazardous constituents is to review existing documents with data on chemical concentrations associated with the tailings or soils. In order to determine the distribution of both Ra-226 and the nonradiological hazardous constituents, it may be necessary to characterize the soils and select a series of samples from previous sampling operations for analysis. When it can be demonstrated that samples collected during previous characterization efforts have not been chemically altered (such as by oxidation or dehydration) during storage, archived samples will be appropriate for analysis. Analyses may be for both the chemical constituents present and the minerals with which the individual constituents are associated. When fresh samples are required, the sampling interval will depend upon the observed changes in the contaminated materials. In the event that there is no apparent change in the geochemical character or texture of the materials, a regular sampling interval based on depth will be chosen. Indications that there is a change in the geochemical environment such as the color change at a redox interface or a noticeable layer of organic material or clay will require

that sampling be performed in such a way as to determine whether or not the interface has affected the distribution of hazardous constituents. Site characterization for nonradiological hazardous constituents should also be conducted in such a way as to support use of the DECHEM method (Section 9.4) and hydrochemical modeling (Section 9.3).

The data collected from these analyses may be used to support modeling and risk assessments and compliance with the groundwater cleanup standards. It is critical that the appropriate analytical methods be used, as these will greatly influence the outcome of modeling. It is also important to assure that it is appropriate to use archived samples, because the improper use of archived samples may cause misleading results. Decision criteria for the use of archived samples are discussed below. The following methods of soil analysis may be appropriate for characterizing chemical concentrations and quantifying geochemical conditions that may affect contaminant mobility.

EPTOX evaluation: Conduct the EPA's Extraction Procedure Toxicity test on the soil or sediment samples and determine which constituents will be leached from the sediments.

Digestion and analysis: Extract the contents of the soil samples using EPA method 3050--acid reflux digestion--and analyze for major, minor, and trace constituents.

Bulk mineralogy: Point count under an optical microscope to determine the relative abundance of the individual mineral phases.

Carbonate content: Acidification of the sample followed by collection and measurement of the evolved carbon dioxide.

Clay mineralogy: Collection of the clay-sized material followed by multiple X-ray defractograms with intervening heat and chemical treatments.

SEM analysis: Conduct scanning electron microscopy/energy dispersive spectroscopy of the secondary minerals to determine the mineral phase/hazardous constituent relationships.

The use of archived soil samples for the quantification of geochemical parameters is justified only when it can be demonstrated that the samples have not changed their compositions during storage. Collecting and storing a sample can expose it to conditions that cause a significant relocation of the hazardous constituents. The major processes that will affect the geochemistry of a sample are oxidation and dehydration. If the sample was collected from a reducing environment, exposure to air will cause reduced constituents such as iron and manganese to oxidize and to form amorphous iron or manganese oxyhydroxides or hydroxysulfates. These minerals are usually porous and have very large surface areas. Such characteristics make the minerals natural scavengers and hazardous constituents that would have been free to move into groundwater when the sample was in place will not be free to move in the archived sample if the sample is inundated with water. As these secondary minerals age, they recrystallize into larger,

more dense crystals and these new, more ordered crystals usually do not have room for the contaminant ions that have been adsorbed on the surface and incorporated into their structure. These expelled contaminant ions then become free to either migrate or to form their own minerals. A similar situation exists when a sample dehydrates. As the water evaporates, the solution left becomes increasingly concentrated up to the point where minerals start to precipitate. Rehydrating the sample may or may not redissolve these secondary minerals. Consequently, any attempt to determine whether certain constituents will be available for advective transport via groundwater can provide a spurious answer. The use of archived samples for the determination of geochemical parameters becomes futile unless it can be demonstrated that the samples were dry and fully oxidized at the time of collection or that they were stored under the same physiochemical conditions as those in which they resided when they were in place.

9.3 HYDROCHEMICAL MODELING

In order to provide input into predictive risk assessment codes and to address regulatory compliance requirements associated with hazardous constituent concentrations in groundwater, it is necessary to determine the tendency of hazardous constituents that are present in soils to be transported to and in groundwater. Using the data collected during characterization, it will be possible to simulate the geochemical system that will exist if the sediments come into contact with water. There are a number of equilibrium geochemical codes that can be used to predict the hazardous constituent species in solution. The codes currently used on the UMTRA Project are PHREEQE (Parkhurst et al., 1980) and WATEQF (Plummer et al., 1976). These programs calculate equilibrium speciation in solution, saturation indicies for minerals whose components are in solution, the resultant composition of a varying mixture of groundwater solutions, and the amount of a given mineral phase that will precipitate for any phases that are out of equilibrium. An additional code that has been acquired recently is MINTEQA1 (Brown and Allison, 1987). This program not only calculates the equilibrium species and potentially precipitated mineral phases, but also includes expressions for the removal of constituents from solution via sorption upon mineral surfaces. The MINTEQA1 code requires the detailed characterization outlined in the previous section and provides a much more constrained estimate of groundwater composition than most models. The Electric Power Research Institute currently has a contract with the modeling group at Battelle's Pacific Northwest Laboratories to develop a code which couples a fluid mass transport code with an equilibrium geochemistry code. If this effort is successful, the contributions of groundwater exposure to total potential health risk will be much easier to determine.

The hydrochemical modeling activities will provide an estimate of the mobility of hazardous constituents in leachate and can be coupled with groundwater contaminant transport models to predict concentrations of the various hazardous constituents in the groundwater at the point of exposure. The risk assessment models will then use these data as input for the

assessments of hazards from drinking and consuming food raised with contaminated water.

9.4 HUMAN RISK ASSESSMENT MODELING: THE DECHEM METHOD

The evaluation of the potential risk to future occupants of property in the vicinity of an UMTRA Project site requires a knowledge of the potential uses of the property, an analysis of the potential exposure pathways, and the concentrations of the hazardous constituents within the materials along the pathway. A methodology and code has been developed to compare maximum acceptable intake levels with the intake levels that would be expected as a result of various remedial actions. This methodology has been named the DECHEM method and is described in detail in DECHEM: Final Report and Users Guide (DOE, 1989). The DECHEM method includes a toxicology review to establish maximum acceptable intake levels, incorporation of the site-specific characterization data into the database, and execution of the DECHEM pathways code. However, the DECHEM method is only a part of the overall evaluation of contaminated residual materials that may contain nonradiological hazardous constituents. The evaluation of quantitative exposure to hazardous constituents will primarily follow methodologies set forth in Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites (EPA, 1988). This methodology assesses all potential pathways including exposure from excavation.

Figure 9.1 illustrates the various elements of the DECHEM Method, which derives site-specific cleanup criteria based on:

- Potential post-remedial action uses of the site.
- Characteristics of the local sediment, climate, and hydrology that affect contaminant migration pathways.
- Contaminant distribution and speciation within the sediment.

The DECHEM code currently specifies cleanup criteria for a limited number of metals and metalloids in contaminated soils. The method does not currently address contamination by organic compounds. Hazardous inorganic constituents not in the DECHEM model and organic compounds will be evaluated using methodologies described in Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites (EPA, 1988). The DECHEM method and determining the depth of excavation is more suitable for the UMTRA Project than for waste sites covered under other regulations because excavation has already been planned to comply with the radon standard. The uranium processing wastes and contaminated soils must be excavated and placed in a specifically designed disposal cell to comply with the radon standard. The DECHEM method is used to determine whether additional materials will need to be excavated based on chemical toxicity evaluated by exposure pathways. If the depth of excavation is deep and the associated costs are excessive, it may be necessary to evaluate the use of surface

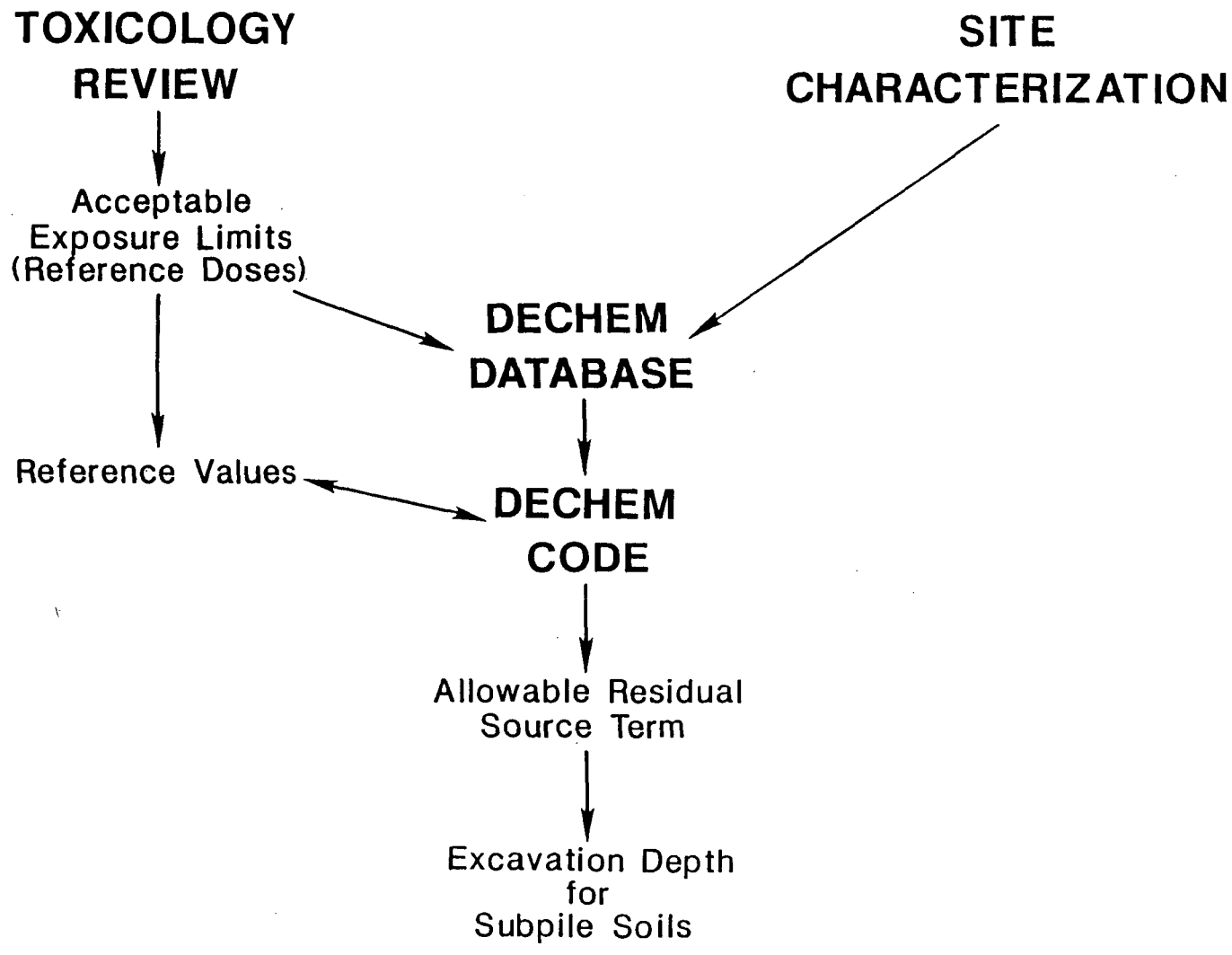

FIGURE 9.1
RELATIONSHIPS AMONG COMPONENTS OF DECHEM METHOD

capping or institutional controls as methods of closure. The DOE is currently revising DECHEM to incorporate more inorganic hazardous constituents in the database.

9.4.1 Toxicology review

A toxicology review is performed to establish maximum acceptable intake limits for nonradiological hazardous constituents. The DECHEM code requires these baseline data to establish cleanup criteria to ensure that users of a remediated UMTRA Project site do not receive excessive exposure. Table 9.1 lists reference doses for six elemental contaminants that are prevalent at UMTRA Project sites. The reference dose is the total allowable exposure via inhalation or ingestion per unit time that an individual can receive without experiencing adverse health effects.

The reference doses are used by the DECHEM code to calculate reference values--the ratio of the predicted exposure to the reference dose. The sum of the reference values for all of the chemicals by all exposure modes must be less than one for the code to consider the exposure to be safe. The majority of the reference doses that have been compiled are based upon EPA determinations of acceptable exposure limits issued in support of the Superfund Program. Where sanctioned EPA values are not available, other sources were used (e.g., threshold limit values (TLVs) established by occupational organizations). The appropriate calculations were made to extrapolate from 40-hour/week occupational exposures to round-the-clock environmental exposures.

Documentation explaining the basis for the selected reference dose for each constituent includes:

Table 9.1 Summary of reference doses

Constituent	Reference dose (mg/yr)[a]	
	Ingestion	Inhalation
Arsenic	74	18
Lead	36[b]	11[b]
Molybdenum	77[b]	434
Selenium	77[b]	26[b]
Uranium	49[b]	17
Vanadium	511[b]	4.3

[a]Assumes an individual weighing 70 kilograms; mg/yr = milligrams per year.
[b]Calculated from EPA data.

- Calculations that transform the intake limits or TLVs in the literature to reference doses for use in the DECHEM code.

- Discussions of the rationale behind the selection of appropriate literature values, along with a concise discussion of alternative values that were not used.

- Anecdotal narrative on the environmental chemistry and toxicology of the element.

- A list of references.

The reference doses in Table 9.1 are programmed into the DECHEM code as default values. Revised numbers may be used when necessary. Toxicology reviews will have to be performed for additional constituents (e.g., cadmium and chromium) for sites where such elements are important.

9.4.2 Parameter determination for the DECHEM code

Site-specific data are required before the DECHEM code can be executed. The DECHEM final report (DOE, 1989) includes a detailed site characterization procedure to guide the efforts of an UMTRA Project staff member in performing the following:

- Review the existing information to determine which contaminants are prevalent and should be emphasized in subsequent data compilations.

- Compile environmental and land-use data--including characteristics of climate, soil, and groundwater--necessary for execution of the code.

- If meaningful data can be obtained from archived samples, select appropriate samples for analysis.

- Reduce data from the analysis of soil samples into the 15-cm depth increments required by the DECHEM code.

- Determine the need for additional sampling and analysis.

Table 9.2 lists the input parameters for the DECHEM code. About half of the parameters (left column) are site-specific data and are addressed within the site characterization procedure. If site-specific data are not available, conservative default values may be used. However, site-specific data always provide predictions with higher confidence levels.

The parameters listed in the right column of Table 9.1 are of a generic nature and need not be derived for each site. The DECHEM code contains default values that have been compiled from the

Table 9.2 Input parameters for the DECHEM code

Measured at each site	Chemically independent parameters (Literature value is generally used)
Contaminant concentration in soil[a]	Plow layer depth
Contaminant concentration in groundwater[a]	Atmospheric soil loading (resuspension)
Areal extent of soil contamination	Vegetation consumption rate by animals
	Soil consumption rate by animals
Measured or estimated at each site	Vegetation consumption rate by humans
	Milk and meat consumption rate by humans
Soil bulk density[a]	Human breathing rate
Volumetric water fraction[a]	
Aquifer dispersivity[a]	**Chemically dependent parameters**
Aquifer porosity[a]	
Aquifer thickness[a]	Solubility in water at soil temperature
Aquifer seepage velocity[a]	Concentration factor for uptake of chemical from soil by pasture grass
Soil/water distribution coefficient (K_ds) for soil and aquifer sediment	Concentration factor for uptake of chemical from soil by edible parts of crops
Also determined for each site	Average fraction of cow's daily intake of chemical that appears in milk
Anticipated food production	Average fraction of cow's daily intake consumption of chemical that appears in flesh
Anticipated well locations	
Anticipated food and water	Reference doses (intake rate)

[a]Default values are not provided in DECHEM code.

literature. The judgement of the user and subsequent reviewers is the final arbiter in the decision as to whether site-specific data must be collected or whether the literature data provide sufficiently confident predictions.

9.4.3 DECHEM database

The DECHEM database is a compilation of the input parameter values from government reports and the open literature, as well as site-specific data regarding the environment and concentrations of chemicals. Included within the database are the toxicology reference doses, soil hydrologic characteristics, geochemical characteristics, plant and animal contaminant uptake distribution ratios, and land use data. Along with the data are documentation and reprints of the source materials. The database resides within an IBM PS/2 Model 80 computer and can be accessed via a modem. Details of access and specifics of the information available are contained within DECHEM: Final Report and Users Guide (DOE, 1989).

9.4.4 DECHEM code

The DECHEM code is a series of pathways models that quantitatively estimate contaminant migration from a source to humans. It was developed by John Till (Radiological Assessments Corporation) and several associates expressly for the UMTRA Project; many elements of the code were adapted from the DECOM[R] method, which specifies site-specific cleanup guidelines for radionuclides in soil (Till and Moore, 1988). Both DECHEM and DECOM utilize long-standing relationships and principles that have been developed in the fields of radioecology and environmental chemistry.

A detailed report has been prepared for the UMTRA Project (Till et al., 1989) on the development of the DECHEM code. The report lists the key equations and models used in the code, along with sample calculations for two UMTRA Project sites where chemical contaminants occur in the soil. This section provides a brief description of how the code may be used for remedial planning on the UMTRA Project.

The DECHEM code requires the users to obtain site-specific data for all the parameters in the left columns of Table 9.2 using guidelines in the site characterization procedure.

The code also requires that contaminant concentration/depth profiles be provided as input and then estimates the final depth of excavation that will be necessary to ensure that humans will receive safe exposures upon completion of the remedial action. Mean concentrations are entered for each desired soil layer from the surface down to some depth (to a maximum of 450 cm) for which data are no longer available. The code iteratively evaluates the exposure consequences associated with the removal of each layer until it finds an excavation depth for which the final human exposure would be acceptable. This value is then specified as the recommended excavation depth. Acceptable residual contaminant concentrations then may be inferred by inspecting the input data for the uppermost layer below the recommended excavation depth. The code provides an assessment of excavation depths required as a function of time in years following remediation of the source contaminants. This allows the user to determine the maximum excavation necessary to prevent adverse health effects at a given receptor location.

Despite using the DECHEM code to develop cleanup criteria, verification sampling of soil contaminant concentrations must be performed during the remedial action, and before backfilling, to ensure that the contaminant concentrations at depth are equal to or less than the mean values used as input for the code, and to ensure that the residual concentrations in the uppermost level will be less than the concentrations recommended by the code.

The DECHEM code was developed primarily to guide the excavation of subpile soils that must be performed after the removal of tailings to an alternate disposal site. The code may be used with the assumption that the contaminants in each layer are evenly distributed over the entire area of subpile soil. Alternatively, the user may recognize, upon reviewing the site characterization data, that distinct areas with differing concentration profiles may be identified within the overall area of contamination. In such cases, the code may be executed separately for each area and will make different recommendations for excavation depth. It is at the user's discretion that the code may be applied to small areas, and the reduced confidence associated with the smaller sample size must be recognized.

The code may also be used with caution for areas other than subpile soils such as mill yards, raffinate ponds, and areas of windblown or waterborne contamination. If concentration/depth profiles cannot be reliably constructed, the only option may be to assume (conservatively) a uniform concentration as a function of depth.

The use of any simulation code automatically requires the statement of a caveat: The confidence in the predictions made by the code is a function of the reliability of the input data. The following questions must be considered in using the predictions for decisions which may involve significant added expense.

- Were the samples analyzed representative of actual zones of contamination?
- Were the methods of extraction and analysis appropriate for the hazardous constituents?
- Are the mechanisms of attenuation that can be expected along the groundwater pathways simulated by the code?
- Do variations in parameters with values that naturally range over an order of magnitude or more cause the predictions to become unreasonable?

9.5 ECOLOGICAL RISK ASSESSMENT

Ecological risk assessments may need to be performed for nonradiological hazardous constituents at some UMTRA Project sites. The EPA's preliminary draft Guidance for Establishing Target Cleanup Levels for Soils of Hazardous Waste Sites (EPA, 1988) includes a detailed description of the method of performing an ecological risk assessment.

The need for an ecological risk assessment for one or more nonradiological hazardous constituents is related to the likelihood of those constituents causing harm to species other than humans. The likelihood of

nonradiological hazardous constituents posing a threat to the biota may first be judged by evaluating existing sources of data and comparing contaminant concentrations in tailings or soil to local background levels or, if those are unknown, to regional or global averages. The subsequent analysis of archived or fresh samples will provide more information on concentrations of nonradiological hazardous constituents. The DECHEM model can also be used to determine if one or more contaminants appear likely to concentrate at potentially harmful levels in one or more components of the ecosystem. This may be determined by looking at intermediate outputs of DECHEM along pathways leading to humans.

If it is likely that nonradiological hazardous constituents may occur in potentially harmful concentrations in accessible components of the ecosystem, then a more detailed ecological risk assessment may be necessary. Ecological risk assessments so far have not been performed for nonradiological hazardous constituents on the UMTRA Project, and a detailed methodology has yet to be developed. Primary elements in the risk assessment should be to:

- Eliminate insignificant risks early in the process.
- Concentrate on key (relevant and susceptible) species.
- Make the best use of existing models.
- Use conservative or qualitative predictions unless more precise quantification is available.

The need for ecological risk assessments for nonradiological hazardous constituents at UMTRA Project sites may be determined on a site-specific basis, based in part on the results of hydrogeochemical and DECHEM modeling. If necessary at a given site, a risk assessment may be performed using methods by the EPA (EPA, 1988) and other guidance documents. If ecological risk assessments prove necessary at many UMTRA Project sites, then it may be advisable to develop a systematic, project-wide approach analogous to the DECHEM method for human risk assessments.

9.6 COMPLIANCE WITH THE GROUNDWATER CLEANUP STANDARDS

In addition to performing quantitative pathways analyses, it is necessary to demonstrate that residual levels of hazardous constituents will not prevent the remedial action from complying with the groundwater cleanup standards. The methodology to do this is discussed in detail in Section 8.0.

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10.0 ALTERNATE SITE SELECTION

This section describes the guidelines and processes, to be used by the DOE with input from the affected states and tribes, to select alternate disposal sites in compliance with each established cooperative agreement. The revised screening and selection criteria, primarily for hydrological and geological conditions at candidate disposal sites, will assist the project in selecting disposal sites where the probability of compliance with the proposed groundwater standards is high.

The Alternate Site Selection Process (ASSP) described in Sections 10.1 through 10.3 consists of three phases (Figure 10.1): Phase I--designation of a search region; Phase II--preliminary screening of the designated search region; and Phase III--identification and evaluation of candidate sites. Section 10.4 discusses how the results of the ASSP will be reported. This process provides a technically sound and publicly defensible approach for identifying potentially suitable disposal sites.

10.1 PHASE I--DESIGNATION OF A SEARCH REGION

The initial phase in the ASSP is the designation of a search region. The search region is selected in consultation with the affected state or tribe. Factors to be considered include local, state, or tribal preferences; political boundaries (e.g., within the county of the processing site); the likelihood of finding suitable sites (e.g., underlying strata may not be suitable); and other factors appropriate to the site in question (e.g., including specific locations).

Typically, a search region includes the lands within a five-mile radius of the processing site. The search region is plotted on USGS topographic maps. In other cases, the factors listed above may modify the search region. For example, at the Lakeview, Oregon, site, the former mines from which the ore was extracted were included in the search region.

It also should be recognized that the ASSP (see Figure 10.1) can consist of several iterations, as necessary. For example, should it be determined that there are no suitable sites within the search region, the region would be modified and the evaluation process repeated.

10.2 PHASE II--PRELIMINARY SCREENING OF SEARCH REGION

Phase II involves the use of regional screening guidelines based on geotechnical, hydrological, and environmental factors. The guidelines are applied to the area within the search region to eliminate areas that are unsuitable for tailings disposal.

A team of specialists with expertise in the fields of geotechnical and design engineering, geology, hydrology, seismology, and the environmental sciences will develop and apply the guidelines in consultation, as necessary, with the affected state or tribe. Each guideline will be

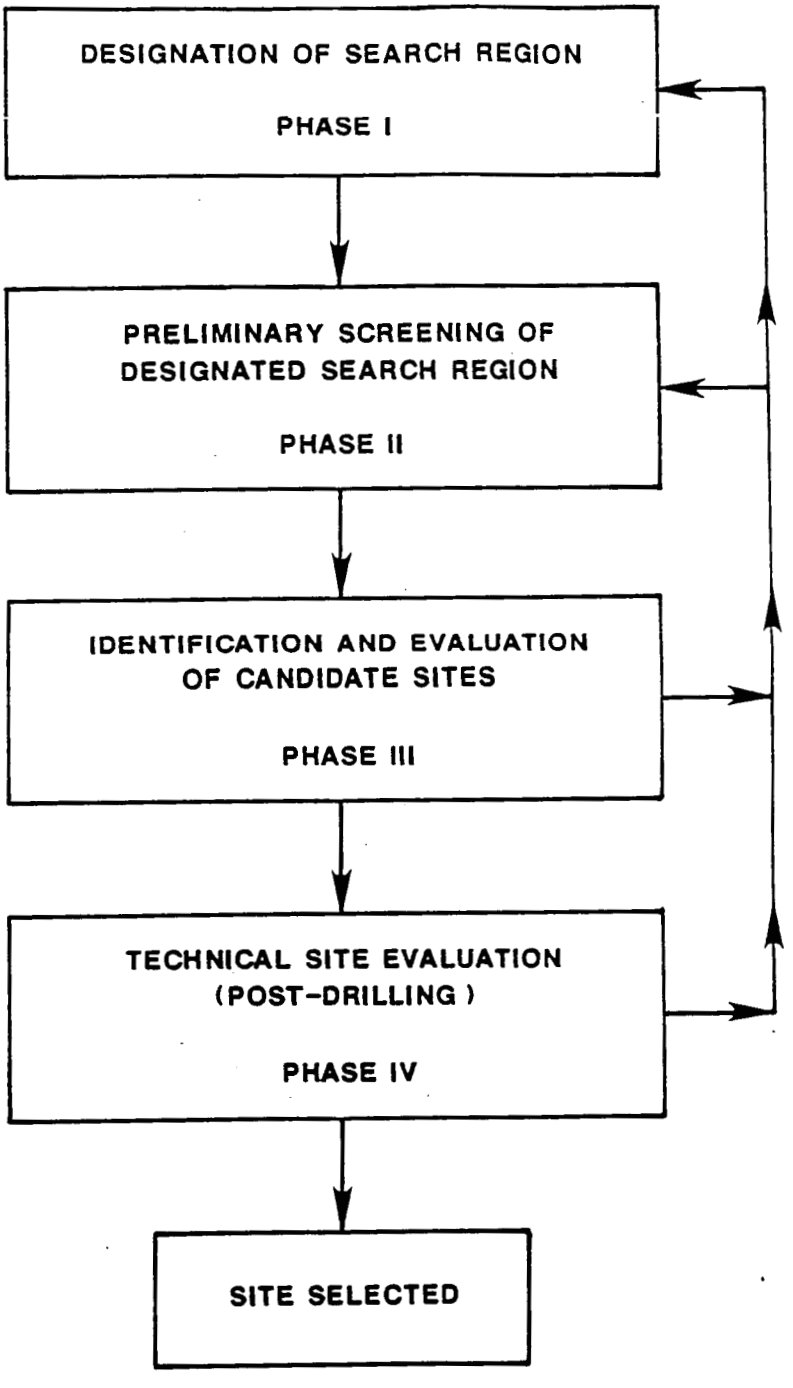

FIGURE 10.1
ALTERNATE SITE SELECTION PROCESS

identified by the team from existing information. Geotechnical, hydrological, environmental, and economic information may be obtained from Federal, state, and local sources including, but not limited to, the USGS, Bureau of Land Management (BLM), state regulatory agencies, state geological surveys, state engineer's office, health departments, municipalities, university and state libraries, and the Bureau of Mines and Mineral Resources.

Table 10.1 provides the basic list of regional screening guidelines. These guidelines were selected as a means of avoiding areas for potential disposal that may have regulatory or legislative constraints (e.g., wetlands and parks), engineering constraints (e.g., erosive soils), or significant negative environmental impacts. Aspects of the regional screening guidelines will vary from site to site; therefore, certain factors may require additional investigations on a site-specific basis. For example, a guideline for geothermal resources may require additional attention, or definitions of a guideline may be altered to account for state regulations (e.g., state endangered species).

The guidelines are not weighted or ranked by their relative importance but are used to eliminate broad areas from consideration that, if included, would require a more complex design (e.g., steep slopes) or pose problems of a regulatory nature (e.g., presence of endangered species).

Each guideline will be used to identify unsuitable lands within the search region. These lands will be plotted on topographic maps and will not be considered further in the ASSP.

10.3 PHASE III--IDENTIFICATION AND EVALUATION OF SITES

Phase III requires that the selection team examine the lands not eliminated after the Phase II screening and select no more than three areas for further evaluation (an area is defined as a location ranging in size from 40 to 600 acres). The team will reexamine the literature and select areas having characteristics that are conducive to disposal of tailings in a manner that will meet the standards without overly complex design features. Characteristics considered for design include area accessibility and terrain, nearby structures, potential borrow sites for cover material, and constructibility. Hydrologists will evaluate the presence or absence of complex watersheds, flooding potential, geomorphic stability, potential surface water quality impacts, aquifer parameters, depth to groundwater, direction of groundwater flow, volume flux beneath the disposal site, aquifer and subsoil geochemical properties, background water quality and classification of groundwater (EPA, 1986), and potential impacts of tailings seepage on groundwater quality including compliance with EPA groundwater standards. Geotechnical engineers will consider nearby faults and fault zones, latest seismic activity and extent, erosion potential, liquefaction potential, slope stability, and other considerations. Environmental scientists will evaluate distances to parks, monuments, critical habitats, prime farmlands, cultural resources, and the like.

Table 10.1 Regional screening guidelines

Characteristic	Definition
Geologic faults	Areas within 3000 feet of capable faulting as defined by 10 CFR 100, Appendix A.
Liquefaction potential	Areas within 0.25 mile of areas having saturated loose sands or visible surface indications of disrupted drainage or broken ground.
Landslides	Areas within 0.25 mile of visible indications of slope instability.
Erosive soils	Areas of known highly erosive soils, including fluvial environments subject to flash flooding or mainstream river flooding.
Slopes and escarpments	Slopes steeper than 33 percent or areas from the top of an escarpment in excess of 10 measured feet in height to a distance established by the intersection of the ground surface with a plane inclined at a 20° angle from a horizontal plane passing through the toe of the escarpment, or 100 feet, whichever is greater.
Water bodies	Lakes, ponds, reservoirs, rivers, or perennial streams.
Wetlands	Wetlands as defined by the U.S. Fish & Wildlife Service or U.S. Army Corps of Engineers.
Floodplains	100-year floodplains as defined by the U.S. Department of Housing & Urban Development, or within 0.125 mile of a stream centerline.
Aquifers	Any area underlain by Class I groundwater.
Surface drinking water supplies	Areas within one mile of surface waters that are sources of domestic water for either individual households or communities.
Communities	Areas within one mile of community limits (legal boundary).

Table 10.1 Regional screening guidelines (Concluded)

Characteristic	Definition
Mineral resources	Area with significant known recoverable resources of oil, gas, coal, and other minerals (except uranium and gravel).
Subsidence areas	Within 0.25 mile of areas susceptible to subsidence by natural or human causes.
Transportation and communication corridors	Areas within the rights-of-way of state, Federal, or county roads.
Archaeological & historical resources	Within 100 feet of archaeological or historical districts and sites listed or eligible for listing on the National Register of Historic Places.
Prime farmlands	Areas designated by the SCS as being within the Class II soil capability classification.
State & National Parks	Within 0.25 mile of parks or monuments under Federal, state, or local jurisdiction.
Wilderness & natural areas	Within 0.25 mile of Wilderness Areas, Wilderness Study Areas, Natural Areas, areas of critical environmental concern, and roadless areas as identified by the U.S. Forest Service or BLM.
Wildlife refuges	Within 0.25 mile of wildlife refuges and designated migratory bird feeding areas.
Critical habitat	Within 0.25 mile of designated critical habitat for threatened or endangered species, fishery resource areas, and botanically sensitive areas.

Table 10.2 presents examples of desirable characteristics used in the selection of alternate disposal sites. Suitable alternate areas are delineated on composite maps that incorporate geotechnical, hydrological, engineering, and environmental factors.

Once the areas have been selected, the evaluation team will conduct a field inspection to select no more than three sites (a site ranges from 40 to 100 acres in size) from within the areas. The criteria in Table 10.2 will form the basis for site selection.

Each site selected by the team may be drilled or have test pits dug to provide information regarding depth to groundwater, lithology, relative contaminant attenuation capacity, soils thicknesses, and other hydrological and geological features. The minimum number of holes needed to provide this information will be used. Each site will be drilled or have test pits dug only if the information needed is not available for the specific site or immediately adjacent areas from other sources.

After drilling and test excavations are complete, the alternate site selection team will rank each site using the geotechnical, hydrological, and environmental criteria shown in Table 10.3. The criteria were based on modifications to Criteria for Evaluating Disposal Sites (DOE, 1982), and the geotechnical ranking matrix used by the Colorado Geological Survey in a preliminary disposal site screening report (CGS, 1982); the hydrological ranking criteria were established to take into account the groundwater protection standards set forth in 40 CFR 192. These criteria rank each alternate site for 32 site-specific characteristics. Each characteristic is weighted and a total of 432 points is possible.

10.4 REPORTING

The results of the ASSP are reported principally in the Comparative Analysis of Disposal Site Alternatives Report, Environmental Assessment, or Environmental Impact Statement for each site. Each phase is described and the results are noted. Data gathered from the drilling program will be reported in these documents as well as in the Disposal Site Characterization Report (if required). The topographic maps, which will depict the search region, areas eliminated from consideration, and the areas/sites selected, will be retained in the UMTRA Project Document Control Center, Albuquerque, New Mexico.

Table 10.2 Selected desirable characteristics for alternate areas

- GEOTECHNICAL
  - Distant from active faults.
  - Low potential for liquefaction.
  - Highly stable slopes.
  - Low erosion potential.
- HYDROLOGICAL
  - Minimal upstream surface-water drainage area.
  - No flooding potential.
  - Favorable geochemical properties; high cation exchange capacity and the presence of iron and manganese oxide adsorbents, high acid neutralization capacity for disposal of acid tailings, and the presence of organic carbon or other chemical reducing agents.
  - Class III groundwater.
  - Upgradient groundwater contamination.
  - Upward vertical hydraulic gradients beneath a low-hydraulic conductivity strata.
- ENGINEERING
  - Close to existing tailings location.
  - Close to borrow materials.
  - Existing transportation network.
  - Favorable topography.
  - Few existing structures.
- ENVIRONMENTAL
  - Distant from critical habitats.
  - Distant from state and national parks.
  - Distant from wildlife refuges.
  - Distant from wilderness and natural areas.
  - Distant from populated areas.

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a]

FACTOR	RANK					WEIGHT	FACTOR[b] SCORE
GEOTECHNICAL	0	1	2	3	4		
1. Land slope	>10%		5 to 10%		2 to 5%	1	
2. Surficial materials lithology	Gravel or sand	Very fine sand or sandy silt	Silt	Silty clay	Clay	2	
3. Surficial materials thickness	0 to 2 ft	2 to 5 ft	5 to 10 ft	10 to 20 ft	>20 ft	1	
4. Distance to nearest seismic risk capable fault[c]	0.5 to 1.0 mi	1 to 5 mi	5 to 10 mi	10 to 20 mi	>20 mi	4	
5. Susceptibility to slope failures, subsidence, or hydroconsolidation[d]	Moderate to high		Low		Very low	4	
6. Present erosion	Intense gullying	Moderate gullying	Minor gullying	Sheet or rill wash	No erosion	4	
7. Geomorphic stability	Very poor (fluvial environment)	Poor	Moderate	Good	Excellent (non-fluvial environment)	4	
8. Conflict with mineral resources	Serious conflicts		Moderate conflicts		No or minor conflicts	1	
9. Relative strength & compressibility of foundation soil & rock (if rock is -4 only)	Very soft or very loose	Soft or loose	Medium stiff to stiff or medium dense	Very stiff or dense	Hard or very dense	4	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Continued)

FACTOR	RANK						
HYDROLOGICAL	0	1	2	3	4	WEIGHT	FACTOR[b] SCORE
10. Well yields are less than 150 gpd (Class III groundwater)	No	---	---	---	Yes	10	
11. Background water quality (TDS in mg/l) and aquifer classification	<1000	1000-2999	3000-4999	5000-9999	Class >10,000	10	
12. Widespread ambient contamination, not due to activities at the processing site, that cannot be treated by public water supply systems	No	---	---	---	Exceed EPA MCLs	5	
13. Upgradient groundwater contamination above EPA MCLs, that affects local background	No	---	---	---	Yes	3	
14. Geologic strata where there is no existing groundwater and the strata are underlain by lithologies of relatively lower hydraulic conductivity	No	---	---	---	Yes	2	
15. Volumetric flux of uppermost aquifer through cross-sectional area under disposal site (gpm). Applies only if Item 10 is "no"	<1	1-10	10-100	100-1000	>1000	5	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Continued)

FACTOR	RANK					WEIGHT	FACTOR[b] SCORE
HYDROLOGICAL	0	1	2	3	4		
16. Geochemical properties of aquifer and subsoils; cation exchange capacity (CEC), acid neutralization capacity (ANC), iron and manganese oxide absorbants (IMOA), and chemical reducing agents	None	Low	Moderate	Medium	High	7	
17. Potential for upward hydraulic gradients below a low hydraulic conductivity stratum	Downward	Neutral	Low	Medium	High	4	
18. Proximity to point of groundwater discharge (ft)	None	<500	500-300	300-100	Toe of pile	4	
19. Depth to groundwater in shallowest aquifer	<20	20-50	50-200	>200	No groundwater underlain by low hydraulic conductivity strata.	3	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Continued)

FACTOR	RANK						
ENVIRONMENTAL	0	1	2	3	4	WEIGHT	FACTOR[b] SCORE
20. Distance to nearest point of groundwater withdrawal from potentially affected aquifer (mi)	On site	0-0.5	0.5-1.0	1.0-2.0	>2	6	
21. Precipitation frequency (events per year of more than 1/8 inch)	>100	100-75	75-50	50-25	<25	2	
22. Total annual precipitation (inches)	>40	40-30	30-20	20-10	<10	3	
23. Annual pan evaporatation (inches)	<40	40-50	50-60	60-70	>70	3	
24. Population density[e]	Site is within one mile boundary of any size city or town.	Site is within one mile of a subdivision.	Site is within one mile of a proposed subdivision or projected residential growth area.	Site is within one mile of scattered private residences.	Site is in an uninhabited area; no residences are within two miles.	4	
25. Transportation network[e]	Traffic congestion very likely, accident potential enhanced.		Traffic congestion likely, accidental potential moderate.		Traffic congestion unlikely, accident potential low.	3	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Continued)

FACTOR	RANK						
ENVIRONMENTAL	0	1	2	3	4	WEIGHT	FACTOR[b] SCORE
26. Presence of cultural[e] or historical sites	Nationally significant cultural sites are known to be present within a two-mile radius.	Cultural sites of minor importance have been found within a one-mile radius.	The area was known to be inhabited in prehistoric times.	The area may have the characteristics for finding cultural sites but none are known to exist within a one-mile radius.	There are no known cultural sites within a two-mile radius, nor is it likely that nationally significant sites would be found.	3	
27. Threatened, endangered, or economically important species[e]	Threatened, endangered, or economically important species are known to inhabit currently the area during any part of the year.	Prior use of the area by threatened, endangered, or economically important species is established although no recent (within five years) sightings within a two-mile radius have been made.	The area contains suitable habitat for threatened, endangered, or economically important species.	The area contains suitable habitat for threatened, endangered, or economically important species; however, similar habitat is abundant throughout the area.	There are no known threatened, endangered, or economically important species within a two-mile radius, nor is the habitat suitable for listed threatened or endangered species.	4	
28. Scenic values[e]	Site has high recreational use or is along the travel corridor to areas frequented by tourists.	Site is clearly visible to the majority of town residents or is visible from area scenic viewpoints.	Site is visible to residents of existing or planned subdivisions.	Site is not visible from high use areas, viewpoints, or populated areas.	Site is not visible to any residents within the city limits, surrounding unincorporated areas, or planned growth areas.	3	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Continued)

FACTOR	RANK						
ENVIRONMENTAL	0	1	2	3	4	WEIGHT	FACTOR[b] SCORE
29. Land use[e]--current	A change in land use would directly affect the livelihood of the owner or surrounding owners.	A change in land use would impact surrounding landowners.	The site would disrupt existing use but suitable, adjacent land could be traded satisfactorily so as not to impact negatively the landowner's economic base.	Current use of the site is considered low in productivity/quality relative to other areas.	A change in land use would have an insignificant effect on the existing or adjacent landowner or user.	4	
30. Land use[e]--potential	The area has potential for higher uses.	Adjacent land is suitable for development; presence of tailings would preclude desirability of other future adjacent land areas.	Land may have potential for development but similarly suitable land is abundantly available in the area.	The area does not have potential for productive use without stimulation or change by humans.	Land has no recognized inherent value or potential.	5	
31. Land ownership	Surface and subsurface rights are owned by multiple, and different, parties.		Surface rights are owned by multiple parties; subsurface rights are owned by a single party.		Surface and subsurface rights are owned by a single party.	6	

Table 10.3 Geotechnical, hydrological, environmental, and economic rating matrix[a] (Concluded)

FACTOR	RANK						
ECONOMIC	0	1	2	3	4	WEIGHT	FACTOR[b] SCORE
32. Distance from existing site	Longest		Moderate		Shortest	7	
33. Distance to potential borrow sites: fine materials/coarse materials	Longest		Moderate		Shortest	2.5/2.5	
34. Existing road network	Poor condition, extensive improvements required.		Moderate condition, some improvements required.		Good condition, no or few improvements required.	3	
35. Road has spots with positive grade from mill site and tailings to disposal site	>10%		8 to 10%		0 to <8%	3	

[a]ft = feet; mi = mile; gpd = gallons per day; TDS = total dissolved solids; gpm = gallons per minute.
[b]Factor score = rank x weight.
[c]Refers to a capable fault as defined by 10 CFR 100, Appendix A.
[d]Determination of susceptibility is based on evidence of recent slope failures, subsurface materials, and subsurface conditions.
[e]If more than one ranking definition applies, site would be ranked for the lowest point value.

REFERENCES FOR SECTION 10.0

CGS (Colorado Geological Survey), 1982. "Preliminary Disposal Site Screening Report for the Grand Junction and Rifle Mill Tailings Piles," Department of Natural Resources, Denver, Colorado.

DOE (U.S. Department of Energy), 1982. Criteria for Evaluating Disposal Sites, UMTRA-DOE/ALO-7, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

EPA (U.S. Environmental Protection Agency), 1986. "Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy," final draft, EPA Office of Ground-Water Protection, Office of Water.

11.0 SITE DESIGN CRITERIA

11.1 PURPOSE

This section documents formats for drawings, specifications, calculations, schedules and cost estimates, and minimum design constraints, and provides the basis or guideline for preparing the final design documentation for UMTRA Project sites. This section is also intended to enable the reader to understand the constraints, procedures, codes, and standards to be used during the design and performance of remedial action at UMTRA Project sites.

Section 11.2, Design Instructions, establishes minimum design and construction requirements for the remedial action. Section 11.3, Environmental Design Criteria, describes the environmental criteria and standards that are required during the remedial action work. Section 11.4, Special Operating Procedures, describes the required communications, documentation, records, drawings, specifications, calculations, and design review procedures. Section 11.5, Specifications, details performance specifications for all construction activities. Section 11.6, Schedules, lists the criteria and instructions for the preparation of required remedial action schedules. Section 11.7, Cost Estimates, describes the estimating requirements and Section 11.8, Quality Assurance, discusses the necessary project quality assurance criteria.

11.2 DESIGN INSTRUCTIONS

11.2.1 General instructions

The design criteria have been developed for use as a guide for the detailed design. In no instance are they to be interpreted as precluding good engineering judgement and accepted professional procedures.

The design engineer shall examine the site-specific conceptual design and these criteria prior to initiation of the detailed design. In addition, the design engineer is referred to the Plan for Implementing EPA Standards for UMTRA Sites (DOE, 1983) for additional understanding of the design criteria. The design engineer shall not proceed with the detailed design of a particular aspect of the conceptual design until all questions regarding that aspect of the design have been resolved, except where resolution will not substantially affect the design. The design engineer shall examine the available data relative to a particular site and shall bring any additional data needs to the attention of the UMTRA Project Office in a timely manner.

11.2.2 Design features

General

These criteria are developed to permit the design and construction of a remedial action that will ensure compliance with the EPA standards as well as the environmental design criteria stated in Section 11.3.

The following sections discuss major features of remedial action construction. The RAC will address those items applicable to a specific site in developing detailed designs for that site. Further design instructions may be developed on a site-by-site basis and will be included in the site-specific RAPs.

Stabilized embankment system

The stabilized embankment is defined as a pile of tailings and other contaminated materials covered with clean earthen material to provide isolation and stabilization. The tailings include any existing pile of tailings, which will be relocated or reshaped and stabilized in place (depending on the appropriate remedial action), and any relocated tailings from windblown areas and vicinity properties. Other contaminated materials may include wood, organic debris, or demolition debris that may or may not be contaminated. The cover generally will consist of a multilayer system of uncontaminated earthen materials with several functions as described in the following section. The following describes the basic criteria for the embankment system.

a. Purpose of the stabilized embankment system

The primary objectives for design of the stabilized embankment are (1) isolation and stabilization of the tailings and contaminated materials to prevent their misuse by humans or dispersion by natural forces such as wind, rain, and flood waters; (2) reduction of radiation emissions from the tailings pile; and (3) control seepage of contaminants to the extent required to achieve compliance with the groundwater protection standards.

b. Area

A preliminary estimate of the quantity of material to be placed in the stabilized embankment system for a specific site is determined during site characterization activities. The stabilized embankment system, as depicted in the conceptual design documentation, has been sized to contain this estimated quantity of contaminated materials. The area and volume of the embankment may be

increased or decreased as necessary, consistent with good engineering practice, the quantity of contaminated material, the economics of construction, and the availability of land. The embankment system shall not expand into or move to areas outside the designated site, or onto floodplains or other areas that may reduce the performance of the remedial action without prior written approval from the UMTRA Project Office.

c. Slopes

Maximum and minimum slopes for the stabilized embankment and cover are designed to assure slope stability and to minimize subsidence and erosion during the design life of the embankment.

The maximum design slope for the entire embankment shall not exceed one vertical to five horizontal (20 percent) unless otherwise specified in the RAP. The minimum design slope for the embankment and cover shall be sufficient to promote drainage and prevent ponding. Corners, peaks, and other changes in direction shall be contoured and rounded to minimize erosion and present a natural appearance.

d. Distribution of tailings and other wastes

Prior to placing the cover over the tailings, other materials such as wood, organic debris, or demolition debris may be placed within the tailings embankment. At specific sites where large amounts of debris require disposal, the debris may be placed in a separate area within the designated site but outside the embankment. Relocated tailings and other materials shall be distributed and placed within the stabilized embankment, to the extent practicable, in such a manner as to perform the following:

- Minimize differential settlement.
- Reduce radon emanation.
- Control the upward migration of contaminants by capillary action.
- Withstand the destructive forces of a Maximum Credible Earthquake.

If wood or other organic debris is placed within the embankment, it shall be chipped or otherwise reduced in size. The debris shall then be distributed throughout

the lower portion of the tailings so as not to exceed five percent by volume in any lift or layer; this distribution will minimize differential settlement.

If demolition debris is placed within the stabilized embankment, larger pieces of debris such as metal, stone, or concrete shall not be nested. The debris shall be placed in layers, and tailings shall be tamped or otherwise compacted within and around individual pieces to prevent voids and minimize differential settlement.

Typically, tailings exist in two physical forms as either sands or slimes. Sands consist of material containing a relatively small percentage of particles passing through a No. 200 sieve. Slimes consist of material containing a relatively large percentage of particles passing through a No. 200 sieve. Tailings that consist primarily of sands contain less radium than slimes. Since radon emanation is primarily dependent upon radium content, it is desirable to construct the upper portion of the tailings embankment of sands.

During tailings relocation, it is beneficial to place tailings containing significant proportions of slimes in the lower levels of the embankment. To the extent practicable, contaminated materials containing a significant portion of slimes should not be placed within six feet of the radon barrier. Pockets of slimes that are to be relocated during construction should be mixed with sand tailings to produce a more homogeneous material.

e. Cover

The cover shall be designed to retain its integrity for up to 1000 years, to the extent reasonably achievable, and in any case for at least 200 years. The cover shall be designed as a barrier to perform the following:

- Limit infiltration.
- Effectively minimize the potential for misuse and spread of the contaminated materials.
- Limit the average radon emission from the surface of the embankment to no greater than 20 pCi/m^2s.
- Protect against the effects of flooding.
- Protect from wind and water erosion.

Primarily, the cover will act to attenuate both radon emanation and water infiltration. Moisture in cover materials is desirable for radon attenuation. However, water passing through the cover, into and through the contaminated materials, and into the groundwater is undesirable. Compaction and other cover design criteria are designated to provide a balance between the moisture content in the cover and water infiltration through the cover and into the contaminated materials. (For more details, refer to DOE, 1983.)

The cover shall normally be constructed of earthen materials. The radon attenuation and water infiltration characteristics of the cover materials are a function of soil properties, construction methods, and thickness. Soil conditions that provide the best radon attenuation characteristics do not necessarily provide the best water infiltration characteristics. For each site, a potential source of cover material will be identified and used as a basis for cover thickness design in the RAP. Alternate sources of earthen material may be used for the cover provided that adequate analyses and cover design calculations are submitted to and approved by the UMTRA Project Office.

f. Erosion protection

A primary criterion established by the EPA standards is the longevity of the effectiveness of the remedial action. Therefore, the cover shall be designed to (1) withstand the effects of flooding, and (2) protect from wind and water erosion. Criteria used for design analysis shall be the PMP and PMF unless otherwise specified in the RAP. To accomplish this, the radon barrier shall be covered with a layer of rock or vegetated soil. The thickness and other design features of the erosion protection cover are discussed in site-specific RAPs.

g. Restoration

Portions of a site outside the stabilized embankment may be excavated to varying depths below the natural grade to remove contaminated material. Subsequently, these areas shall be restored with soil to natural grade (or as specified in the RAP), contoured to provide positive drainage, and revegetated to the extent reasonably achievable.

Placement and compaction

The following provides criteria for the placement and compaction of earthen materials. Other compaction requirements may be

used with DOE approval. These criteria are designed to demonstrate the quality of compaction which is appropriate and should be used as a guide.

a. Structural fill

Structural fill to be placed below any portion of the embankment to establish a subgrade elevation shall be compacted to produce a relatively incompressible soil mass. To achieve this, the fill shall be placed and compacted to a minimum of 90 percent of the maximum dry density as determined by the standard Proctor method (ASTM D698). If the fill is to be placed and compacted immediately adjacent to and abutting lower-density existing soils, the existing soils shall be reworked or the structural fill shall be placed in such a manner so as to minimize the potential for differential settlement.

b. Contaminated material

If existing undisturbed tailings are resting at a slope of greater than one vertical to five horizontal (20 percent), the surface of the slope shall be scarified, benched, or otherwise disturbed prior to placing material immediately adjacent to and abutting the slope. Tailings or other contaminated materials that are relocated or otherwise disturbed shall be placed in lifts or layers not to exceed 12 inches in thickness and shall be compacted to a minimum of 90 percent of the maximum dry density as determined by the standard Proctor method (ASTM D698) at a moisture content below optimum.

c. Radon/infiltration barrier

Radon barrier materials shall be placed in loose lifts or layers (not to exceed 12 inches) and compacted to a minimum of 95 percent of the maximum dry density and, where practicable, at optimum to three percent above optimum moisture content as determined by the standard Proctor method (ASTM D698).

Other radon barrier placement and compaction criteria may be used provided that such criteria are approved by the DOE and result in a permeability or radon diffusion no greater than that specified in the RAP.

d. Erosion barrier

Rock erosion barriers shall be placed and graded in such a manner as to form a uniformly distributed, dense, compact mass. Vegetated cover soils will be of proper texture and sufficient thickness, and placed at an optimum

density to serve as a rooting medium for a climax community of vegetation.

e. Riprap

Riprap may be required on the site for flood protection or specific drainage features. The riprap, when placed, is not to be compacted, but shall be dumped and graded in such a manner as will ensure that the rocks are uniformly distributed in size to form a dense, compact mass.

f. Restoration material

Restoration material shall be placed in loose lifts or layers (not to exceed 12 inches) and compacted to a minimum of 90 percent of the maximum dry density as determined by the standard Proctor method (ASTM D698).

Revegetation

During remedial action, portions of a site may be disturbed and vegetation destroyed. The site cover and all areas where vegetation has been destroyed shall be revegetated as specified in the site-specific RAP. Where revegetation is required, the top six to 12 inches of soil shall not be compacted and shall be prepared with adequate organic substance, fertilizer, or other materials necessary to promote vegetation. The area shall be seeded with hardy native grasses. Trees, shrubs, or other deep-rooted vegetation shall not be planted unless otherwise specified.

Irrigation

Long-term permanent irrigation will not be part of the remedial action; however, temporary irrigation may be desirable in order to establish vegetation. Where temporary irrigation is required, the system shall be totally above ground and readily removable without excavating or otherwise significantly affecting the integrity of the cover.

Existing utilities

Existing utilities within the proposed final disposal site must be relocated or decommissioned to preclude any future need for excavation or access within the disposal site. Any active utility system shall be relocated to prevent its passing under, over, or through the site. The relocated system shall conform to current applicable standards. Any abandoned system or portion of a system passing through or under the stabilized embankment which has a capacity to produce a void shall be removed, crushed, or filled with a nondegradable material.

Water distribution

During construction activities, temporary water systems may be required to supply potable, dust suppression, and compaction water. To the extent available, storm water and any water from dewatering of tailings and near-surface material shall be used for dust suppression and compaction. The potable water distribution system shall be designed and constructed in accordance with minimum Federal, state, and local codes. Upon completion of the remedial action, temporary systems shall be removed.

Wastewater

During construction activities, personnel will be associated with residual radioactive materials and may become contaminated. Wash basins and showers shall be provided for personnel decontamination (DOE, 1985). Portable construction toilets may be used for sanitary facilities. Wastewater and sanitary waste facilities shall be designed in accordance with minimum Federal, state, and local codes (see Section 11.3).

Health physics support

Occupational and environmental monitoring programs shall be designed by the RAC in accordance with the procedures and limits presented in the UMTRA Project Environmental, Health, and Safety Plan (DOE, 1985). These programs shall be implemented and maintained by the RAC or its subcontractors during construction operations.

Fencing

During the construction period, temporary fencing may be required to ensure site security. If there is existing fencing around portions of the site, all or part of it may be used if it is in good condition. In general (near populated areas), the temporary fencing shall be a six-foot-high chainlink fence with gates installed at appropriate locations. At sites in remote areas, other types of fencing may be used with DOE approval. Work areas shall be posted in accordance with the environmental, health, and safety plan section of site-specific RAPs.

Monitor wells

Some of the existing monitor wells may be preserved during construction for use as monitor wells after completion of the remedial action. These wells shall be identified by the DOE prior to construction. Existing wells that are to be abandoned shall be plugged or capped in conformance with applicable regulations.

Where it is not possible to preserve existing wells, or where additional wells may be required, new monitor wells shall be installed following completion of construction. Wells shall be completed in accordance with the maintenance and surveillance plan (DOE, 1986a).

Buildings

Buildings that shall remain on the site after the completion of remedial action shall be decontaminated to meet the limits specified in the UMTRA Project Environmental Health and Safety Plan (DOE, 1985), and to follow the guidance of the radiological support plan section in site-specific RAPs.

11.2.3 Codes and standards

The RAC shall follow local and national codes and standards during design and construction. These shall include, but are not limited to, the following codes and standards in effect at the completion of design.

AASHTO	American Association of State Highways and Transportation Officials
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
ACI	American Concrete Institute
CFR	Code of Federal Regulations, as applicable (e.g., 10 CFR, 29 CFR)
DOE	DOE Order 6430 - General Design Criteria Manual
DOL/OSHA	Department of Labor/Occupational Safety and Health Administration
NEC	National Electrical Code
UBC	Uniform Building Code
UL	Underwriters Laboratory
UPC	Uniform Plumbing Code

In addition to the above list, any other applicable city, county, state, tribal, and Federal codes and regulations shall

also be followed. In the event of a conflict, the most stringent code shall apply.

In addition to the codes and standards listed, the designer is referred to specific DOE documents such as the UMTRA Project Environmental, Health, and Safety Plan (DOE, 1985); the UMTRA Project Quality Assurance Plan (DOE, 1986b); and the Plan for Implementing EPA Standards for UMTRA Project Sites (DOE, 1983).

The RAC shall have ready access to the applicable codes and standards at all times. Specific codes with the date of issue and other identification shall be referenced in contract documents.

11.3 ENVIRONMENTAL DESIGN CRITERIA

11.3.1 General instructions

The following is a discussion of the environmental design criteria that shall be incorporated into the RAC's final design in order to comply with regulatory requirements for construction at the site. In addition, the site-specific RAPs stipulate the reviews, approvals, and permits to be acquired prior to initiation of construction.

11.3.2 Wastewater control and discharge

Site grading

All construction activities shall be planned and conducted to minimize, to the extent practicable, disturbance and contamination of uncontaminated land. All new work shall be stabilized as soon as possible after final grading is completed.

The site shall be graded such that contaminated storm water runoff from the disturbed site is controlled and will drain to a single, or system of, wastewater retention basin(s). Runoff from off-site areas shall be diverted away from and around all disturbed areas.

Diversions and channels of conveyance for overland flow shall be designed to meet all Federal and state requirements applicable to the specific site. As a minimum, the sediment control measures, diversions, and channels of conveyance shall be designed in accordance with the "Permanent Program Performance Standards--Surface Mining Activities," Part 816, Subchapter K, as established by the Office of Surface Mining (DOI, 1982).

Wastewater retention basins

All water produced on the site during construction activities shall be collected and treated as required prior to discharge.

This includes rainfall, dewatering water, seepage, and all other sources of water. These waters shall be collected in a basin or system of basins and either evaporated or treated to the extent necessary to meet National Pollutant Discharge Elimination System (NPDES) discharge limits, if applicable, prior to discharge to a natural waterway.

The basins shall be designed to meet all Federal and state requirements applicable to the specific site. As a minimum, the wastewater retention basins shall be designed in accordance with the "Permanent Program Performance Standards--Surface Mining Activities," Part 816, Subchapter K, as established by the Office of Surface Mining (DOI, 1982).

Basins shall have emergency outlets designed such that any flow will enter a natural waterway at a location where the projected elevation of the outlet structure will allow for free drainage. Sediment shall be removed from the basins when the volume of sediment accumulates to 60 percent of the design sediment storage volume. Dredged sediments shall be added to the stabilized embankment.

Secondary wastewater treatment

Wastewater may be generated from the following sources:

- Groundwater collected from any necessary excavation dewatering.
- Storm water runoff.
- Decontamination water from equipment washdown.
- Laundry waste from washing protective clothing.
- Shower and wash basin wastewater.

Wastewater from these sources will flow to the wastewater retention basin, which shall provide primary settling as well as flow and contaminant equalization. This water may be utilized for road and pile wetdown, dust and radon emanation control, and compaction. The remainder shall be either evaporated or treated to meet the established NPDES discharge limits (Table 11.1) prior to discharge to a natural waterway. These limits (as stated in 40 CFR 440.32) should be used until the site-specific NPDES discharge limits have been established by the appropriate regulatory agency.

The wastewater treatment facility, if required, shall be designed to treat a maximum of 125 percent of the calculated average daily quantity of water to be discharged. Suspended solids and other contaminated materials from the water treatment

Table 11.1 NPDES discharge limits

Effluent characteristic[a]	Effluent limitation: Maximum for any 1 day	Effluent limitation: Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
COD	200	100
Zn	1.0	0.5
Ra-226[b] (dissolved)	10	3
Ra-226[b] (total)	30	10
U	4	2
pH	c	c

[a]TSS = total suspended solids; COD = chemical oxygen demand.
[b]Values in picocuries per liter (pCi/l).
[c]Within the range of 6.0 to 9.0.

facility shall be disposed of with other contaminated material on the site.

The performance specifications for the treatment unit shall be detailed by the RAC for construction by an experienced manufacturer. The system shall include automatic controls as required, be weatherproof, and not require an enclosure. After completion of the remedial action, if possible, the treatment system shall be decontaminated and salvaged for reuse.

11.3.3 Fugitive emissions

Fugitive dust

Dust generated by earth movement, vehicle use, stockpiling, and similar activities shall be controlled and minimized. Special emphasis shall be placed on controlling dust that will originate from building decontamination, excavations, temporary stockpiling, or mixing of contaminated materials.

Dust control measures such as water sprayed under pressure, with a water-based surfactant (if necessary), shall be used to control dust. In addition, hoses shall be available for each area of excavation and at the staging area. The source for dust-suppression water shall include impounded tailings water, runoff, and/or potable water. Recycled water shall be used for nondomestic purposes as much as practicable.

Combustion products

Storage, vehicles, and equipment shall comply with state standards for such equipment and products.

11.3.4 Transportation of tailings and borrow material

Vehicles used to haul tailings or other contaminated materials on public thoroughfares shall be securely covered (by a tarp, canopy, or other approved method). Truck bed openings shall be sealed to prevent leakage in transit and the resultant spread of contaminated material. Vehicles designated for the transport of contaminated materials shall not be used to transport uncontaminated material without prior decontamination, as necessary.

To prevent tracking of contaminated materials off the site and to minimize dust generation, a paved decontamination pad shall be designed. This shall be used to drop or wash off any residual tailings or borrow materials that adhere to the exterior of the vehicles. The paved area shall be equipped with a high-pressure hose or spray, wash area, and monitoring equipment (DOE, 1985).

Wastewater from the decontamination pad shall drain to a holding tank, be transported to the basin(s) (Section 11.3.2), or drain to sedimentation basins. The paved area shall be cleaned on a regular basis.

The final routes selected for the transport of tailings or borrow material shall, to the extent possible, avoid areas of extreme congestion, minimize interference with daily commuter traffic, and minimize adverse impacts to roadways and to the health of area residents.

11.3.5 Noise

Noise levels resulting from construction activities shall be minimized by the use of mufflers on all vehicles and combustion-engine equipment. Noise levels shall be in compliance with local, state, or Federal regulations.

11.4 SPECIAL OPERATING PROCEDURES

11.4.1 Communications

The RAC shall initiate and maintain an effective flow of communication in accordance with contract requirements with the DOE throughout the life of the UMTRA Project. A proposed plan for distribution of project communications shall be submitted to and approved by the UMTRA Project Office. Types of communications include, but are not limited to:

- Letters.
- Memoranda.
- Technical reports.
- Telephone conversation records.
- Conference notes or meeting notes.
- Project status reports.
- Schedules.
- Bid documents.
- Design reviews.
- Daily inspection logs.

11.4.2 Documentation

The RAC shall fully document the project by developing project notes and status reports, and maintaining personal diaries, in addition to formal correspondence, computations, and drawings. All documents and records shall be signed or otherwise authenticated by the originator or by another authorized person. All engineering drawings, specifications, and calculations shall be certified and sealed by a professional engineer registered in the subject discipline.

11.4.3 Records

The RAC shall develop and submit for approval an effective recording and filing system for all communications, documents, and records generated during the remedial action program. This system shall allow ready access and retrieval. After approval, the system shall be maintained in a current status and available for audit upon request.

11.4.4 Drawings

General

Plans, sections, layouts, and details shall be effectively designed and arranged to complete the proposed design efficiently.

Each set of drawings shall include a title sheet, vicinity map, site plan, index of sheets, plot plan, grading plan, and such profiles, sections, details, sketches, notes, and other features as necessary to carry out the remedial action. The title sheet shall be formatted as shown in Figure 11.1. Each drawing is to be uniquely and sequentially numbered, certified by a registered professional engineer, and prepared with a fully executed title block.

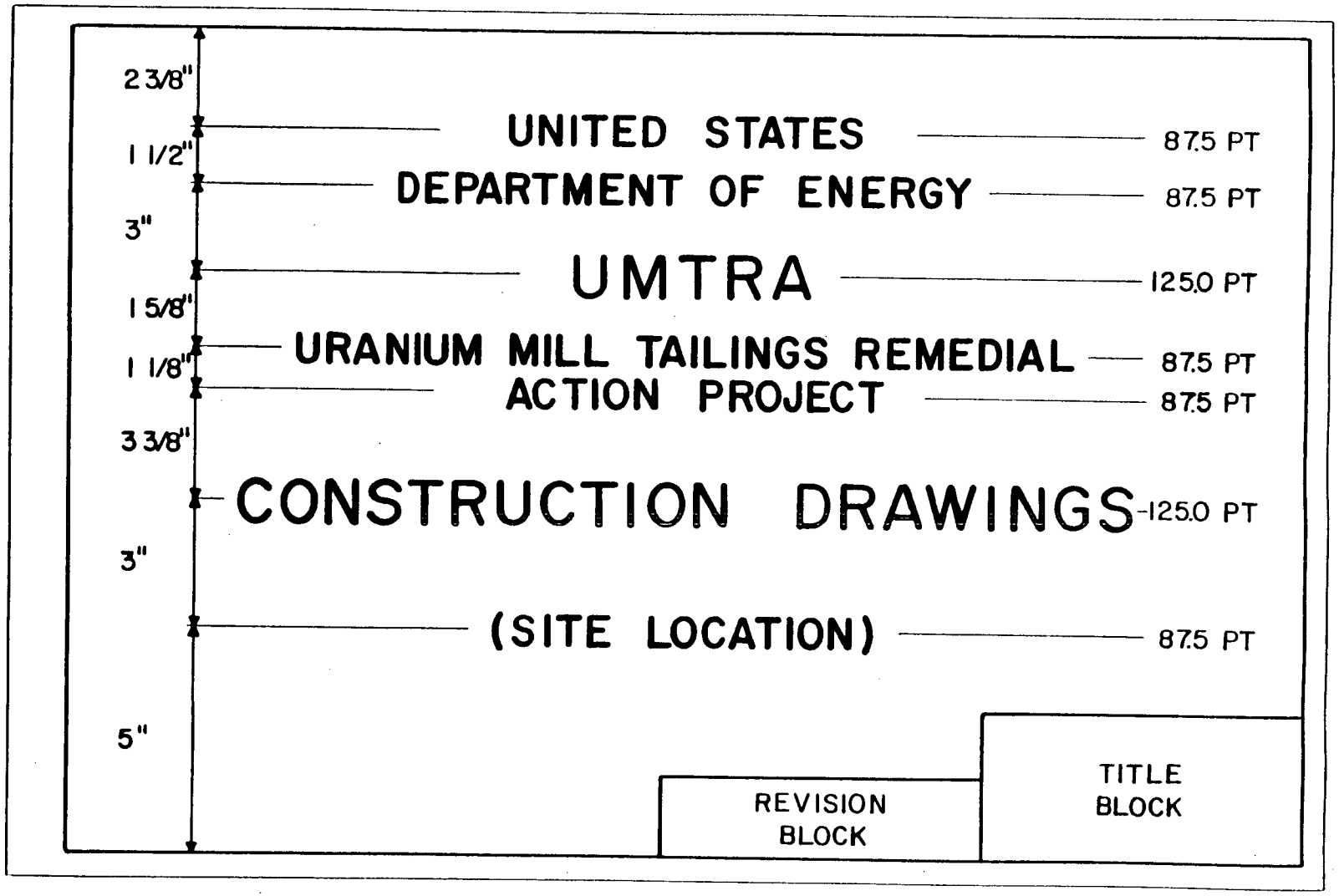

FIGURE 11.1 FORMAT FOR TITLE SHEET

Medium and quality

All drawings shall be of a level of detail and quality suitable for reproduction by microfilming. Original drawings shall be prepared on three-mil, matte, one-sided Mylar or equivalent using black ink or highlighting materials.

Format

The following format criteria shall be used:

a. Sizes

The following sizes shall be used.

A Size: 8-1/2" x 11"--may be used for sketches and graphs.

B Size: 11" x 17"--shall be used for reduced copies of drawings.

D Size: 22" x 34"--shall be used for all full-sized drawings.

Margins are defined on Figures 11.2 and 11.3.

b. Orientation

The format arrangement shall be as shown on Figures 11.2 and 11.3.

All plan views shall indicate north. North shall be oriented to the top, 45° to the left of the top, or left of the sheet. A north arrow shall be placed on all plan sheets in the top right-hand quarter of the sheet.

Graphic scales shall be oriented in the lower portion of the drawing near the title block.

General and construction notes shall be placed on the right-hand side of the drawing starting from the top of the sheet. This portion of the drawing shall be reserved for this purpose.

c. Title blocks

The title block for drawing size D shall be 8-1/4" x 3-5/8". Drawing sizes A and B shall have title blocks measuring 4" x 1-7/8" (60 percent of the size D title block). The title block shall be in strip form as shown in Figure 11.4. The RAC or subcontractor name, location, and other identification shall occupy the bottom left

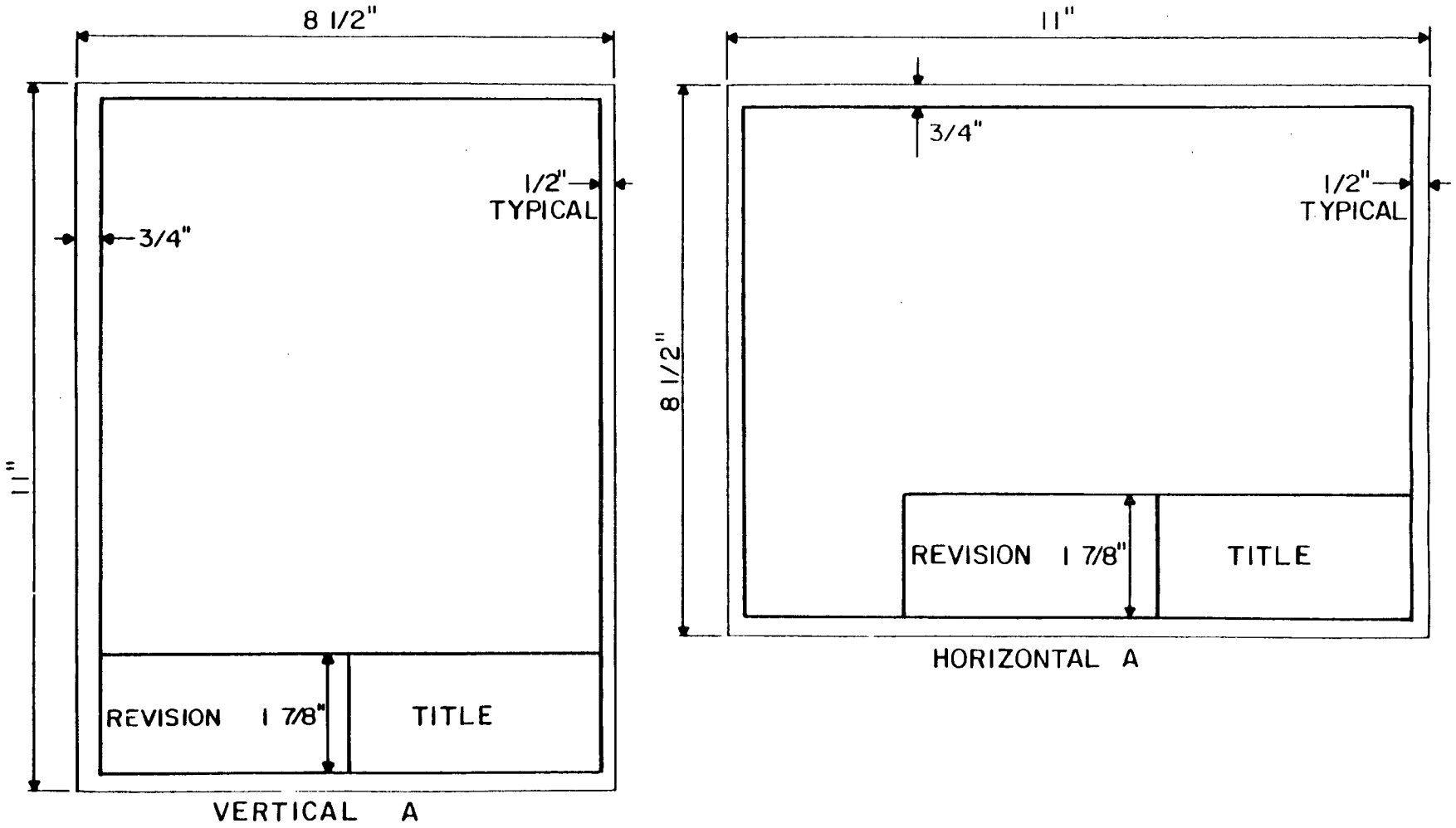

FIGURE 11.2 FORMAT FOR "A" SIZE SHEET

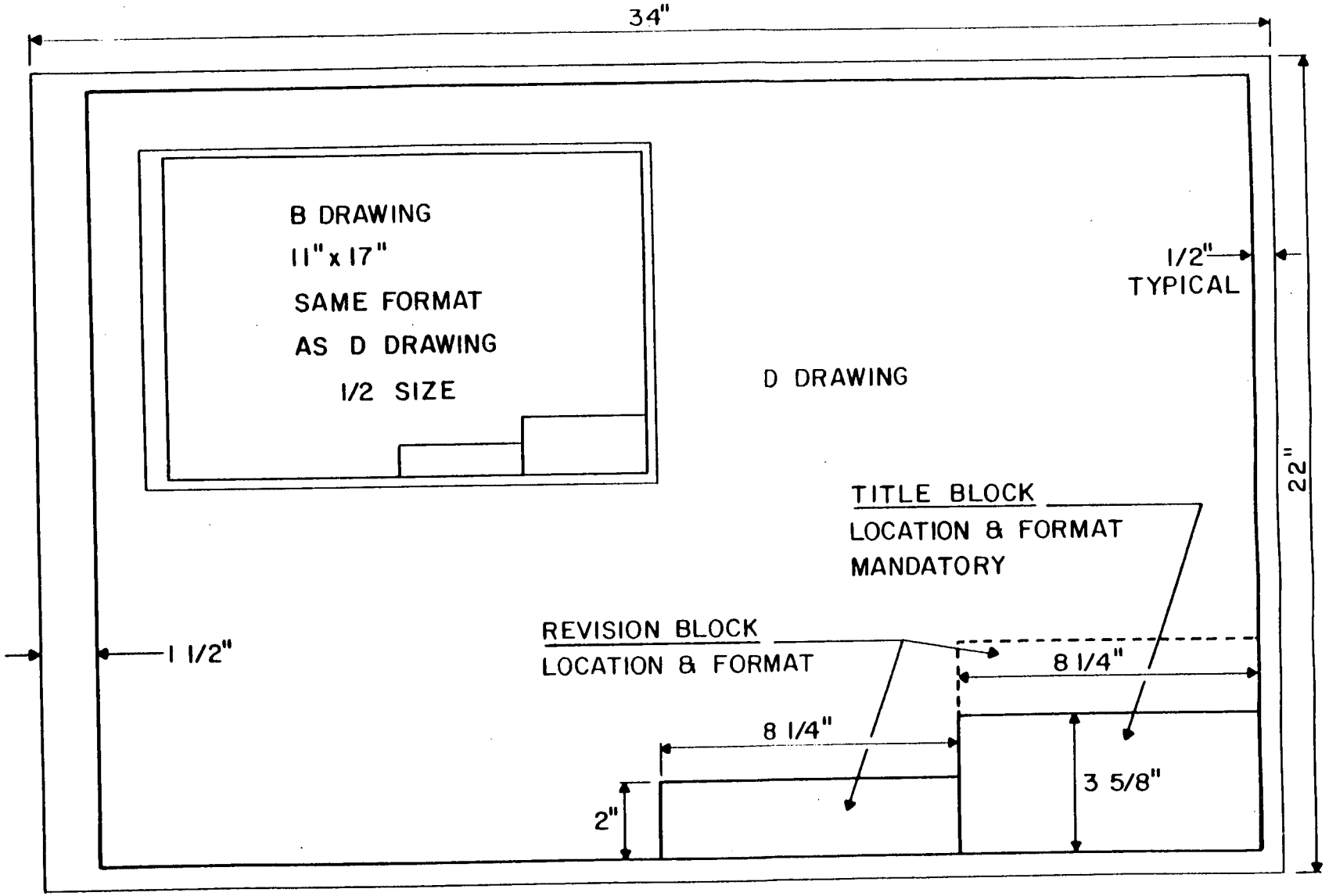

FIGURE 11.3 FORMAT FOR "B" & "D" SIZE DRAWINGS

TO REFLECT CONTRACTOR'S
QUALITY ASSURANCE PROCEDURES

U. S. DEPARTMENT OF ENERGY ALBUQUERQUE, NEW MEXICO					
	TITLE SHEET				
	DATE	DOE PROJECT MANAGER	DATE	DOE ENGINEER	DATE
CONTRACTOR IDENTIFICATION	PROJECT NO.				
	DRAWING NO.				REV.

FIGURE 11.4 EXAMPLE OF STANDARD TITLE BLOCK

block. Lettering used in the title block is optional as long as it is a block letter and meets the point size for the top block as shown in Figure 11.4.

d. Revision block

All drawings shall contain a revision block in strip form as shown on Figure 11.5. For size D drawings, the block shall be at least 8-1/4" x 2" with six lines as shown on Figure 11.5.

e. Drawing numbering system

The RAC and any subcontractors with design responsibilities shall use the following standard drawing numbering system for processing sites and disposal sites:

XXX-PS-10-0000 or XXX-DS-10-0000

The first three letters identify the tailings location (e.g., CAN for Canonsburg); the second two letters identify either the processing site (PS) or the disposal site (DS). The two-number group shall be 40 for the Technical Assistance Contractor (TAC) and 10 for the RAC. The last four-digit group is for the sequential numbering system of the drawings.

The following applies to the numbering system:

- Letters shall be upper case.
- Letters "I," "O," "Q," and "X" shall not be used.
- Numbers shall be whole arabic numerals; fractional, decimal, and Roman numerals shall not be used.
- Blank spaces shall not be used.
- Symbols such as (), *, and / shall not be used.
- The drawing revision letter or number shall not be considered as part of the drawing number.

11.5 SPECIFICATIONS

The design engineer shall develop performance specifications for all construction activities in sufficient detail to control the quality of the construction. The design engineer shall develop purchase specifications for all work, equipment, and materials in sufficient detail to support competitive procurement. Specifications shall be prepared in accordance with the format provided by the Construction Specifications Institute (CSI) and the guide specifications provided in the Guide Specifications

NO.	DATE	REVISIONS	BY	CK	ENG.	APP.

FIGURE 11.5 EXAMPLE OF STANDARD REVISION BLOCK

Attachment of this document. In the event of a conflict between the CSI format and the Guide Specifications Attachment format, the Guide Specifications Attachment format shall prevail.

11.5.1 Calculations

The design engineer shall prepare calculations and rationale for design decisions for all design items in sufficient detail to support the design. Such design calculations and analyses shall be bound and submitted for preliminary review at the completion of preliminary engineering. Final design analyses and calculations shall be submitted at the completion of final design. Preliminary engineering designs and calculations may reflect calculations of a preliminary nature or to that level of detail completed at the time of submission; the scope of incomplete data shall be identified. Final design calculations and design analyses shall be complete.

11.5.2 Design reviews

Purpose

To ensure that the detailed design and construction is in compliance with the approved RAP and applicable standards, as well as to promote an efficient remedial action program, the RAC shall submit plans, drawings, specifications, design analyses, and calculations for review and comment as set forth below. The reviews described in these criteria shall serve as minimum requirements.

Preliminary design

The RAC shall review the approved conceptual design presented in the draft site-specific RAP and present the design at the 30 percent design level to the DOE and TAC at an on-board meeting. At this meeting, the RAC shall present any proposed changes to the conceptual design with reasons for the changes. All comments at this review shall be informal; no formal review comments will be submitted unless requested at the meeting by the DOE, RAC, or TAC and approved by the DOE.

If any significant modifications have been made to the conceptual design, they shall be resolved at the on-board meeting.

Draft design

The RAC shall prepare the site-specific draft design, including drawings, specifications, and calculations, which shall be submitted for review and comment when the total design is approximately 60 percent complete. The design will also be submitted to

the NRC and any reviewing state or tribal agencies at the same time.

Design and analysis documents submitted to the DOE for review shall be accompanied by a transmittal sheet listing all documents submitted. Each transmittal sheet shall list the document number, title, revision number or letter, and quantity sent. Documents shall be signed and dated when issued for review and approval. Submittals shall contain at least one reproducible plus four copies of each document. Review documents shall be full-sized.

All comments will be returned to the RAC for resolution and/or incorporation into the design. The comments documentation, along with a record of the deposition of the comments, shall be retained by the RAC for historical record.

Final design

When final design is approximately 90 percent complete, drawings, specifications including special conditions and technical provisions, and other documents shall be submitted to the DOE for approval. Submittals for approval shall be in the same format and number as stated for the draft design. Individual documents or sets of related documents may be submitted when complete. The document shall be resubmitted for review, as necessary, until the document is returned as "approved" or "approved as noted." The design progress shall be considered complete when design documents submitted for approval have been approved by the DOE. Design or field changes to design during construction require similar program approvals for any change that deviates from the approved RAP.

Bid document review

Once the 90 percent design comments have been resolved, the RAC shall prepare the bid documents and submit them to the DOE and TAC for final review. The bid documents shall constitute a 100 percent design ready for DOE approval for bid. Any comments by the TAC or the DOE shall be resolved in the most expeditious manner possible.

Any amendments to the bid documents shall also be subjected to the same review process regardless of their significance to the design.

As-built

Upon completion of the construction activity, the RAC shall update drawings, specifications, and all other documents to reflect the final as-built condition of the project. Reproducible

copies of each as-built document, of suitable quality for microfilming, shall be submitted to the DOE.

11.6 SCHEDULES

A planning schedule for the remedial action shall be provided in the site-specific conceptual design.

The RAC shall prepare schedules for engineering and construction activities in a form acceptable to the DOE. The schedules shall show sufficient detail to allow the DOE to monitor progress of all engineering and remedial actions for the processing site. The schedules shall identify significant work items and shall identify scheduled completion dates for the work items.

Significant site-specific status information shall be provided to the DOE in a weekly status meeting. Additionally, the RAC shall provide comprehensive site schedule status information on actual completion dates and percentage of work complete for all schedule work items in a format established by the DOE on a monthly basis. Overall RAC activities shall be reported in the Monthly Status Report as required in accordance with Exhibit C of the RAC's contract. Additionally, daily logs of construction activities shall be developed and maintained on the construction site by the RAC and shall be available for DOE review.

11.7 COST ESTIMATE

A planning estimate of the remedial action cost shall be provided in the site-specific conceptual design. This estimate shall be consistent in the format of the Site Cost Estimate Summary utilized in the UMTRA Project Schedule and Cost Estimate Report.

The RAC shall prepare a preliminary and a final definitive estimate for all site and remedial action work required based on the RAP, and other available information. The estimate shall provide the estimated cost for scheduled work items at a level of detail sufficient to identify the labor, material, and equipment costs associated with the work items. The estimate shall also identify, as separate items, the anticipated construction management costs for the site activities.

11.8 QUALITY ASSURANCE

The RAC shall prepare a quality assurance (QA) plan that complies with guidelines established in the UMTRA Project Quality Assurance Plan (DOE, 1986b).

The RAC shall provide and maintain an effective plan and procedural system to ensure that all work, materials, supplies, and services required shall conform to UMTRA Project requirements, whether constructed or processed by the RAC or its subcontractors or vendors. The RAC shall

perform, or have performed, adequate inspections and tests as will ensure and substantiate that all designs, materials, supplies, and services conform to UMTRA Project requirements.

The RAC shall furnish a QA test and inspection plan for each site that defines the activities to be incorporated into the design and/or performed during construction to ensure UMTRA Project compliance and site certification. Test and inspection plans shall be subject to approval by the DOE prior to the start of construction work. If the RAC revises the plan, the RAC shall concurrently furnish a copy of the changed plan to the DOE for approval prior to implementation.

REFERENCES FOR SECTION 11.0

DOE (U.S. Department of Energy), 1986a. Guidance for UMTRA Project Surveillance and Maintenance, UMTRA-DOE/AL-350124.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1986b. UMTRA Project Quality Assurance Plan, UMTRA-DOE/AL-185, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1985. UMTRA Project Environmental, Health, and Safety Plan, UMTRA-DOE/AL-160224.0006, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1983. Plan for Implementing EPA Standards for UMTRA Project Sites, UMTRA-DOE/AL-163, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico

DOI (U.S. Department of Interior), 1982. Surface Mining Water Diversion Manual, OSM/TR-82/2, Office of Surface Mining, U.S. Government Printing Office, Washington, D.C.

ATTACHMENT TO SECTION 11.0

GUIDE SPECIFICATIONS

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1.0 GENERAL INSTRUCTIONS

1.1 INTRODUCTION

This appendix contains instructions and recommendations that shall serve as a guide for preparing specifications for remedial action construction.

To the extent practicable, the specifications shall be prepared using the format and numbering system designed and developed by the Construction Specifications Institute (CSI) and are to be obtained from their current SPECTEXT library.

The SPECTEXT sections are categorized into sixteen divisions. Division 1 defines the general requirements and directly controls the content of Divisions 2 through 16. The CSI SPECTEXT sections have been developed as an "edit and delete" type of master guide text to be used for various types of projects.

The CSI specifications have not been developed and published for all aspects of the remedial action construction. However, it is intended that UMTRA Project specifications be developed using the CSI specifications for format and as a checklist or guide. The text for the specifications shall be developed from information contained in the Project Site Design Criteria and site-specific site conceptual designs, and as developed during design.

In addition to the instructions that follow, the remaining sections in this attachment include a recommended list of SPECTEXT sections, a series of comments on specific sections, and an example of a typical specification that will assist in developing the project specifications. Use of specific SPECTEXT sections included in Section 2.0 are not mandatory, but are intended to serve as a guide.

1.2 CSI SPECTEXT DIVISIONS

1.2.1 Division 1 - general requirements

Division 1 sections specify:

- Administration Requirements: Such as identification of construction contractor (or contractors), contractor and owner responsibilities in use of construction site, allowances, description of alternates, coordination of work, and progress meetings.

- Procedural Requirements: Such as submittals, quality control, inspection and testing requirements, record documents, and contract closeout procedures.

- Temporary Facilities and Controls: Such as construction facilities and temporary utilities provided by the contractor, or by the owner.

Division 1 sections must be closely coordinated with other elements of bidding and contract documents, and the relationships defined by references as shown in the following:

- Bidding Requirements: The user should refer to Division 1 sections to incorporate procedures in Division 1 which apply during the bidding period, such as contractor's options in selection of products, procedures for consideration of substitutions, and descriptions of alternates and unit prices.

- Conditions of the Contract: Division 1 sections expand administratively and procedurally on statements in general conditions, and may use references to general conditions to assure coordination with its particular requirements. The published sections rely on provisions of the published general conditions of the American Institute of Architects (AIA) and of the Engineers Joint Contract Documents Committee (EJCDC). When other general conditions are used, the specifier must edit these Division 1 sections to adapt the text to any differing provisions in the general conditions used for the project.

- Sections of Division 2-16: The user should refer to Division 1 sections to incorporate those administrative and procedural requirements which directly control content of the section, such as the monetary amounts of allowances, submittal procedures, inspection and testing procedures, and closeout procedures.

- Drawings: Close coordination will be required between drawings and administrative procedural sections of Division 1 which define scope of alternates, limits of work of separate contracts, work sequence or phased construction, limitations on use of site, and owner occupancy.

To avoid overspecifying, the user should be continuously alert to the scope of project needs, regional variations in construction practices, and the construction budget when writing Division 1 requirements. Administrative and procedural matters, and temporary facilities, are cost items to the contractor, and too-rigid or too-voluminous specifications of Division 1 sections will unnecessarily increase construction costs.

The CSI specification format provides for two levels of Division 1 text for flexibility in specifying: broad-scope sections which cover the scope of Division 1 topics appropriate for normal construction requirements, and narrow-scope sections which cover the

topics in greater detail for use when more complex construction conditions warrant more detailed requirements. Normal practice is to base project specifications on broad-scope sections, expanding to narrow-scope only when the subject matter requires that detail.

Because of the sensitive nature of the problem and because administrative and procedural controls are especially critical to the successful accomplishment of this project, the Division 1 specification sections will generally be narrow-scope.

1.2.2 Divisions 2 through 16 - detail requirements

Divisions 2 through 16 detail specification requirements for construction activities. In addition to the normal design, fabrication, and installation requirements, the following items should be addressed, as appropriate, in each specification:

- Expected design life.
- Any special operability, maintainability, or reliability requirements.
- Explicit description of any document submittals required.
- Special environmental or design conditions beyond those stated in the Contract Special Provisions.
- Explicit description of any procedures required to satisfy codes and standards, design conditions, or manufacturer's recommendations.
- Manufacturer's representative.

Those divisions and specification sections which appear to be applicable to this project are listed in Section 2.0 of this attachment and commented upon in Section 3.0.

1.3 ORGANIZATION AND PAGE FORMAT

1.3.1 Review and approval sign-off sheet

Each specification shall have a review and approval sign-off sheet as its front cover page. The sign-off sheet shall record revisions and amendments to the specification and shall not carry a page number unless an alpha designation is desired. The sign-off sheet shall contain the complete specification or document number, the CSI section number (unless identified in the specification number), and the section title.

1.3.2 List of article titles

A list of article titles shall be used for all specifications. The list is the first page of the specification and shall be numbered as page 1. The first page and each remaining page of the specification shall carry, as a minimum, the site designation and the CSI section number, followed by a consecutive page number. If it is desired that the full specification or document number be shown on each page, then the page numbers need only carry the CSI section number and the consecutive page number.

1.3.3 Specification section format

The specification section format was developed for use in writing sections in Divisions 2 through 16. If desired, however, its principles can be applied to sections in Division 1.

The text of each specification section shall be divided into three distinct parts of related information. The name and brief description of the function of each part is as follows:

Part 1 - General: Covers those general areas of concern which relate to the work and which define the general administrative and technical requirements specific to a particular specification.

Part 2 - Products: Defines, in detail, the acceptable equipment, materials, fixtures, mixes, and fabrications (i.e., "product" items) to be incorporated into the work.

Part 3 - Execution: Describes, in detail, the manner in which items covered by Part 2 are to be incorporated into the work.

The following is a detailed outline of the kinds of information to be included and the sequence in which such information may be found under the three parts of the section format.

Part 1 - General

- o Work Included (optional)
- o Related Work
- o System Description
- o Quality Assurance
- o References
- o Submittals
- o Delivery, Storage, and Handling
- o Project/Site Conditions
- o Sequencing/Scheduling
- o Alternates/Alternatives
- o Allowances

- o Unit Prices
- o Warranty

Part 2 - Products

- o Acceptable Manufacturers
- o Materials
- o Equipment
- o Mixes
- o Fabrication

Part 3 - Execution

- o Inspection
- o Preparation
- o Installation/Application/Erection
- o Field Quality Control
- o Adjusting and Cleaning
- o Protection
- o Extra Stock/Spare Parts
- o Schedules

Each major article shall be numbered consecutively with each article and paragraph numbered in the following manner:

Part 1 - General

1. 1 ARTICLE	(1st level)
A. Paragraph	(2nd level)
1. Subparagraph:	(3rd level)
a. Subparagraph:	(4th level)
1) Subparagraph:	(5th level)
a) Subparagraph:	(6th level)

As an example, a fifth-level paragraph would be referenced as follows: paragraph 1.1.A.1.a.1). However, use of the fifth or sixth level should be avoided if possible. If a major "part" of the specification section is not used, write "Not Applicable" under the title of that part.

Tables shall be used where the data can be presented with greater clarity. If the table is too complex or extensive, it should be added as an attachment. Tables shall be numbered consecutively.

The end of each section is designated with END OF SECTION centered two lines below the last line of the section text, without parenthesis or other adornment. No end-of-division designation is needed.

1.4 SPECIFICATION LANGUAGE

The following language guidelines are to be used in writing specifications:

- The word "shall" is used for all contractual requirements binding on the subcontractor. The word "will" is used to indicate action to be taken by the Remedial Action Contractor.

- Numbers that occur at the beginning of a sentence should be written as words. If one number follows another, write the smaller number in words and the larger number in numerals, e.g., "three 94-lb sacks" or "122 four-inch bolts."

- Do not specify trade names or proprietary materials unless excluding other products can be justified. Specifying product requirements is preferable to using trade or vendor names. If it is appropriate to specify an item by brand name, the words "or equal" and "or approved equal" should not be included in the specification. The term "or equal" is addressed in the Special Provisions section of the contract package.

- If submittal of shop drawings is required, the specific type of drawing should be identified (e.g., shop fabrication drawings, outline dimension drawings, and similar items).

1.5 SPECIFICATION NUMBERING

Each specification section shall be assigned a number that provides proper identification of the document. The format of the numbering system is at the discretion of the Remedial Action Contractor as long as the following information is provided:

- Site identification - using both alpha and numeric designations.

- Revision number.

- CSI section number - this item is optional if already clearly identified on the sign-off sheet. The section number is already required in numbering each additional page of the specification.

- Any other identification deemed appropriate by the Remedial Action Contractor to meet the needs of internal document control systems.

1.6 QUALITY CONTROL

Specifications shall reflect the necessary requirements needed for adequate inspection of the products or services furnished. These requirements may include test procedures, material certification, qualification of personnel performing tests, and calibration of test equipment.

The specification requirements for shop inspection and testing, and field inspection and testing performed by the contractor and the subcontractor, are unique to each specification. Factors to be considered include importance to safety of off-site and on-site personnel, complexity, uniqueness, and reliability.

Whenever tests are specified, the acceptance criteria should also be included either by reference to an appropriate code or standard or by spelling out the specific conditions of acceptance.

2.0 RECOMMENDED SPECIFICATIONS

The following is a list of recommended SPECTEXT sections for this project.

Division 1

Section 01010 - Summary of Work
Section 01022 - Inspection and Testing Allowances
Section 01040 - Contract Coordination
Section 01050 - Field Engineering
Section 01090 - Reference Standards
Section 01100 - Alternates
Section 01152 - Application for Payment
Section 01153 - Change Order Procedures
Section 01201 - Preconstruction Conferences
Section 01202 - Progress Meetings
Section 01300 - Submittals
Section 01405 - Contract Quality Control
Section 01410 - Testing Laboratory Services
Section 01511 - Temporary Electricity
Section 01512 - Temporary Lighting
Section 01513 - Temporary Heating, Cooling, and Ventilating
Section 01514 - Temporary Telephone Service
Section 01515 - Temporary Water
Section 01516 - Temporary Sanitary Facilities
Section 01530 - Barriers
Section 01540 - Security
Section 01550 - Access Roads and Parking Areas
Section 01560 - Temporary Controls
Section 01563 - Temporary Water Control
Section 01569 - Construction Cleaning
Section 01570 - Traffic Regulation
Section 01580 - Project Identification and Signs
Section 01590 - Field Offices and Sheds
Section 01712 - Final Cleaning
Section 01720 - Project Record Documents

Division 2 - Sitework

Section 02060 - Demolition
Section 02110 - Clearing
Section 02214 - Excavation
Section 02219 - Embankment
Section 02221 - Trenching, Backfilling, and Compacting
Section 02260 - Finish Grading
Section 02270 - Slope Protection and Erosion Control
Section 02401 - Dewatering
Section 02444 - Chain Link Fences and Gates
Section 02485.01 - Seeding
Section 02592 - Sedimentation Basin

Division 11 - Equipment

Section 11395 - Packaged Wastewater Treatment Plant

Division 15 - Mechanical

The user should select and edit appropriate broad scope sections to support design and sections from specification Divisions 1, 2, and 11.

Division 16 - Electrical

The user should select and edit appropriate broad scope sections to support design and sections from specification Divisions 1, 2, 11, and 15.

3.0 COMMENTS

The following comments will be helpful when editing the following specifications sections. To understand these comments, the user should read them in context with the referenced specifications section and the RAP for a site.

Section 01010 - Summary of Work

Paragraphs in this section relating to future work are not applicable.

The DOE shall not use the premises during construction except for administration relating to this project. Public access to the premises shall be severely restricted. The sequencing of construction tasks, however, may be critical to the successful completion of the work. (See Section 01010.M for guidance when the work is to be accomplished by multiple contractors.)

Section 01040 - Contract Coordination

Paragraphs in this section relating to coordination of space are not applicable to this project.

Section 01513 - Temporary Heating, Cooling, and Ventilating

Heating, cooling, and ventilating shall be required to provide a suitable environment in the office and decontamination units, including change rooms and showers.

Paragraphs in this section relating to existing systems and permanent systems are not applicable.

Section 01514 - Temporary Telephone Service

Paragraphs in this section relating to existing systems and permanent systems are not applicable.

Section 01530 - Barriers

It is not expected that temporary fencing during construction will require barbed wire topworks.

Security requirements shall be given priority consideration when locating all gates.

Section 01550 - Access Roads and Parking Areas

Construction vehicles only shall be allowed on the site. Vehicular access to the site shall be strictly controlled. All vehicles leaving the site shall be monitored and decontaminated if necessary. Employee and visitor parking shall be provided off the site.

Section 01560 - Temporary Controls

Surface waters which collect during construction shall be held in lined ponds and treated prior to discharge, if required. Contaminated materials shall not be permitted to leave the site.

Section 01563 - Temporary Water Control

This section should be coordinated with Section 02401 and the design.

Section 01580 - Project Identification and Signs

Standard international symbols designating the presence of radioactive materials shall be displayed during construction.

Section 01590 - Field Offices and Sheds

Field offices shall be required for the owner, engineer's representatives, and supervisory, security, and health personnel. A decontamination unit with showers shall be required. Provisions shall be made for laundering contaminated clothing.

All temporary structures and their contents shall be decontaminated before removal from the site.

Section 01712 - Final Cleaning

Paragraphs referring to cleaning of interiors or buildings, except those referring to decontamination of temporary units prior to removal from the site, are not applicable to this project.

The user shall address the decontamination of all equipment which is to be removed from the site at the completion of the project.

Section 01720 - Project Record Documents

Radiation exposure and health records shall be maintained for all personnel working on the site. Requirements for the documentation and maintenance of these records are defined in the UMTRA Project Environment, Health, and Safety Plan.

Section 02060 - Demolition

The user should coordinate this section with the Remedial Action Plan and with Section 01560. The following shall also be addressed (if applicable):

- The spraying of a structure with a contamination fixative prior to demolition.
- The disposition of contaminated rubble on the site in a controlled fashion.

- The removal of, or decontamination and disposal of, large on-site vegetation.

- Verification that there are no known antiquities or relics on the site.

- The restriction against burning rubbish on the site.

Section 02110 - Clearing

This section shall be modified to address the unique aspects of dealing with possibly radiologically contaminated debris, and be consistent with Section 02060.

Section 02221 - Trenching, Backfilling, and Compaction

This section shall address the installation of relocated utilities so as to preclude the need for human intrusion into the completed restricted site.

Section 02260 - Finish Grading

In order to encourage the establishment of minimum-maintenance native vegetation, appropriate soil enrichments may be added to the top layer of fill materials in lieu of imported topsoil. The user shall ensure that such additives are compatible with the radon attenuation cover.

Section 02485.1 - Seeding

Consistent with Section 02260, appropriate soil enrichments may be added to the top layer of fill materials in lieu of importing topsoil. Seed mixture shall be a blend of local native grasses.

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