

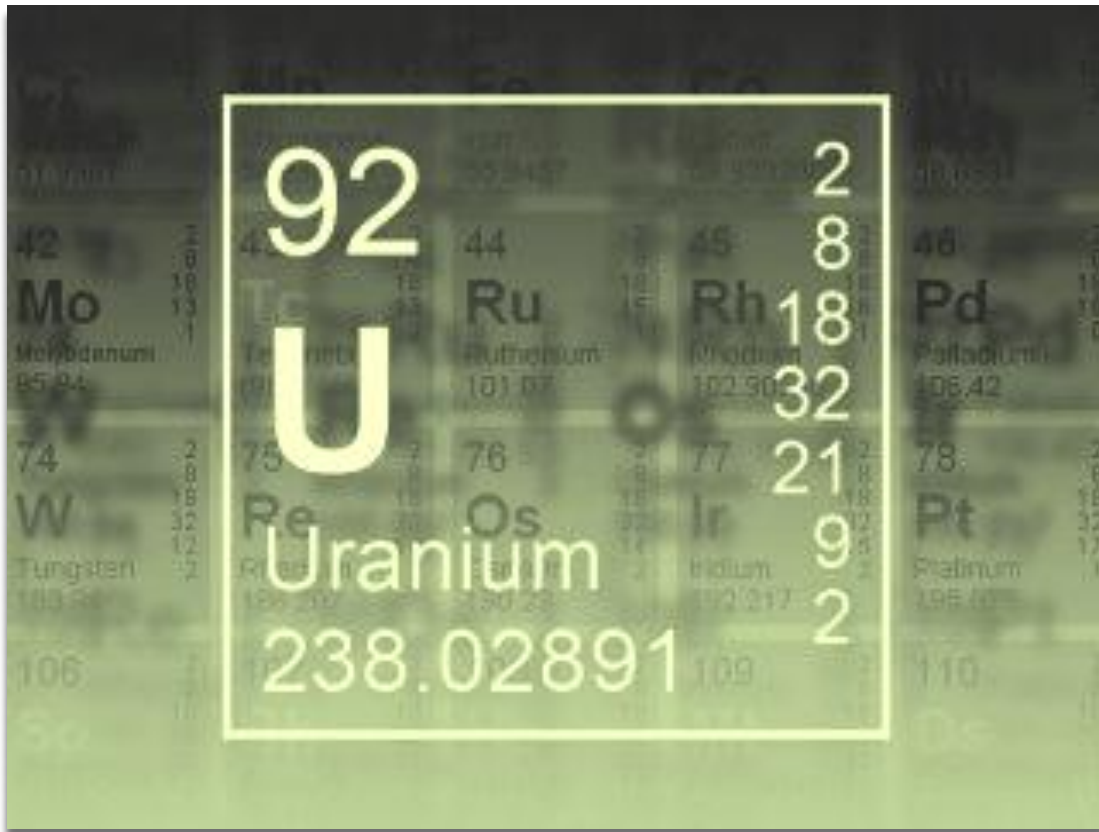
Uranium Study: Safe Disposal of Mine and Mill Wastes

Commonwealth of Virginia

Department of Environmental Quality

Department of Mines, Minerals and Energy

Date: October, 2012



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ABBREVIATIONS

ABA – Acid Base Accounting
ADEQ – Arizona Department of Environmental Quality
ANSI – American National Standards Institute
ARD – Acid Rock Drainage
ASTM – American Society for Testing and Materials
BADCT – Best Available Demonstrated Control Technology
BLM – Bureau of Land Management
BMP – Best Management Practice
CCR – Code of Colorado Regulations
CDPHE – Colorado Department of Public Health and Environment
CMLRB – Colorado Mined Land Reclamation Board
CFR – Code of Federal Regulations
CNSC – Canadian Nuclear Safety Commission
CO – Colorado
DOE – Department of Energy
EA – Environmental Assessment
EIS – Environmental Impact Statement
EPA – Environmental Protection Agency
GARD – Global Acid Rock Drainage
HCT – Humidity Cell Testing
IAEA – International Atomic Energy Agency
ICRP – International Commission on Radiological Protection
INAP – International Network for Acid Prevention
MSHA – Mine Safety and Health Administration
MWMP – Meteoric Water Mobility Procedure
NAAQS – National Ambient Air Quality Standards
NAS – National Academy of Sciences
NPDES – National Pollutant Discharge Elimination System
NRC – Nuclear Regulatory Commission
NUREG – Nuclear Regulatory Commission Regulatory Guides
OSHA – Occupational Safety and Health Administration
PAG – Potentially Acid Generating
RCW – Revised Code of Washington
RFP – Request for Proposal
SWPPP – Storm-Water Pollution Prevention Plan
UMTRCA –
UWG – Uranium Working Group
VA – Virginia

ABBREVIATIONS (CONTINUED)

VAC – Virginia Administrative Code

VDEQ – Virginia Department of Environmental Quality

VDH – Virginia Department of Health

VDMME – Virginia Department of Mines, Minerals, and Energy

WA – Washington

WAC – Washington Administrative Code

WY – Wyoming

WYDEQ-LQD – Wyoming Department of Environmental Quality, Land Quality Division

1.0 INTRODUCTION

In response to renewed interest in uranium mining and milling, and concerns regarding the potential environmental and public health risks versus potential economic benefit, the Commonwealth of Virginia (Virginia) has undertaken studies assessing the range and form of possible regulatory frameworks that might be adopted should the existing moratorium on uranium mining be lifted. On January 19, 2012, the Governor directed members of his cabinet to form a Uranium Working Group (UWG) to provide a scientific policy analysis to help the General Assembly assess whether the moratorium on uranium mining in Virginia should be lifted, and if so, how best to do so.

A study by the National Academy of Sciences (NAS) titled “*Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia*” (NAS, 2011) and other recent studies on uranium mining and milling in Virginia have identified issues related to the protection of public and occupational health and safety, as well as the potential environmental and socioeconomic impacts. Consequently, the UWG has been directed to develop a conceptual regulatory framework that would address these issues, as well as other issues identified by the UWG, the public, and other stakeholders.

In response to this directive, this report outlines disposal of mine and mill wastes and addresses: acid rock drainage and other leachates; waste rock segregation; minimizing ecological risks; mitigation of contaminants to surface water and groundwater; and on-site workers’ health and safety.

This report has been developed in response to the Virginia Department of Environmental Quality (VDEQ)/Virginia Department of Mines, Minerals, and Energy (VDMME) procurement. The VDEQ/VDMME procurement is briefly described below.

1.1 Procurement Summary

On March 2, 2012, the Virginia Department of Environmental Quality issued the request for proposal (RFP) #12-06-PJ (Uranium Study). The purpose of the procurement was to acquire contractor services to provide information and expert analysis of uranium mining and milling issues in Virginia relevant to the statutory jurisdictions of VDEQ and VDMME. Sealed bids were submitted by April 3, 2012 and contract EP881027 was awarded on May 21, 2012.

The Contract identifies two major Work Tasks (A and B). Work Task A involves the development of an initial report based on 1) a review of studies related to uranium mining and milling in Virginia, 2) a comparison of other existing regulatory programs for uranium mining

and milling, and 3) a review of emerging standards from international organizations. The initial report was developed in response to Work Task A, and was submitted on July 6, 2012.

Work Task B involves ongoing technical advice and assistance to the UWG. The efforts of Work Task B will result in a series of interim reports analyzing a range of issues identified in the RFP as well as other issues identified by the UWG. The efforts of Work Task B will provide additional detail to the issues and recommendations addressed in the Work Task A report. This report has been prepared to address Part E of Work Task B (B.2.e) and provides a discussion of the disposal of mine and mill wastes.

1.2 Purpose and Scope

The purpose of this report is to respond to Work Task B, Part E in Contract EP881027, which assesses standards for the disposal of mine waste, including but not limited to:

- The potential for environmental problems resulting from acid mine drainage or other leachate from mine waste;
- Segregation and disposal of sub-ore grade waste rock;
- Minimizing the ecological risks from the release of radionuclides and contaminants from mining and milling;
- Mitigation of mine and mill contaminants from existing sources to both groundwater and surface water; and
- Addressing on-site workers health and safety related to radiation exposure from mine and mill waste.

Based on a review of existing studies, existing regulatory programs, and the current standard of practice by design professionals, this report presents an initial review of the disposal practices for mine and mill wastes.

This report includes various references to federal and state regulations and guidelines pertaining to uranium mining and milling. These references are not intended to be an exhaustive list of all pertinent or applicable regulations and guidelines. Rather, they are cited as representative examples which are included to aid the VDEQ and VDMME in decision making.

2.0 THE POTENTIAL FOR ENVIRONMENTAL PROBLEMS RESULTING FROM ACID ROCK DRAINAGE OR OTHER LEACHATES

2.1 Introduction

Mine and mill waste materials are associated with geologically anomalous concentrations of chemical elements (ore deposits). Thus, they commonly have an elevated risk of leaching chemical constituents that may impact water resources. This potential is increased by disaggregation of rock into smaller pieces as well as by potentially exposing material to previously absent geochemically oxidizing conditions. An assessment of the potential mine waste impacts to water resources meets at least two significant needs. First, the assessment provides the proponent of the mine project the needed perspective and guidance to develop designs and costs for appropriate material handling plans as well as potential water treatment and other mitigation costs. Second, an assessment of potential impacts is needed to aid in preparation of environmental assessment documents (e.g., Environmental Impact Statement [EIS], Environmental Assessment [EA]) as part of the permitting process.

Acid rock drainage (ARD) is widely recognized as a potential environmental hazard and assessment of ARD potential is a routinely required component of mining regulations and guidelines. However, while regulations and guidelines call for such assessment, specific details of what should be done vary and the criteria for acceptance are not universally available.

Although ARD potential is a primary concern, the formation of other leachates from mine materials should also be given consideration. Leachates may generally be considered to be all water contacting mine materials and can include surface runoff of meteoric precipitation, underflow of surface water, upwelling of groundwater, or rinsing of entrained metallurgical process solutions. Leachates may be linked to ARD (sulfide mineral weathering) or the dissolution of other chemical constituents under neutral to alkaline pH.

Several regulating agencies offer either guidelines or regulations concerning the characterization of mine and mill waste for environmental purposes. This report reviews regulations and guidelines from several regulating agencies: the states of Arizona, Colorado, Washington, and Wyoming, the Bureau of Land Management (BLM), and the Nuclear Regulatory Commission (NRC). The BLM oversees much of the minable public lands in the western United States and oversaw the permitting of a uranium mine in Utah in 2009, the first one to be permitted after a 30-year hiatus.

Aside from regulatory guidance or rules, there is an abundance of information regarding methods used to geochemically characterize mine materials. Industry groups support and publish guidance for the state-of-the-art ARD management approaches. One example is the Global Acid

Rock Drainage (GARD) Guide (INAP, 2012) which takes a holistic view of a mining project. Other non-governmental organizations have commissioned technical reviews of methods employed to assess potential water resource impacts from mining projects involving ARD or neutral to alkaline pH drainage (Kuipers et al., 2005). Although these resources include descriptions of utilizing data typically called for by regulatory agencies (modeling) to assess ultimate water resource impacts, regulatory guidance is noticeably vague regarding the need, style, or requirements for modeling.

2.2 Summary of Acid Rock Drainage and Other Mine Rock Leachates

ARD is a low pH iron sulfate solution that may or may not contain a range of trace, and often pollutive, elements (e.g., arsenic, cadmium, copper). ARD results from the exposure of sulfide minerals (primarily pyrite, iron disulfide) to water and oxygen. Sulfide minerals are commonly associated with many metal ore deposits including uranium and precious metals. ARD can negatively impact water resources and requires treatment prior to discharge if it cannot be managed and avoided outright.

Although the low pH conditions associated with ARD favor the solubility and mobilization of a range of regulated trace metals, some chemical constituents of concern may be released from mine and mill wastes under neutral pH conditions. Common constituents of concern under neutral pH conditions are arsenic, selenium, and molybdenum; other constituents of concern can include total dissolved solids and sulfate. Many of the constituents of concern in ARD are pH sensitive and are often absent or very low in concentration in neutral pH drainage (e.g., cadmium, copper).



Figure 2-1 Photograph of ARD (Environment Australia, 1997)

2.3 Material to Which ARD and Leachate Concerns Apply

With sulfide minerals (primarily pyrite) as the source of ARD, concerns regarding ARD formation technically apply to any and all materials that may contain sulfide minerals. Waste rock is perhaps the most obvious material of concern, and includes all mapped rock units and alteration types associated with the deposit. However, the issue extends to stockpiles of ore grade material, as well as low-grade ore and all rock exposed by mining. This includes the walls and floor of open pits and the surfaces along the length of tunnels in the case of underground mining. Depending on the mineralogical composition of ore and the particulars of ore processing, ARD may also be associated with mill waste (tailings).

From the perspective of regulating agencies, concerns regarding ARD are primarily directed at waste rock. The state of Washington (RCW 78.56.100 Subsection 1(b)) identifies only waste rock as a material of concern. Similarly, the Wyoming Department of Environmental Quality - Land Quality Division (WYDEQ-LQD) guidelines indicate a focus on topsoil and overburden materials (WYDEQ-LQD, 1994a).

However, the state of Colorado's *Mineral Rules and Regulations of the Colorado Mined Land Reclamation Board (CMLRB) for Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010; Rule 6.4.21 Subsection 14) indicates a need to “include appropriate geochemical evaluations of any material that will be exposed by mining, placed in on-site solution containment systems or facilities, stockpiled, or disposed of on the affected land, and that involves uranium mining or has the potential to cause acid mine drainage or to release designated chemicals, or toxic or acid-forming materials.”

BLM Nevada State Office (BLM, 2010) provides rock characterization guidelines that specifically cite the need to consider ore, waste material, process components, and long-term management. Pits, mine workings, and tailings are not directly specified, although the Colorado regulations and the Nevada State Office BLM guidance directly imply their significance in their identification of all material exposed.

2.4 Sampling

As stated by the Arizona Department of Environmental Quality (ADEQ, 2004) “The primary objective of a sampling program is to obtain representative samples from a range of geochemical groups within each lithologic unit in order to characterize materials that may generate an acid rock drainage and have a reasonable probability of causing pollutant to reach an aquifer.”

As mentioned above, the Colorado Mined Land Reclamation Board (CMLRB, 2010) indicates that virtually all rock associated with a mining project should be considered for its potential to form ARD (see CMLRB, 2010, pages 72-74 and pages 162-163). Many mine materials and

individual rock types can be quickly excluded from ARD concerns due to the lack of sulfide minerals or an abundance of carbonate minerals. However, all materials and individual rock types are generally sampled for potential leaching of chemical constituents of concern. Whether for ARD potential and/or metal leaching potential, proper sampling is a concern.

Suggested rates of sampling (for hard rock mining) have been offered by a variety of entities and are summarized by the U.S. Environmental Protection Agency (EPA) (EPA, 1994b). These rates are in terms of the number of samples taken per mass of rock unit being excavated as waste, and range from 8 to 50 samples per million tons of material. WYDEQ-LQD (WYDEQ-LQD, 1994a; Section II (B)(3)(a) and (b)) offers guidance specifying the number of drill holes per unit area, as well as guidance for compositing drill cuttings at 5-foot intervals and core at 10-foot intervals. This guidance does not, however, specify how many of the prepared samples should be submitted for laboratory testing.

The CMLRB requires that materials and rock types should be sampled in such a way that it may be considered representative. CMLRB (CMLRB, 2010; Rule 6.4.21 Subsection (14)(b)) mandates that “...evaluations shall be conducted on materials that are representative of the composition of the mineral, rocks or materials that are exposed or to be exposed during the proposed life of the mining operations.” Guidelines from the BLM Nevada State Office (BLM, 2010) require a permit applicant to define and substantiate statistical adequacy of characterization, with stipulated review by the agency. ADEQ (ADEQ, 2004; Appendix B Subsection (3)(B)) provides the most detailed description of required sampling, although specific criteria for the number of samples is not provided.

The frequency of sampling described above by EPA (EPA, 1994b) and WYDEQ-LQD (WYDEQ-LQD, 1994a) seeks to address the issue of representativeness for waste rock, but does not speak to tailings. Metallurgical testing during mine feasibility evaluations produces tailings samples, and these are commonly associated with specific time periods (years of development) for a proposed mine project. Tailings samples are routinely sampled for all anticipated time periods for future development, to ascertain what changes in tailings may occur as a result of ore compositional changes. This is normally considered to be representative sampling of tailings. ADEQ (ADEQ, 2004; Appendix B) identifies that different rock types may have a greater range of variance of their chemical characteristics and that iterative sampling and characterization may be required to demonstrate that material characterization is representative. ADEQ (ADEQ, 2004) calls out several aspects of the mine rock that should be considered in the sampling program to address representativeness, including:

- Lithological and mineralogical variation;
- Degree and extent of primary and secondary sulfide, and oxide mineralization;
- Form in which mineralization occurs (e.g., disseminated or in veins);

- Mass and volume of different lithologies;
- Degree and extent of fracturing; and
- Degree of oxidation.

2.5 Laboratory Testing

Representative samples of mine rock and tailings are tested to assess ARD formation potential and leaching of chemical constituents. The potential test procedures range from assessing the balance of acid-producing and acid-consuming potential to short- and long-term leach testing.

2.5.1 Acid Base Accounting

Acid base accounting (ABA) is a fundamental testing technique to gauge the potential of a mine material to form ARD. ABA testing is commonly conducted, although it is not specified in any state regulations reviewed, and it should be considered a best management practice (BMP). Colorado and Washington do not specify the use of ABA, but state that “*appropriate geochemical evaluations*” (CMLRB, 2010) or “*accurate identification of the acid generating properties*” (RCW 78.56.100) should be produced. WYDEQ-LQD (WYDEQ-LQD, 1994a), Nevada State Office BLM (BLM, 2010), and ADEQ (ADEQ, 2004) indicate specifically that ABA tests need to be completed. Of these, only Arizona (ADEQ, 2004) is a regulated policy and is part of their Aquifer Protection Permit application process. Other entities offer the ABA specification in non-regulatory guidance documents.

2.5.2 Long-Term Leach Testing

For material considered uncertain with respect to ARD formation on the basis of ABA characterization, long-term leach testing is routinely expected although it should be considered a BMP, not a regulated requirement. This testing is also referred to as kinetic testing. Humidity cell testing (HCT) is a type of kinetic testing in which samples are exposed to alternate humid air/dry air cycles with weekly leaching by distilled water (ASTM D5744-12). Chemical parameters are tracked weekly to assess if a material produces ARD and to gauge the chemical composition of contact water. Additionally, the rate at which chemical constituents are released can be determined. HCT is specified by Nevada State Office BLM (BLM, 2010) guidance, and is suggested for use by ADEQ (ADEQ, 2004) in cases where ARD formation cannot be ruled out by static (ABA) methods. Other states do not specifically describe or call for HCT work in any guidance documents or state regulations. As with ABA testing, HCT work should be considered a BMP since it is considered an appropriate geochemical evaluation (CMLRB, 2010) and is ordinarily expected from permitting agencies.

As cited in ASTM D5744-12, the HCT method “...is not intended to provide leachates that are identical to the actual leachate produced from a solid material in the field or to produce

leachates to be used as the sole basis of engineering design.” However, because the actual leachate is not available, HCT leachate composition can be used to predict the actual leachate composition. HCT leachate analyses can be used in conjunction with hydrologic seepage analyses to produce a fate and transport model to simulate potential impacts to water resources.

A variation of kinetic testing is the use of field scale bin tests. These tests are less common and use large amounts of mine rock in confined bins that are placed on-site and exposed to site weathering conditions (rainfall, temperature, etc.). All effluent is collected from the test bins and analyzed. Field scale tests are not specifically called for in any regulations, but are implied in Colorado (CMLRB, 2010; Rule 6.4.21 Subsection (14)(c)) in calling for evaluations to “*...be appropriate for the intended use or fate of the material exposed...shall simulate, to the extent reasonable, the conditions under which the material used, stockpiled or disposed...*”

2.5.3 Short-Term Leach Testing

Whereas, long-term leach tests are applicable to material that may produce ARD, or at least possess an appreciable chemical load through the oxidation of sulfide minerals, leaching of metals and other chemical constituents of concern associated with neutral to alkaline pH materials are typically determined using short-term leach tests. ADEQ (ADEQ, 2004), although not specifically requiring the use of kinetic testing (e.g., HCT), does require leach testing of materials. ADEQ (ADEQ, 2004) accepts the use of EPA (EPA, 1994a) Method 1312 (Synthetic Precipitation Leaching Procedure) for all sampled materials, as well as the Meteoric Water Mobility Procedure (MWMP) (ASTM E2242-02) and other less rigorous tests. BLM Nevada State Office (BLM, 2010) calls for use of the MWMP. WYDEQ-LQD (WYDEQ-LQD, 1994a) offers guidelines to determine the suitability of the material as an agricultural medium for purposes of reclamation of waste materials for a variety of chemical properties but does not specify leach testing with respect to chemical constituents that may leach from mine rock.

3.0 SEGREGATION AND SAFE DISPOSAL OF SUB-ORE GRADE WASTE ROCK

Whether as representative of an ARD risk or non-acid leaching of chemical constituents, appropriate waste rock handling (including sub-grade ore), reclamation, and mitigation plans are integral to mining permits. ARD concerns are a common basis for segregating sub-ore grade waste rock. However, segregation may also be driven by non-acidic leachates that contain pH insensitive metalloids (e.g., selenium, molybdenum) or radionuclides. The need for segregation is typically identified by recognition of a significant potential to form ARD or leach testing of mine materials that identify potential concerns regarding non-acid constituents.

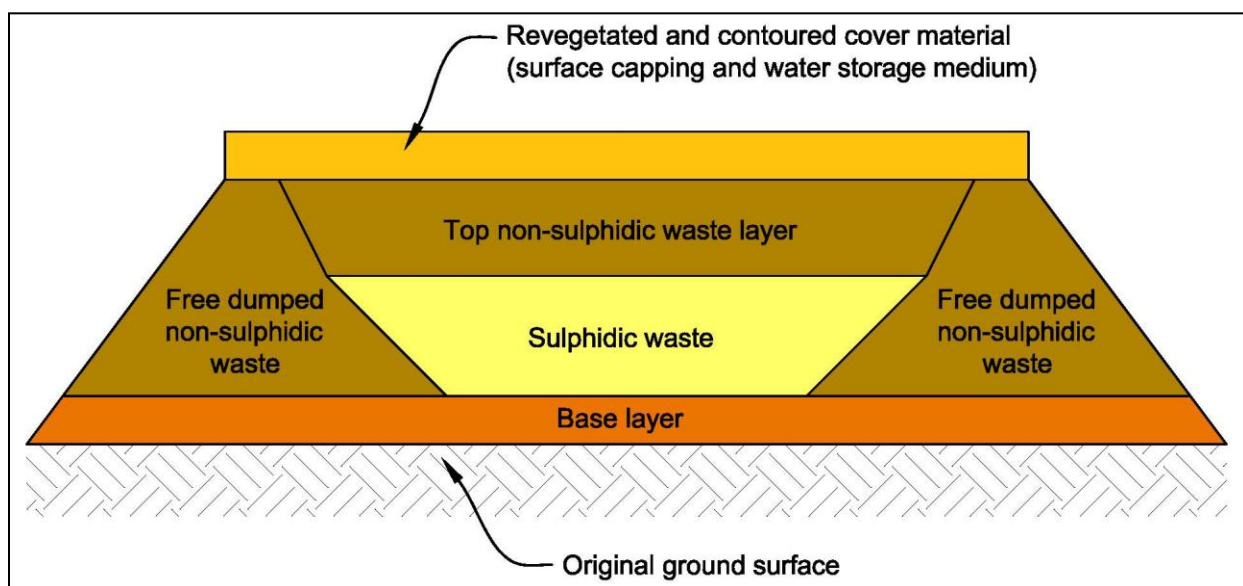


Figure 3-1 Example of Waste Segregation (Environment Australia, 1997)

All agencies considered in the present review, except ADEQ (ADEQ, 2004), specifically call for waste rock handling plans that include segregation. However, specific details as to what comprises an acceptable plan, criteria for segregation, and other engineering details are not addressed. Specifically,

- **Washington:** The state of Washington (RCW 78.56.100, Subsection (1)(b)(ii)) calls for “*a strategy for encapsulating potentially toxic material from the environment, when appropriate, in order to prevent the release of heavy metals and acidic drainage.*”
- **Wyoming:** WYDEQ-LQD (WYDEQ-LQD, 1994a; Subsection (II)(A)(5) and (6)) offers guidelines that “*The results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that*

all toxic or acid-forming material is stockpiled and backfilled in a manner that will prevent environmental degradation” and “A reclamation plan should be developed, using the overburden and interburden analyses, demonstrating that toxic or acid-forming overburden material will be placed so as not to preclude surface reclamation and revegetation or the re-establishment of acceptable surface water and groundwater quality and quantity.”

- **Colorado:** The CMLRB (CMLRB, 2010; Rule 6.4.21 Subsection (6)(ii)) in specifying required designated chemical and material handling plans calls for a plan that *“describes how materials that have the potential to produce acid mine drainage or are toxic or acid-forming will be handled to ensure that the affected lands will be reclaimed and returned to the approved post-mining land use.”*
- **Nevada State Office BLM:** The BLM (BLM, 2010, Subsection (VI)(4)) describes the need to “Describe how potentially acid generating (PAG) rock will be selectively mined, segregated and managed to preclude exposure to air and water. Need to address metals mobility/accumulation for both PAG and non-PAG materials.”

The overarching concern and regulatory guidance described above is that the overall mine plan includes a specific plan for handling of mine materials. Segregation is a component of the handling plan and can be considered a BMP that reduces the likelihood of ARD formation and production of poor quality leachates. Likewise, reclamation is a BMP against undue discharge of low quality discharge to water resources and also promotes improved aesthetics and practical uses of mine land following mining. Other BMPs exist and are routinely included in mine material handling plans employed at hardrock (including uranium) mine projects, and are determined on a site-specific basis. These BMPs can include:

- Development of rapid turnaround time analytical procedures to facilitate identification of material requiring special handling and/or segregation;
- Amendment of potential ARD-forming material with limestone (calcium carbonate) brought on-site as either a structural cap, admixed with waste, or placed as a protective base layer;
- Construction of oxygen barriers on the surface of waste rock and tailings facilities;
- Placement of ARD-forming material in a PAG cell in a waste dump interior;
- Mixing various mine rock types to offset the ARD-forming potential of other rock types;
- Grading of waste dump slopes and the construction of water channels on dump faces to encourage stormwater runoff rather than infiltration;

- Waste dump construction in lifts rather than by end-dumping;
- Incorporation of a passive treatment wetland to capture and treat discharging leachates (both acidic and neutral/alkaline pH);
- Surface water capture and routing to water treatment facilities prior to discharge; and
- Groundwater pump back systems (to water treatment prior to discharge).

Best management practices vary depending on site-specific materials and conditions. The same BMPs need not apply to all mine site locations, and can even vary across a single location. The material handling plans developed by the project proponent would require demonstration (e.g., numerical models, field test plots, engineering designs) that any and all best available demonstrated control technologies (BADCTs) were being employed, within the limits of uncertainty.

4.0 MINIMIZING THE ECOLOGICAL RISKS FROM THE RELEASE OF RADIONUCLIDES AND CONTAMINANTS FROM MINING AND MILLING

4.1 Introduction

The minimization of the ecological risk from the release of contaminants is accomplished through characterization of potential contaminant sources and engineering design to contain potential sources that might result in physical and/or environmental impacts. Characterization of the waste source and engineering design for containment is driven by regulations and BMPs associated with the uranium mining and milling industry.

As stated earlier, mining of uranium is generally regulated by state agencies. The milling of uranium has historically been regulated by either the NRC or state agencies under an agreement with the NRC. This report reviewed selected NRC and state standards related to minimizing ecological risks from radionuclides and contaminants resulting from the mining and milling of uranium. For this section of the report, efforts focus on regulatory guidance from Colorado, Wyoming, Washington State, and the NRC. Guidance from other agencies has been reviewed and cited as appropriate. A summary of our findings and selected BMPs are provided below.

4.2 Methods of Placement of Uranium Mine and Mill Wastes

4.2.1 Waste Rock

Conventional mining of uranium results in the development of waste rock. Waste rock is generally composed of sub-grade ore and overburden. This material has historically been stored on the surface or placed back in the underground workings or open pits. Figure 4-1 shows an example waste rock facility.



Figure 4-1 Example of Waste Rock Facility (Environment Australia, 1997)

4.2.2 Tailings

Tailings are the result of milling the ore. Milling is accomplished by grinding the ore and extracting the uranium, the remaining material is considered tailings. The process of milling results in tailings slurry that is generally conveyed by pipe and spigoted into lined impoundments. Tailings impoundments are operated to keep only a minimum of the tailings surface above the water surface to limit radon flux and blowing dust. Tailings impoundments are drained and covered with a multi-layer cover during closure. The tailings are considered radiological waste material and are governed by the NRC. Figure 4-2 shows a generalized tailings impoundment cross-section.

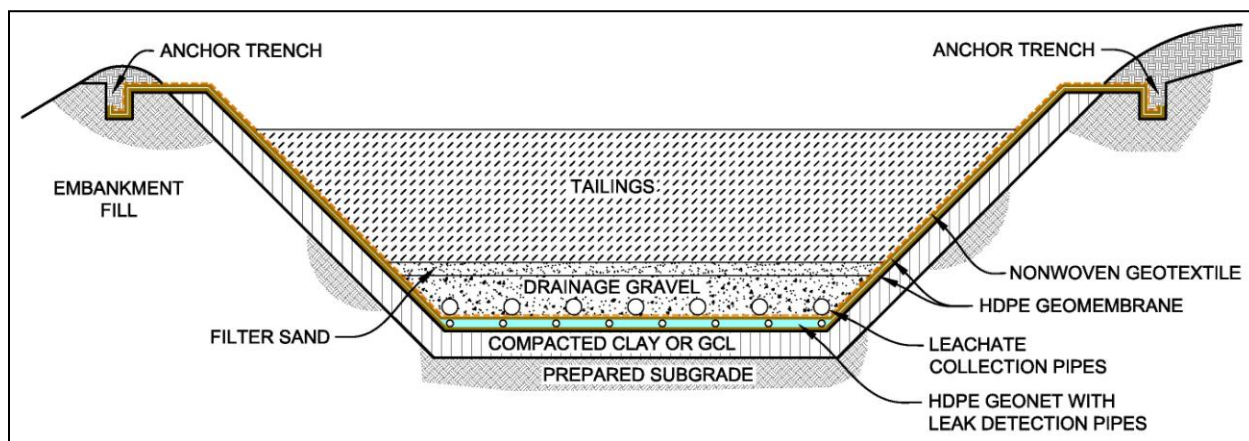


Figure 4-2 Generalized Tailings Impoundment Cross-Section

4.2.3 Heap-Leach

The heap-leaching process is completed by stacking the ore, which may be crushed, on a lined pad and applying a leaching solution (acid or base) to the surface of the ore to extract the uranium. The ore can be stacked on the pad either by placement with a conveyor system or trucks and loaders. The pregnant solution is collected and the uranium is extracted in an ion-exchange facility. The leached ore is considered radiological waste material and is governed by the NRC. Heap-leach pads are drained and covered with a multi-layer cover at closure. Figure 4-3 shows a generalized heap-leach pad and pond.

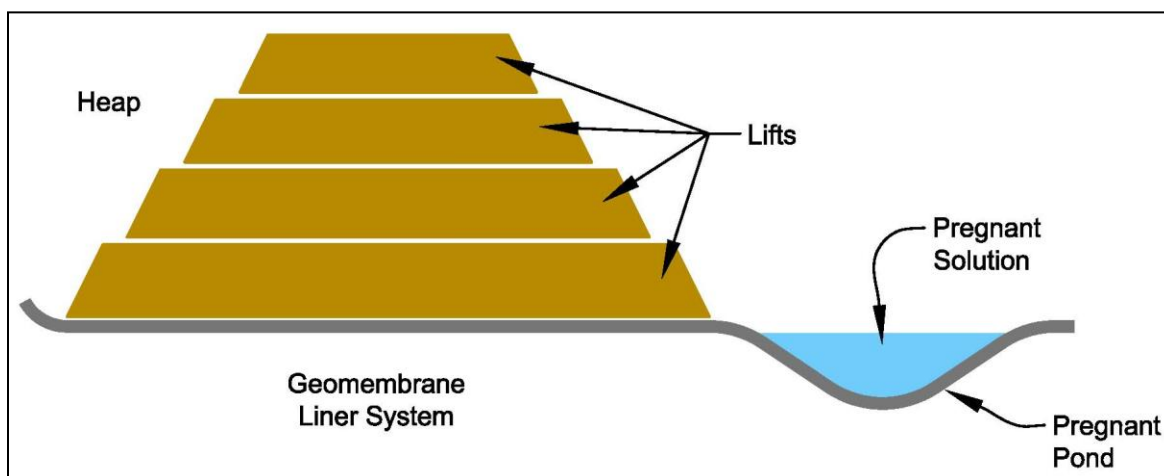


Figure 4-3 Generalized Heap-Leach Pad

4.3 Mining BMPs

The following subsections address the regulatory guidance and BMPs for mining processes that are common in the uranium mining industry. The need for an initial characterization of materials is discussed followed by summaries of specific mining BMPs such as: waste rock handling plans; encapsulation and isolation; ore pad liners; back stowage of waste; waste storage areas; storm-water pollution prevention plans; dust minimization and control; mine effluent control; and acid rock drainage control. Also included is a discussion of mine closure requirements.

4.3.1 Characterization of Materials (ore/wastes/topsoil)

The current practice prior to commencement of mining operations is to characterize the ore, waste rock, and topsoil. The results of the characterization should be used to develop ore, waste rock, and topsoil handling plans. Characterization of the material includes determining the potential for ARD, the mineral content, and the potential for leaching of constituents of concern. Characterization of materials is discussed in more detail in Section 2.0.

- **Washington:** Washington (RCW 78.56.100, Subsection (1)(b)(i)) indicates that characterization of the waste rock shall consist of “*an accurate identification of the acid generating properties of the waste rock.*”
- **Wyoming:** The Environmental Protection Performance Standards for non coal (WYDEQ-LQD, 2006; Section 2 (c)(iv)(D)) indicate “The operator may be required to have analyses made of spoil material in order to determine if it will be a source of water pollution through reaction with leaching by surface water. If it is determined that this condition may exist, the operator shall describe proposed procedures for eliminating this condition.”

- **Colorado:** Colorado (CMLRB, 2010, Section 6.4.9 (1)) requires that “In consultation with the Soil Conservation Service or other qualified person, the Operator/Applicant shall indicate on a map (in Exhibit C) or by a statement, the general type, thickness and distribution of soil over the affected land. Such description will address suitability of topsoil (or other material) for establishment and maintenance of plant growth.” Colorado (CMLRB, 2010, Section 6.4.21 (14)) also indicates that the applicant should “...include appropriate geochemical evaluations of any material that will be exposed by mining, placed in on-site solution containment systems of facilities, stockpiled, or disposed of on the affected land, and that involves uranium mining or has the potential to cause acid mine drainage or to release designated chemicals, or toxic or acid-forming materials.”

4.3.2 Waste Rock Handling Plans

As discussed in Section 3.0, the segregation of waste rock and ore during operations is an integral part of the mine operations. It is common practice for conventional open pit mining facilities to segregate waste rock and ore.

- **Washington:** Washington (RCW 78.56.100, Subsection (1)(b)(i-iii)) indicates that “*the applicant must develop a waste rock management plan approved by the department of ecology and the department of natural resources which emphasizes pollution prevention.*” This plan normally includes an assessment of the ARD potential, encapsulation of the waste rock, and reclaiming the waste rock to reduce infiltration.
- **Wyoming:** WYDEQ-LQD (WYDEQ-LQD, 1994a; Subsection (II)(A)(5)) offers guidelines that state: “*The results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that all toxic or acid-forming material is stockpiled and backfilled in a manner that will prevent environmental degradation.*”
- **Colorado:** Colorado (CMLRB, 2010; Section 6.4.21 (6) (b) (ii)) in specifying required designated chemical and material handling plans calls for a plan that “*describes how materials that have the potential to produce acid mine drainage or are toxic or acid-forming will be handled to ensure that the affected lands will be reclaimed and returned to the approved post-mining land use.*”

4.3.3 Encapsulation and Isolation of Mine Waste

The current method for mitigating the effects of uranium mine waste is to isolate the waste from external receptors.

- **Washington:** Washington (RCW 78.56.100 Subsection (1)(b)(ii)) calls for applicants to provide “*A strategy for encapsulating potentially toxic material from the environment, when appropriate, in order to prevent the release of heavy metals acidic drainage.*”
- **Wyoming:** While a requirement that states that mine waste should be covered is not identified, WYDEQ-LQD (WYDEQ-LQD, 1994a; Section II (A)(5)) states that “*The results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that all toxic or acid forming material is stockpiled and backfilled in a manner that will prevent environmental degradation.*”
- **Colorado:** Colorado (CMLRB, 2010; Section 3.1.5) states that “*all mined material to be disposed of within the affected area must be handled in such a manner so as to prevent any unauthorized release of pollutants to the surface drainage system.*”

4.3.4 Ore Pad Liners

Ore has the potential for leaching into the underlying soils. However, it has been our experience that although lined ore pads are used in mill areas, they are not normally used in mining operations. The length of time that the ore is anticipated to be stored on the ground dictates the use of the liner under the ore. In most mining operations the ore is moved to the processing facility (i.e., mill or heap-leach pad) quickly and is not stored in the mine area for an extended period of time. However, the use of liners under ore pads could reduce the potential for leaching constituents of concern from the ore into the soil and/or groundwater.

4.3.5 Back Stowage of Waste

There are many underground mining operations, both uranium and non-uranium, where pre-sorting of the ore is completed underground. The material that is below the cut-off grade (i.e., waste rock or sub-ore grade rock) is placed in exhausted workings without bringing it to the surface. There are precedents for disposal of uranium mine wastes in mine workings. Wyoming, Colorado, and Utah require at least partial backfilling of open pits with mine waste. The Butler-Weddington abandoned mine land reclamation uranium project site in southeast Texas is an example of a open pit that was reclaimed using radioactive, acidic, and high metals mine waste to backfill the open pit. This work was completed as part of the Texas Abandoned Mine Land Program (<http://www.rrc.state.tx.us/programs/mining/texasamlprojects.pdf>).

Internal backfilling of open pits as soon as feasible after mining has been used to reduce the amount of waste stored in waste rock disposal areas, reduce the formation of pit lakes, and provide for stable long-term slope surfaces for closure. Backfilling the pit also minimizes the oxidation of the pit wall rock, thus potentially improving the water quality.

- **Wyoming:** The State Environmental Protection Performance Standards (Chapter 3) for Noncoal Mines (WYDEQ-LQD, 2006; Section 2 (b)(iii)(A)) state: *“If the reclamation plan does not provide for a permanent water impoundment, all disturbed areas shall be returned to a condition suitable for the use specified in the approved plan. The final pit area shall be backfilled, graded, and contoured as much as possible considering the physical characteristics of the land and rock materials.”*

Though state requirements for uranium mine waste reclamation are not as rigorously defined as those for mill tailings the overall objective is essentially the same: long-term physical stabilization and isolation of contaminants from human and environmental receptors. Again, the applicant would have to demonstrate to satisfaction of the regulatory agency (e.g., Virginia Department of Mines, Minerals and Energy) that the proposed method of mine waste back storage would not pose a substantial present or potential future hazard to public health safety or the environment or violate the non-degradation statute for waters of the Commonwealth (9VAC25-280-30).

4.3.6 Waste Storage Areas

Characterization of waste should be performed to determine if there is the potential for ARD and leaching of metals from the waste rock as discussed in Sections 2.0 and 3.0 of this report. The applicant should show that leachate from the waste rock facility will not impact surface water or groundwater quality. Controls such as grading to minimize run-on to the waste pile, treatment of the waste as discussed in Section 3.0, and placement of a cover to minimize infiltration and oxidation are common. The use of liners under waste rock facilities is not a common practice and not required by the regulations reviewed for this section. However, liners could be considered as an additional alternative, if necessary to control water quality. The states of Washington, Wyoming, and Colorado indicate the following are related to waste disposal control:

- **Washington:** Washington (RCW 78.56.100 (1) (b) (iii)) requires *“A plan for reclaiming and closing waste rock sites which minimizes infiltration of precipitation and runoff into the waste rock and which is designed to prevent future releases of regulated substances contained within the waste rock.”*
- **Wyoming:** The WYDEQ-LQD (WYDEQ-LQD, 1994a; Section II (A)(5)) states that *“The results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that all toxic or acid*

forming material is stockpiled and backfilled in a manner that will prevent environmental degradation.”

- **Colorado:** Colorado (CMLRB, 2010; Section 3.1.5 (5)) states that “*All refuse and acid forming or toxic producing materials that have been mined shall be handled and disposed of in a manner that will control unsightliness and protect the drainage system from pollution.*”

4.3.7 Storm-Water Pollution Prevention Plans

It is common practice for states to require Storm-Water Pollution Prevention Plans (SWPPPs) as part of the mining application process. The EPA provides guidance for the development of SWPPPs on their website (EPA, 2012). In mining applications the primary concern is sediment containment.

- **Wyoming:** The WYDEQ-LQD (WYDEQ-LQD, 2005; Section III Surface Water (B)(2)) states: “*Runoff from disturbed and reclaimed areas should be controlled either by sediment ponds (see LQD Guideline 13), alternative sediment control measures (see LQD Guideline 15), or a combination of both. Detailed design specifications are required for those structures that are planned to be built during the term of permit.*”
- **Colorado:** The CMLRB (CMLRB, 2010; Section 6.4.21 (10) (b)) specifies that the applicant shall “*...submit a Storm Water Management Plan, if required by the Water Quality Control Division, including a copy of such plan and a maintenance and inspection program to ensure all drainage control and containment facilities will be properly operated and maintained.*”

4.3.8 Dust Minimization and Control

During operations it is required that the operator reduce the amount of dust. Dust emissions are regulated under the National Ambient Air Quality Standards (NAAQS). Dust control methods that are required to be compliant with the NAAQS are generally specified in the specific mine permit. However, dust control is commonly accomplished by placing sprayer bars on conveyors, wetting of stockpiles, location of stockpiles in areas protected from the wind, wetting of haul roads, use of chemical dust suppressants, and covering of haul trucks.

- **Wyoming:** The WYDEQ-LQD (WYDEQ-LQD, 2012; Section III, Mine Plan, (E)(b)) requires that the applicant provide a “*Dust management plan.*” The details of the plan are developed between the applicant and the administrator.



Figure 4-4 Example of Dust Control Using a Water Truck

4.3.9 Mine Effluent Control

Conventional mining operations, open pit or underground, generally require dewatering operations. The amount of dewatering required depends on many factors including the hydraulic properties of the regional aquifers and the depth of the formation. The amount of water generated from dewatering will dictate how the operator handles disposal. Generally, the preferred use of the water generated from mining operations is to include it in the milling process. However, if excess water is produced then that water must be managed. The water must meet state and federal water quality standards for the water to be discharged. In some instances this will require the installation of a water treatment system.

- **Wyoming:** The WYDEQ-LQD (WYDEQ-LQD, 2005; Section III Surface Water (B)(3)) states that a National Pollutant Discharge Elimination System (NPDES) permit “...is required for point sources of discharge into surface drainages but not for non-point discharges.”
- **Colorado:** Colorado (CMLRB, 2010; Section 6.4.7 (5)) requires that “*The Operator/Applicant shall affirmatively state that the Operator/Applicant has acquired (or has applied for) a National Pollutant Discharge Elimination System (NPDES) permit from the Water Quality Control Division at the Colorado Department of Health, if necessary.*”

4.3.10 Acid Rock Drainage Control

The development of ARD is a concern for regulators and operators and has resulted in many long-term treatment and cleanup operations around the world. The quantification of the potential for ARD is discussed in detail in Sections 2.0 and 3.0. Materials and individual rock types are generally evaluated for potential leaching of chemical constituents of concern. Whether for

ARD potential or metal leaching potential, proper sampling is a concern. After the geochemical properties have been identified then appropriate segregation and handling and encapsulation plans should be developed to reduce the potential for ARD drainage to occur.

- **Washington:** Washington (RCW 78.56.100 Subsection (1)(b)(ii)) calls for applicants to provide “*a strategy for encapsulating potentially toxic material from the environment, when appropriate, in order to prevent the release of heavy metals acidic drainage.*”
- **Wyoming:** Wyoming statutes (Title 35-11-406(b)(ix)) require “*A plan for insuring that all acid forming, or toxic materials, or materials constituting a fire, health or safety hazard uncovered during or created by the mining process are promptly treated or disposed of during the mining process in a manner designed to prevent pollution of surface or subsurface water or threats to human or animal health and safety. Such method may include, but not be limited to covering, burying, impounding or otherwise containing or disposing of the acid, toxic, radioactive or otherwise dangerous material.*”
- **Colorado:** Colorado (CMLRB, 2010; Section 6.4.21 (1)) implies that sufficient characterization of the ore and waste rock is required to complete an “*...Environmental Protection Plan [that] shall describe how the Operator/Applicant will assure compliance with the provisions of the Act and Rules in order to protect all areas that have the potential to be affected by designated chemicals, toxic or acid-forming materials or acid mine drainage, or that will be or have the potential to be affected by uranium mining.*”

4.3.11 Closure

It is common practice for the applicant to submit a closure plan as part of the application process. A closure plan is also part of the surety bonding process. The long-term care of mine waste remains the responsibility of the permit holder under the review of local regulators. Once a bond is released for a mine, the responsibility of the mine waste becomes the responsibility of the land owner. At a minimum, the reclamation plan normally includes plans for: regrading of the waste rock to increase the stability; evaluation of infiltration potential of the waste rock cover; development of waste rock cover design; revegetation of surface disturbance with native plants; backfilling of open pits and underground workings; and subsidence analyses of underground workings. The long-term water level and water quality should be analyzed for both the open pit and underground workings.

- **Wyoming:** The Wyoming Environmental Protection Performance Standards (Chapter 3) for Noncoal Mines (WYDEQ-LQD, 2006) state “*Revegetation of all*

affected lands shall be accomplished in a manner consistent with the approved reclamation plan and the proposed future use of the land.”

- **Colorado:** Colorado (CMLRB, 2010; Section 3.1.5 (3)) requires that “*all grading shall be done in a manner to control erosion and siltation of the affected lands, to protect areas outside the affected land from slides and other damage. If not eliminated, all highwalls shall be stabilized.*” Colorado (CMLRB, 2010; Section 3.1.10 (1)) also requires that “*In those areas where revegetation is part of the Reclamation Plan, land shall be revegetated in such a way as to establish a diverse, effective, and long lasting vegetative cover that is capable of self-regeneration without continued dependence on irrigation, soil amendments or fertilizer, and is at least equal in extent of cover to the natural vegetation of the surrounding area.*”

4.4 Milling Best Management Practices

This subsection addresses the requirements for specific milling BMPs that are commonly found in the uranium mining industry. Milling BMPs that are detailed in this subsection include: effluent control and monitoring; ore and tailings characterization; dust control; tailings control; tailings cell design for operations; and closure/reclamation plan.

4.4.1 Effluent Control and Monitoring

The NRC regulations in 10 Code of Federal Regulations (CFR) 40 Appendix A, Criterion 8 reference the EPA regulations at 40 CFR 440.34 which allow for limited permitted discharge of mill process water. 40 CFR 440.34 states: “*In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equivalent to the difference between annual evaporation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged....*”. Most mills in the arid west do not discharge effluent. It is standard practice for excess process water to be disposed of in evaporation ponds or through active evaporation, such as sprayers. However, this mostly likely will not be a practical means of disposal of excess water in the Commonwealth of Virginia.

4.4.2 Ore and Tailings Characterization

The ore and tailings need to be characterized for both geochemical properties and geotechnical properties. The host formation and ore commonly have an elevated risk of leaching chemical constituents and may result in ARD. The quantification of these properties is addressed in Section 2.0. The geotechnical nature of the ore and tailings should be addressed for construction of tailings impoundments and heap-leach pads. The strength and permeability of these materials is used during the design process.

- **NRC:** The NRC (10 CFR 40, Appendix A, Criterion 5A(2) (a)) states that testing of the tailings and ore should be completed to ensure that the tailings impoundments are *“Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the waste or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation...”*

The Commonwealth may consider requirements for characterization of various aspects of the waste materials. Components of this characterization should be determined on a case-by-case basis, as all waste materials are somewhat unique to their site and project. Common characterization elements may include, but not necessarily be limited to, the following:

- Physiochemical characteristics
 - Constituent total mass and available mass;
 - Paste pH;
 - Net neutralizing potential, acid generating potential;
 - Total organic content;
 - Cation exchange capacity; and
 - Leaching characteristics of wastes as proposed to be placed.
- Mechanical properties
 - Bulk density, porosity;
 - Strength properties; and
 - Consolidation properties.

Assessing the waste materials for their mass of constituents that may be available to be dissolved, mobilized and transported is a key issue that is also likely case-specific to each site and waste material. In addition, understanding not only the amount of mass of each constituent that might be available but also the leaching behavior under various geochemical conditions is desired. Ideally, an understanding of the mass leached relative to pore volume and the mass leached relative to time (kinetics) will be developed. Maest presents a summary of possible geochemical test methods for such waste physiochemical properties (Maest et al., 2005).

4.4.3 Ore Pad Liners

Once ore enters the mill site (i.e., is taken across the radiation control boundary) it is governed by the NRC or agreement state agency and should be placed on a liner.

- **NRC, Washington, Colorado:** The NRC (10 CFR 40 Appendix A, Criterion 5H) states that *“Steps must be taken during stockpiling of ore to minimize penetration of radionuclides into underlying soils; suitable methods include lining and/or*

compaction of ore storage areas.” Washington regulations (WAC 246-252-030 Criterion 5 (q)) and Colorado regulations (6 Code of Colorado Regulations [CCR] 1107-1 Part 18, Appendix A, Criterion 5H) contain similar language.

4.4.4 Dust Control

During operations it is required that the operator reduce the amount of dust. Active dust control is commonly accomplished by placing sprayer bars on conveyors and maintaining a wet tailings and heap-leach pad surface. During operation of the tailings impoundment it is common practice to maintain a flooded surface to reduce the potential for dust and radon emissions. In areas where flooding is not possible (e.g., the beach along the face of the dam) it is common to keep the tailings surface wet with sprayers. The active surface of the heap-leach pads is limited to 40 acres to reduce the potential for windblown contamination. The heap-leach pads and tailings impoundments should also be configured to reduce the amount of wind that will impact the surface of the tailings. This can be done by providing a berm around the outside of the pad or impoundment to prevent direct wind.

- **Washington State:** (WAC, 2002; 246-252-0303, Criterion 8) *“To control dusting from tailings, that portion not covered by standing liquids shall be wetted or chemically stabilized to prevent or minimize blowing and dusting to the maximum extent reasonably achievable.... To control dustings from diffuse sources, such as tailings and ore pads where automatic controls do not apply, operators shall develop written operating procedures specifying the methods of control which will be utilized.”*
- **NRC, Colorado:** The NRC (10 CFR 40, Appendix A, Criterion 8) states: *“Milling operations must be conducted so that all airborne effluent releases are reduced to levels as low as is reasonably achievable. The primary means of accomplishing this must be by means of emission controls. Institutional controls, such as extending the site boundary and exclusion area, may be employed to ensure that offsite exposure limits are met, but only after all practicable measures have been taken to control emissions at the source.... To control dusting from tailings, that portion not covered by standing liquids must be wetted or chemically stabilized to prevent or minimize blowing and dusting to the maximum extent reasonably achievable. This requirement may be relaxed if tailings are effectively sheltered from wind, such as may be the case where they are disposed of below grade and the tailings surface is not exposed to wind.”* Colorado regulations (6 CCR 1007-1 Part 18; Appendix A, Criterion 8) contains identical language. In addition, Colorado (6 CCR 1007-1 Part 18; Appendix A, Criterion 4B) requires that the tailings should be placed so that *“topographic features should provide good wind protection.”*

4.4.5 Tailings Cell Design for Operations

4.4.5.1 Siting

The siting of the tailings impoundment is important to the success of both the operations and closure of the impoundment. The selection of a site for a facility and the layout of the facility on the site can greatly reduce the risk of a containment failure and resulting impact to the environment. Regulatory guidance with respect to site selection seeks to promote short-term and long-term stability of all facility features including waste containment features. Regulatory guidance from the NRC and the states of Washington, and Colorado, is summarized below. The excerpts provided are those pertaining to site selection for the purpose of promoting stability of waste containment facilities.

- **NRC, Washington, Colorado:** The NRC addresses facility siting to promote stability of waste containment and other features (10 CFR 40, Appendix A, Criterion 1, 3, 4). Washington regulations (WAC 246-252-030, Criterion 1, 3, 4) and Colorado regulations (6 CCR 1007-1 Part 18, Appendix A) contain similar language.

“Criterion 1 – The general goal or broad objective in siting and design decisions is permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance. For practical reasons, specific siting decisions and design standards must involve finite times (e.g., the longevity design standard in Criterion 6). The following site features which will contribute to such a goal or objective must be considered in selecting among alternative tailings disposal sites or judging the adequacy of existing tailings sites:

Remoteness from populated areas;

Hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from ground-water sources; and

Potential for minimizing erosion, disturbance, and dispersion by natural forces over the long term.

The site selection process must be an optimization to the maximum extent reasonably achievable in terms of these features.

In the selection of disposal sites, primary emphasis must be given to isolation of tailings or wastes, a matter having long-term impacts, as opposed to consideration only of short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site and

engineering design, overriding consideration must be given to siting features given the long-term nature of the tailings hazards.

Tailings should be disposed of in a manner that no active maintenance is required to preserve conditions of the site.”

“Criterion 3 – The ‘prime option’ for disposal of tailings is placement below grade, either in mines or specially excavated pits (that is, where the need for any specially constructed retention structure is eliminated). The evaluation of alternative sites and disposal methods performed by mill operators in support of their proposed tailings disposal program (provided in applicants' environmental reports) must reflect serious consideration of this disposal mode. In some instances, below grade disposal may not be the most environmentally sound approach, such as might be the case if a ground-water formation is relatively close to the surface or not very well isolated by overlying soils and rock. Also, geologic and topographic conditions might make full below grade burial impracticable: For example, bedrock may be sufficiently near the surface that blasting would be required to excavate a disposal pit at excessive cost, and more suitable alternative sites are not available. Where full below grade burial is not practicable, the size of retention structures, and size and steepness of slopes associated exposed embankments must be minimized by excavation to the maximum extent reasonably achievable or appropriate given the geologic and hydrologic conditions at a site. In these cases, it must be demonstrated that an above grade disposal program will provide reasonably equivalent isolation of the tailings from natural erosional forces.

Criterion 4 – The following site and design criteria must be adhered to whether tailings or wastes are disposed of above or below grade.

(a) Upstream rainfall catchment areas must be minimized to decrease erosion potential and the size of the floods which could erode or wash out sections of the tailings disposal area.

(b) Topographic features should provide good wind protection.

(c) Embankment and cover slopes must be relatively flat after final stabilization to minimize erosion potential and to provide conservative factors of safety assuring long-term stability...

(d) A full self-sustaining vegetative cover must be established or rock cover employed to reduce wind and water erosion to negligible levels...”

4.4.5.2 Geotechnical Investigation

Mill tailings are generally contained in an impoundment and leached ore is contained on a heap-leach pad, both of which should be designed using engineering principles. The geotechnical properties of the tailings and leached ore need to be determined as part of the design process.

Laboratory testing of the soil and rock samples collected during the geotechnical investigation generally includes strength testing of the material to be used to construct the impoundments; consolidation/swell testing of the underlying soils; and consolidation/permeability testing of the underlying soils and the material to be placed in the tailings impoundment or on the heap-leach pad. The regulatory guidance reviewed indicated the types of analyses required to be completed for design of the waste containment systems and allowed the applicant to select the appropriate testing to complete the analyses and design.

- **Washington:** Washington (RCW 78.56.090, Subsection (4)) states that *“The technical site investigations phase shall consist of, but not be limited to, the following: (a) Soil characteristics; (b) Hydrologic characteristics; (c) A local and structural geology evaluation, including seismic conditions and related geotechnical investigations; (d) A surface water control analysis; and (e) A slope stability analysis.”*
- **NRC:** *“This review should cover exploration data, sampling and laboratory techniques, test results, descriptions of physical properties, and static and dynamic geotechnical engineering parameters of the materials, as well as discussions of ground-water conditions (e.g., perched, confined, or unconfined) for all critical subsurface strata at the site...”* (NRC, 2003; Nuclear Regulatory Commission Regulatory Guides [NUREG] 1620, Section 2.1.1).

4.4.5.3 Liner Design

Prior to about 1970 many tailings impoundments were constructed without liners. This method of construction of tailings impoundments resulted in long-term environmental impacts. Currently, the design and installation of liners and leak detection systems is standard practice for tailings impoundments and heap-leach pads. The state regulations reviewed (CO, WA, WY) and the NRC require that the applicant design a lined impoundment or heap-leach pad with a leak detection system. The design of these systems is to be provided in an engineering design report.

- **NRC, Washington, Colorado:** NRC (10 CFR 40, Criterion 5E (1)) states: *“Installation of bottom liners (where synthetic liners are used, a leakage detection system must be installed immediately below the liner to ensure major failures are detected if they occur. ... Where clay liners are proposed or relatively thin, in situ clay soils are to be relied upon for seepage control, tests must be conducted with*

representative tailings solutions and clay materials to confirm that no significant deterioration of permeability or stability properties will occur with continuous exposure of clay to tailings solutions.” Washington regulations (WAC 246-252-030, Criterion 5 (n)(i)) and Colorado regulations (6 CCR 1007-1 Appendix A, Criterion 5E) contain identical language.

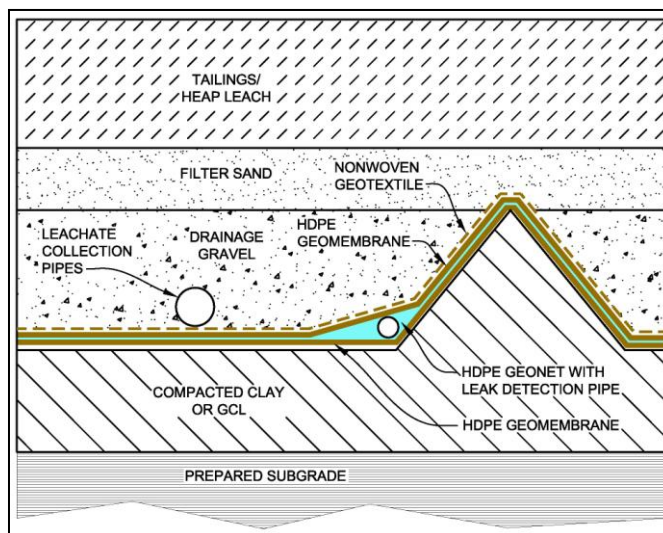


Figure 4-5 Generalized Liner Section

4.4.5.4 Slope Stability

As part of the design process it is common practice to complete slope stability analyses of the impoundments and heap-leach pads. Slope stability analyses should be completed using the seismic standards outlined in Section 7.0 of the Engineering Design BMPs report (Wright Environmental Services, 2012).

- **Washington State:** Washington requires that slope stability analyses be completed (Washington, 1994; RCW 78.56.090 (4) (e)).
- **NRC:** Section 2.2.1 of NUREG-1620 (NRC, 2003) states: “*The staff should examine exploration data, test results, slope characterization data, design details, and static and dynamic analyses related to the stability of all natural and manmade earth and rock slopes whose failure, under any of the conditions to which they could be exposed throughout the period of regulatory interest, could adversely affect the integrity of the slopes or embankments. This review should also include examination of static and dynamic materials properties, test and design methods, pore pressures within and beneath the embankment, and the design seismic coefficient.*”

4.4.5.5 Maintenance and Inspection

Inspections should be completed daily with maintenance as needed to reduce the potential for failure of the tailings impoundment.

- **Colorado:** Colorado (6 CCR 1007-1 Part 18, Appendix A, Criterion 8A) requires that *“Inspections of tailings or waste retention systems must be conducted daily during operations, or at an alternate frequency approved by the Department for other conditions. Such inspections shall be conducted by, or under the supervision of, a qualified engineer or scientist, and documented.”*

4.4.6 Disposal of Mill Tailings in Mine Workings

The disposal of uranium mill tailings (primarily the uranium ore stripped of its uranium content with spent milling liquids) in mine pits from whence the ore material originated is a practice historically employed in many mining industries (e.g., gold, copper, coal, uranium). This practice is contemplated by the NRC regulations and guidance, though it is not frequently used for disposal of uranium milling wastes. This concept is based on the precept that deep burial may afford a greater degree of long-term waste isolation than may be achieved through shallower disposal alternatives, though shallower disposal alternatives may also meet the criteria set forth in the regulations. However, the disposal of mill wastes in mine workings or other deep locations must still be demonstrated to be protective of public health and safety and the environment.

The overall objectives for mill waste stabilization are long-term physical stabilization and isolation of contaminants from human and environmental receptors. Permanent waste isolation *is* the explicit goal for the disposal of mill waste material. This is emphasized both in the siting of the disposal facilities and in the design of the disposal facilities. Specifically, Criterion 1 of 10 CFR 40, Appendix A states:

“The general goal or broad objective in siting and design decisions is permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces, and to do so without ongoing maintenance. For practical reasons, specific siting decisions and design standards must involve finite times (e.g., the longevity design standard in Criterion 6).

Criterion 11 of 10 CFR 40, Appendix A also acknowledges this concept by stating:

“In view of the fact that physical isolation must be the primary means of long-term control, and Government land ownership is a desirable supplementary measure, ownership of certain severable subsurface interests (for example, mineral rights) may be determined to be unnecessary to protect the public health and safety and the environment.”

Further, Criterion 3 of 10 CFR 40, Appendix A specifically identifies that byproduct disposal in mines may be an appropriate technical approach:

*“The ‘prime option’ for disposal of tailings is placement below grade, either in **mines** [emphasis added] or specially excavated pits (that is, where the need for any specially constructed retention structure is eliminated)”.*

Uranium mill tailings from the Riverton, Wyoming uranium mill site were reclaimed under Title I of the UMTRCA by the DOE. The tailings were placed in an approved mill tailings disposal cell in the A-9 uranium mine pit owned by Umetco Minerals Corporation (Umetco); additional tailings material from the Umetco operations were reclaimed deep within the C-18 pit (Umetco, 2004, 2000a, 2000b; NRC, 1999). Both pits were located within the NRC control boundary.

There is little specific guidance regarding subsurface disposal of mill material in mine workings. Deep burial of mill wastes in mine workings in many ways solves some of the challenges with waste isolation and stabilization. Deep burial in underground mine workings or in pits removes the materials from casual, unintentional, or even intentional intrusion by plants, animals, and humans, as the mill waste is beyond the reasonable reach of roots, burrowing animals, and innocent or malicious human intrusion. Further, deep burial isolates these materials from the erosive forces of nature that could transport and disperse contaminants back into the environment. Deep isolation of mill waste also obviates the need for radon barriers as it is considered likely that deep burial could be demonstrated to effectively attenuate radon flux through the thick overlying native materials, even if the properties of the overlying materials that effect radon flux evolved through time (e.g., changes in permeability, bulk density, moisture content, etc.). Similarly, all reasonable exposure to direct gamma radiation from the wastes would not be expected to be measurably different than pre-mining conditions as the wastes would have the same or lower total radioactivity as the ore from whence it was derived and would reside at or near the location they came from.

Where physical isolation may be acceptably accomplished through deep burial, the primary concern becomes immobilization of radiological and non-radiological hazardous constituents from infiltration, gradual dissolution, and subsequent transport by groundwater flow.

Groundwater protection is accomplished primarily through rigorous waste containment and operational design standards (10 CFR 40 Appendix A, Criterion 5). Specifically, Criterion 5A(3) allows for the applicant to propose disposal of mill waste material in unlined subsurface locations (i.e., mines workings as identified in Criterion 3) but must demonstrate:

“...that alternate design and operating practices, including the closure plan, together with site characteristics will prevent the migration of any hazardous constituents into ground water or

surface water at any future time. In deciding whether to grant an exemption, the Commission will consider—

- (a) The nature and quantity of the wastes;*
- (b) The proposed alternate design and operation;*
- (c) The hydrogeologic setting of the facility, including the attenuative capacity and thickness of the liners and soils present between the impoundment and ground water or surface water; and*
- (d) All other factors which would influence the quality and mobility of the leachate produced and the potential for it to migrate to ground water or surface water.”*

The standards for groundwater protection are identified in Criterion 5B through 5E. Therefore, though explicitly allowable as a proposal, the burden of proof of efficacy and durability of such disposal and stabilization proposal is on the applicant. There is no guidance on how an applicant would make this demonstration nor is this addressed within a Standard Review Plan for conventional uranium milling applications. However, the introduction to 10 CFR 40, Appendix A notes:

“All site specific licensing decisions based on the criteria in this Appendix or alternatives proposed by licensees or applicants will take into account the risk to the public health and safety and the environment with due consideration to the economic costs involved and any other factors the Commission determines to be appropriate.”

This section also acknowledges that:

*“In some instances, below grade disposal may not be the most environmentally sound approach, such as **might** [emphasis added] be the case if a ground-water formation is relatively close to the surface or not very well isolated by overlying soils and rock.”*

Regardless, the regulations in 10 CFR 40, Appendix A explicitly state:

“Licensees or applicants may propose alternatives to the specific requirements in this appendix. The alternative proposals may take into account local or regional conditions, including geology, topography, hydrology, and meteorology. The Commission may find that the proposed alternatives meet the Commission's requirements if the alternatives will achieve a level of stabilization and containment of the sites concerned, and a level of protection for public health, safety, and the environment from radiological and nonradiological hazards associated with the sites, which is equivalent to, to the extent practicable, or more stringent than the level which

would be achieved by the requirements of this Appendix and the standards promulgated by the Environmental Protection Agency in 40 CFR Part 192, Subparts D and E.”

Some tailings dewatering processes result in thickened tailings or paste tailings that result in lower water content and high solids content. Tailings can also be mixed with additives that will help it set up like a structural solid (e.g., additives with pozzolonic activity, such as cement or fly ash). Regardless of what manner the tailings are placed, amended or modified, their radiological and non-radiological hazardous constituents must be demonstrated to not pose a substantial present or potential future hazard to public health and safety. The rigor and acceptability of such a demonstration is determined by the regulatory agency, either NRC or the agreement state.

4.4.7 Closure/Reclamation Plan

4.4.7.1 Reclamation Plan

As part of the application process, the NRC and the states of Washington, Wyoming, and Colorado require that a reclamation plan be submitted to ensure that a site can be reclaimed.

- **Washington:** Washington (RCW 70.121.030, Subsection (1)(a)) states: *“The owner or operator of the mill shall submit to the department a plan for reclamation and disposal of tailings and for decommissioning the site that conforms to the criteria and standards then in effect for the protection of the public safety and health.”*
- **NRC:** The NRC (10 CFR Part 40, Appendix A Criterion 6A) states: *“For impoundments containing uranium byproduct materials, the final radon barrier must be completed as expeditiously as practicable considering technological feasibility after the pile or impoundment ceases operation in accordance with a written, Commission-approved reclamation plan.”*

4.4.7.2 Drain Out and Consolidation

Closure of the tailings impoundment involves dewatering and cover design. Primary dewatering of the tailings needs to be completed prior to the installation of the final cover system. Consolidation analyses of the tailings should be completed to estimate the length of time that it will take to develop a stable tailings surface that a final cover with radon barrier can be constructed on. Historically, tailings have taken a long time to consolidate, especially mill tailings with a large amount clay-sized material.

- **NRC:** Section 2.3.2 (3) of NUREG-1620 (NRC, 2003) requires *“...the estimate of the time at which the primary consolidation settlement of the tailings will be essentially complete. Generally, the radon barrier and disposal cell cover may be placed only after the settlement of tailings is essentially complete.”*

4.4.7.3 Final Cover Design

- **Colorado:** Colorado (6 CCR 1007-1 Appendix A, Criterion 6) states that the final cover should be constructed “*which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.*”
- **NRC:** NUREG-1623 (NRC, 2002) also contains similar text as discussed in the bullet above. The final cover design normally consists of radon attenuation analyses, erosional stability, infiltration analyses, stability analyses, and review of the potential intrusion of plants through the cover.

The amount of infiltration through the cover can be analyzed by completing unsaturated flow analyses using local climate data. A generalized cover section is provided in Figure 4-6.

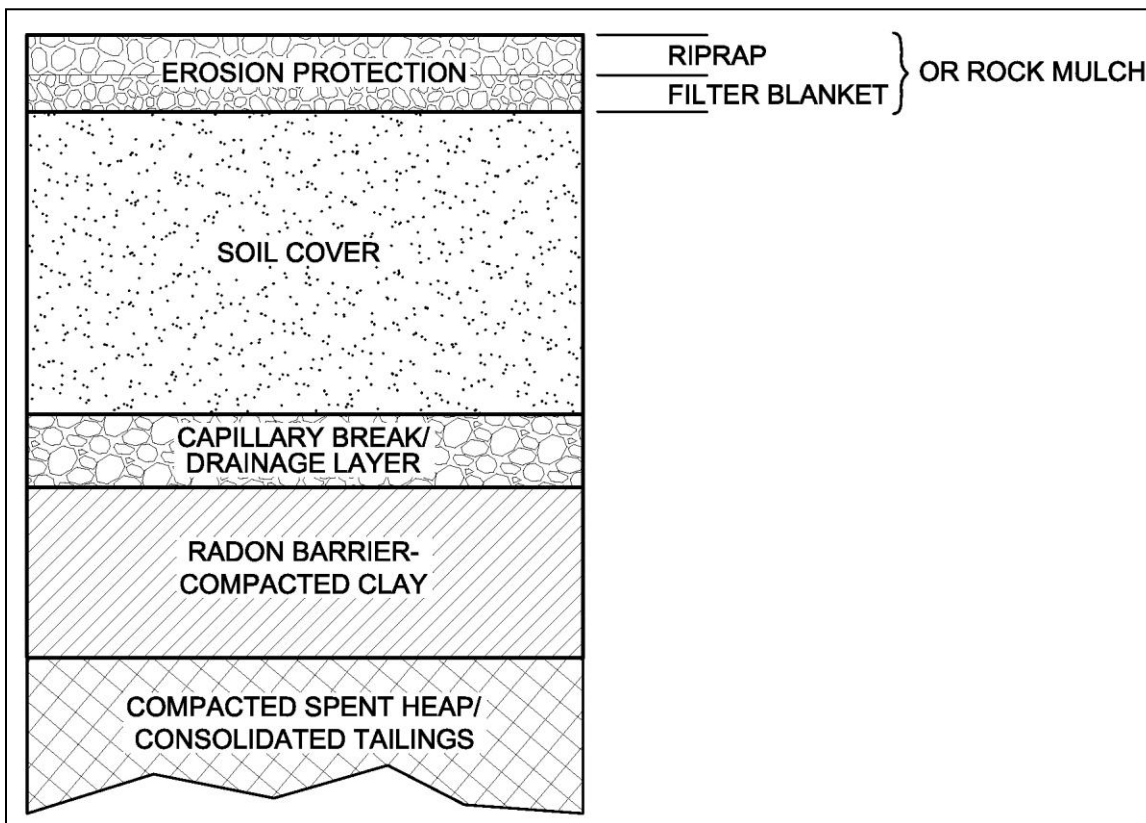


Figure 4-6 Generalized Final Cover Design

Slope Stability

Final stability analyses of the tailings impoundment and cover system is completed for static and pseudo-static cases. The NRC-specified seismic return period of 10,000 years should be used for the pseudo-static case.

- **NRC:** Section 2.2.1 of NUREG-1620 (NRC, 2003) states: *“The staff should examine exploration data, test results, slope characterization data, design details, and static and dynamic analyses related to the stability of all natural and manmade earth and rock slopes whose failure, under any of the conditions to which they could be exposed throughout the period of regulatory interest, could adversely affect the integrity of the slopes or embankments. This review should also include examination of static and dynamic materials properties, test and design methods, pore pressures within and beneath the embankment, and the design seismic coefficient.”*

Radon

The radon attenuation analyses are commonly completed using the NRC RADON program (NRC, 1989).

- **Washington:** Washington (WAC 246-252-030 Subsection (6)) requires that *“licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to: ... (ii) Limit releases of Radon-222 from uranium by-product materials, and Radon-220 from thorium by-product materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second (pCi/m²s).”*
- **Colorado:** Colorado (6 CCR 1007-1 Part 18, Appendix A, Criterion 6) requires *“Licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to (i) be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and (ii) limit releases of radon-222 from uranium byproduct materials, and radon-220 from thorium byproduct materials, to the atmosphere so as not to exceed an average release rate of 0.74 Becquerel per square meter per second (Bq/m² s), or 20 picocuries per square meter per second (pCi/m² s).”*
- **NRC:** NRC Regulatory Guide 3.64 (NRC, 1989) states: *“The NRC staff is required to analyze the adequacy of uranium tailings covers proposed in license applications*

to meet the EPA rules. The EPA rules in 40 CFR part 192 require that a cover be designed to produce reasonable assurance that the radon-222 release rate would not exceed $20 \text{ pCi m}^{-2} \text{ s}^{-1}$ for a period of 1000 years to the extent reasonable achievable and in any case at least 200 years when averaged over the disposal area at least a one-year period. NRC regulations in 10 CFR Part 40 also require that the radon-222 release rate not exceed $20 \text{ pCi m}^{-2} \text{ s}^{-1}$ for active (UMTRCA Title II) sites.” (NRC, 1989; Regulatory Guide 3.64).

Erosion

Erosion control of the tailings cover can be maintained by a vegetative cover and/or a riprap lined cover. While a vegetative cover will have normal growth cycles, a well functioning vegetative cover in a climate that will support good vegetative growth will greatly minimize infiltration over the life of the cover. Erosion analyses are commonly completed using the NRC guidance for determining final rock size and filter criteria for the cover system to reduce the potential for erosion (NRC, 2002; NUREG-1623). Rock mulch is commonly used for erosion control. Where larger material size is required riprap with a bedding layer is used.

- **NRC, Washington, Colorado:** NRC (10 CFR Part 40, Appendix A, Criterion 4(c)), Washington (WAC 246-252-030, Criterion 4(c)), and Colorado (6 CCR 1007-1 Part 18, Appendix A, Criterion 4) state: *“Embankment and cover slopes must be relatively flat after final stabilization to minimize erosion potential and to provide conservative factors of safety assuring long-term stability.”*

Additionally, NRC (10 CFR Part 40, Appendix A, Criterion 4(d)), Washington (WAC 246-252-030, Criterion 4(d)), and Colorado (6 CCR 1007-1 Part 18, Appendix A, Criterion 4(d)) state: “A full self-sustaining vegetative cover must be established or rock cover employed to reduce wind and water erosion to negligible levels.”

Bio-intrusion

Intrusion of plants and animals through the cover should be addressed as part of the final closure criteria. A capillary break is normally installed in the cover system to reduce the potential for burrowing animals to penetrate the tailings. The capillary break also prevents roots from penetrating the tailings, reduces infiltration, and reduces migration of salts to the surface of the cover.

Frost Penetration

Frost has the potential for reducing density of the radon barrier, thus resulting in a less effective radon barrier. The radon barrier needs to be placed below the frost depth to avoid freezing and

cracking of the radon barrier. The U.S. Army Corps of Engineers has developed software to determine the frost depth (Aitken and Berg, 1968).

- **NRC:** Section 2.5.2 (5) of NUREG-1620 (NRC, 2003) states: *“The reviewer should examine the disposal cell design and engineering parameters to assess the geotechnical aspects of the disposal cell cover. Specific aspects of the review should consider the following items:...*

(5) Determination that the disposal cell has been designed to accommodate the effects of anticipated freeze-thaw cycles.”

Construction Quality Assurance

The construction quality assurance is important for the long-term function of the tailings impoundment or heap-leach pad reclamation.

- **NRC:** Section 2.6.1 of NUREG-1620 (NRC, 2003) states: *“The staff should review information on the geotechnical aspects of reclamation construction. These aspects should include details such as the sequence and schedule for construction activities, material specifications and placement procedures, and quality control aspects of the construction procedures. The geotechnical aspects of the planned construction operations should be reviewed to identify any deviations from standard engineering practice for earthworks, including measures to protect against erosion and provisions for a vegetative cover, if appropriate”*

Closure of heap-leach pads is done in the same way as outlined above for tailings impoundments with the exception that heap-leach pads are generally rinsed during closure to avoid long-term seepage, ARD generation, and treatment of leachates. The period of time to drain-down and rinse-out a heap leach pad can be modeled using an unsaturated flow model (e.g., VADOSE/W), transport model (e.g., CTRAN/W), and geochemical model (e.g., PHREEQC).

Long-term care of a closed and reclaimed mill site historically has been turned over to the DOE. Washington (WAC 246-252-030 Subsection, (12)) states:

“The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation. As a minimum, annual site inspections must be conducted by the government agency retaining ultimate custody of the site where tailings or wastes are stored, to confirm the integrity of the stabilized tailings or waste systems, and to determine the need, if any, for maintenance and/or monitoring. Results of the inspection must be reported to the United States Nuclear Regulatory Commission within sixty days following each inspection. The United States Nuclear Regulatory Commission may require more frequent site

inspections if, on the basis of a site-specific evaluation, such a need appears necessary, due to the features of a particular tailings or waste disposal system.”

5.0 MITIGATION OF MINE AND MILL CONTAMINANTS FROM EXISTING SOURCES TO BOTH GROUNDWATER AND SURFACE WATER

5.1 Introduction

Sections 2.0 through 4.0 describe 1) Methods to identify rock which may generate ARD or metals-bearing leachates; 2) Selective handling plans for segregating reactive rock from less reactive and non-reactive rock; and 3) Methods to minimize the ecological risks from the release of radionuclides and contaminants from mining and milling operations. One of the objectives of mine/mill development plans, plans of operations, and closure plans should be to use this type of information to minimize the migration of radionuclide and metal-bearing leachates generated by the mine and mill facilities to groundwater and surface water. In this section, conceptual BMPs to mitigate contamination during the different mine life phases (construction, operation, and closure) are summarized. An overview of existing regulations related to mitigation is also presented.

The term “mitigation,” as defined in the Revised Code of Washington (RCW 78.56.020, Subsection 6) means: *“(a) To avoid the adverse impact altogether by not taking a certain action or parts of an action; (b) to minimize adverse impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology or by taking affirmative steps to avoid or reduce impacts; (c) to rectify adverse impacts by repairing, rehabilitating, or restoring the affected environment; (d) to reduce or eliminate adverse impacts over time by preservation and maintenance operations during the life of the action; (e) to compensate for the impact by replacing, enhancing, or providing substitute resources or environments; or (f) to monitor the adverse impact and take appropriate corrective measures.”*

5.2 Overview of Existing Regulations

- **Washington:** The state of Washington has promulgated regulations that parallel those provided by the NRC. Specifically, WAC 246-252-030, *Criteria relating to disposition of uranium tailings or wastes* is very similar to NRC 10 CFR Part 40 Appendix A and contains the same Technical Criteria (5D, 5E, and 5F) described below.

Washington (RCW 78.56 Part 100(1)(a)(ii)) states: *“The toxicity of mine or mill tailings and the potential for long-term release of regulated substances from mine or mill tailings shall be reduced to the greatest extent practicable through stabilization, removal, or reuse of the substances.”*

- **Wyoming:** The WYDEQ-LQD-Noncoal Program (WYDEQ-LQD, 2006) Chapter 3, Section 2 states:

*(i) Tailings impoundments, tailings disposal areas, heap leach facilities and spent ore disposal areas shall be designed, constructed, and operated in accordance with established engineering principles using best technology currently available to ensure long term stability and to prevent contamination of surface or groundwater. Appropriate leak detection and groundwater monitoring systems shall be installed to detect any movement of contaminated fluids from the facility. **Any leakage or movement of contaminated fluids shall be promptly controlled and remediated using the best technology currently available subject to the Administrator's approval [emphasis added].** Impoundments shall be permitted by the Wyoming State Engineer's Office and copies of the State Engineer's permits shall be attached to the application."*

Additionally, in WYDEQ-LQD (WYDEQ-LQD, 1994b) Guideline No. 6 (*Application for a "Permit to Mine" or an Amendment*), the guidance indicates that the mine plan should contain the following information in the section discussing mine hydrology (Part III.C.8): "*Discussion of potential impacts to surface and ground waters and other water resources from mining and mining-related activity. **Plan to mitigate such impacts during mining [emphasis added].***"

- **Colorado:** Colorado's "mitigation" regulations parallel those provided by the NRC. Specifically, Colorado's 6 CCR 1007-1, Part 18 Appendix A is very similar to NRC Appendix A of 10 CFR Part 40 and contains the same Technical Criteria (5D, 5E and 5F) described below.
- **NRC:** NRC information relevant to mitigation with respect to tailings impoundments is provided in 10 CFR Part 40 Appendix, Criterion 5D. Specifically, Criterion 5D indicates that applicants should consider, among other things:
 - Solution recycling to reduce net input of liquid to the tailings impoundment;
 - Dewatering of tailings to reduce the head within the impoundment; and
 - Neutralization to promote immobilization of hazardous constituents.

If a leak from the tailings impoundment occurs and the groundwater protection standards established under Appendix A are exceeded at a licensed site then, under Criterion 5D, a corrective action program must be put into operation as soon as is practicable, and in no event, later than 18 months after the standards have been exceeded. Furthermore, Technical Criterion 5F states that "*action must be taken to alleviate conditions that lead to excessive seepage impacts and restore ground-water*

quality.” Technical Criterion 5F further indicates that the remedial action “must be worked out on a site-specific basis.”

5.3 Conceptual BMPs for Phases of Mine Life

Some conceptual BMPs for various phases in the mine/mill life cycle are presented in this section. The BMPs are based on information from the NRC and the states of Wyoming, Colorado, and Washington. Additional international sources are also cited.

5.3.1 Site Preparation/Construction Phase

The potential for leachates to be generated during the development phase of a mine and mill are low. Exceptions can occur such as if pre-stripping of overburden for an open pit mine exposes mineralized material, or driving of tunnels, shafts, etc. for an underground mine exposes mineralized material that comes in contact with groundwater.

Construction phase mine and mill surface water contaminants are controlled by erosion and sedimentation controls that must be in place prior to commencement of mining and mill construction. Therefore, the focus at this stage should be on the collection and incorporation of additional site-specific data into the design and construction of engineered structures, revision of site models, and continued enhancement of BMPs. Specific areas of focus should include:

- Continued collection and testing of ore, sub-ore grade material, and overburden to refine the source terms for materials to be placed in tailings impoundments, waste rock piles, etc. This could include the initiation of field-scale testing described in Section 2.0.
- Collection of site-specific hydrologic, hydrogeologic, geologic, and geotechnical data to further the siting and design of the tailings impoundments, waste rock piles, etc. The physical and chemical properties of the soils and groundwater underlying facilities that would contain mine rock, processed ore, etc. could also be characterized to assist in future fate and transport assessments, if required.
- As the mine/mill design continues to be optimized, the site water balance should be updated.

During the site preparation phase, activities could be considered to mitigate contaminants.

- Surface water control to limit the volume of “run-on” water from adjacent up-gradient areas. The run-on control features should be sized to control water generated by a precipitation/flood event that is linked to the duration of the preparation/construction phase.

- Groundwater control depending on the extent of the stripping or tunneling. From an environmental standpoint, the goal of the groundwater control should be to minimize the contact of background water with mineralized surfaces exposed by the stripping/tunneling. If the groundwater control involves pumping, then a monitoring program to document the quality of the produced water will be required.
- Disposal of waste rock generated by the stripping or tunneling at appropriate locations. Where the chemical, radiological, and physical characteristics of the material are appropriate, waste rock may be used for construction purposes at the site provided it would not produce impacts to the surface water or groundwater.
- A management plan for contact water generated from incident precipitation and seepage, including water quality monitoring, may be required.

5.3.2 Operations Phase

During the operations phase, there are opportunities to implement BMPs that reduce the volume of leachate generated and/or to decrease the metals concentration, radionuclide activity, acidity, etc. in the leachate. These include the selective handling of materials, active water management, and use of engineering controls to inhibit infiltration. The permitting process should recognize that each mine and mill is unique and should provide the operator the flexibility to propose to manage mine and mill wastes in a variety of ways that all arrive at the same goal, protection of human health and the environment.

As described in Section 3.0, planned handling and disposal of rocks of different properties (both chemical and physical) can be implemented at various phases in the mine/mill life cycle. For example, rocks with excess net neutralization potential can be strategically placed with respect to rocks with excess net acid generating potential in disposal areas to ameliorate ARD as shown in Figure 3-1. Additionally, larger reactive rock fragments may be co-disposed with finer grained materials to limit water/oxygen contact with the reactive rock and/or to inhibit radon emanation from the larger rock.

Management of water in the tailings and other features can be balanced with the operations of the mine or mill. For example, mill tailings can be processed in a variety of ways to result in tailings of variable water content. The optimal tailings handling method depends on site-specific geography (e.g., distance and elevation difference between mill and tailings facility), overall facility water balance, chemistry of the tailings, health and safety, throughput, etc. Water can also be used as a cover to inhibit ARD generation and to provide a radiation shield.

Measures can also be included in the operations plan to limit water infiltration into processed ore or mine rock storage facilities at mines and mills. The use of interim covers and other

engineering controls should be encouraged to reduce the volume of leachate generated. The use of interim covers may have ancillary benefits by controlling dust and decreasing radon flux.

An adaptive management plan, such as that described by the Canadian Nuclear Safety Commission (CNSC) RD/GD-370 (CNSC, 2012) and the International Atomic Energy Agency (IAEA) NF-T-1.2 (IAEA, 2010), is an important component to the mine permit. By incorporating adaptive management into the permit, the operator can take advantage of site-specific experience to continuously improve waste management practices. Empirical data collected during the operations phase should also be used to update and improve the site water balance on a regular basis, as well as other site models. As mining/milling progresses, empirical data for waste rock, processed ore, etc. should be used to refine source terms used in water quality/water management models. If the mine/mill has incorporated progressive remediation into its mine plan, then data and experience obtained during the operations phase can be employed to refine the closure plan.

5.3.3 Closure Phase

During the closure phase, the goal of the permit should be to quickly transition the facility from active management to long-term maintenance. The objectives of the closure plans with respect to mitigation of contaminants from waste rock piles, tailings impoundments, etc. should include:

- Dewatering tailings, if appropriate, to minimize long-term water treatment obligations and to enhance tailings consolidation (which expedites capping);
- Capping of areas such as waste rock piles, tailings impoundments, heap-leach pads and other areas to isolate potential sources of contaminants to groundwater and surface water;
- Reducing the volume of leachate generated by decreasing both the short- and long-term infiltration into waste rock piles, tailings impoundments, etc;
- To the extent practicable, decreasing the concentration of metals, radionuclide activity, acidity, etc. of the leachate by manipulating the geochemical conditions within the waste rock piles, tailings impoundments, etc;
- Transitioning treatment of leachate (if necessary) from active to passive;
- As the mine/mill progresses through the closure process, the site water balance should be updated; and
- Ongoing monitoring and refinement of the closure plan (adaptive management).

Depending upon the type of tailings, active dewatering during the closure phase may expedite both the transition from active to passive water treatment (if required) and the capping of the pile. As previously discussed, the permitting process should recognize that each milling process

is unique and should provide the operator the flexibility to propose to manage tailings (and water) in a variety of ways that all arrive at the same goal – protection of human health and the environment.

Preparation of the waste rock facilities, tailings impoundments, etc. for temporary cover should begin as soon as practicable. This may include grading and dewatering/consolidation, as previously discussed. After dewatering/consolidation is completed the final cover can be placed on the tailings. The sooner the cover is constructed, the lower the volume of water entering the pile and the lower the volume of leachate generated.

The covers serve multiple purposes. With respect to limiting infiltration, the design basis for the cover must be consistent with the requirements to reduce radon releases from the pile (e.g., NRC, 1989; Regulatory Guide 3.64). The same design criteria limiting radon flux from the pile can also be exploited to limit oxygen flux into the pile, thereby inhibiting ARD generation.

If active water treatment is required at the mine or mill during operations, it will likely be required to operate into the closure period. One of the goals of the closure plan should be to expedite the transition of water treatment from active technologies to passive technologies. Passive technologies will decrease both the carbon and water footprint of the facility, decrease the volume of daily waste generated at the site, and potentially shorten the decommissioning phase. Passive treatment should include the concept of natural attenuation, where it can be demonstrated to be technically viable.

As discussed under the operations phase, inclusion of an adaptive management plan into the permit will allow the operator to take advantage of site-specific experience to continuously improve waste management practices, even during closure. The site water balance should continue to be updated on a regular basis as facilities are closed and reclaimed. As closure progresses, empirical data for waste rock, processed ore, etc. should be used to refine source terms used in water quality/water management models.

6.0 ON-SITE WORKERS HEALTH AND SAFETY RELATED TO MINE AND MILL WASTE

6.1 Introduction

Mines operate under stringent federal and state regulations established to protect workers and the environment. The Federal Mine Safety and Health Act of 1977 gives the U.S. Department of Labor the authority to issue and enforce health and safety standards related to the working conditions in underground and surface mining, milling, and related operations. Within the Department of Labor, the Mine Safety and Health Administration (MSHA) is responsible for oversight and enforcement related to the Mine Safety Act. The Occupational Safety and Health Administration (OSHA) has authority over occupational health and safety matters not regulated by MSHA. The NRC regulates exposure to radiation under 10 CFR Part 20 for all NRC licensed facilities. Agreement states for uranium mining (e.g., Colorado and Washington) have adopted 10 CFR Part 20 regulations as their radiation exposure protection regulations.

At uranium mines and mills, the primary sources of potential radiation exposure are uranium decay and radon gas. Although uranium itself is not highly radioactive, the ore which is mined, especially if it is high-grade ore, must be regarded as potentially hazardous due to uranium's decay products.

Radon gas emanates from the rock (or tailings) as radium decays. Radon gas then decays to (solid) radon daughters, which are energetic alpha-emitters. Radon occurs in most rocks and a trace amount exists in the atmosphere. However, at high concentrations radon is a health hazard since its short half-life means that disintegrations giving off alpha particles are occurring relatively frequently. Alpha particles discharged in the lung can later give rise to lung cancer. Because radon naturally occurs in all mines, radon gas is strictly monitored by MSHA. Monitoring of radon is discussed further in a Virginia Department of Health (VDH) report which is in preparation.

Radiation exposure of workers in the mine, plant, and tailings areas from the ore and tailings are usually very low. Additionally, dust controls are effective in minimizing the exposure of workers to heavy metals and radon. Radon daughter exposure is minimal in an open pit mine because there is sufficient natural ventilation to remove the radon gas.

6.2 MSHA Mining Regulations

Mine health and safety in the U.S. is regulated by the MSHA and the regulations are found in the Code of Federal Regulations 30 CFR – Parts 1 to 199.

MSHA mine worker safety regulations regarding radon exposure are found in 30 CFR Part 57.5037. This regulation pertains to radon daughter exposure monitoring for workers located at facilities where uranium is mined and those where uranium is not mined.

Sampling equipment, sampling procedures, sampling frequency, and record keeping requirements are specified. The regulation states that sampling shall be done using suggested equipment and procedures described in Section 14.3 of the American National Standards Institute (ANSI) N13.8-1973, entitled “*American National Standard Radiation Protection in Uranium Mines*,” approved July 18, 1973, pages 13-15, by the American National Standards Institute, Inc. (ANSI, 1973). This publication may be examined at any MSHA Metal and Nonmetal Mine Safety and Health district office, or may be obtained from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th Floor, New York, NY 10036; <http://www.ansi.org>.

6.3 Current Virginia Radiation Protection Regulations That Apply to Mining

Regulations included in the Virginia Administrative Code (VAC) are not specifically related to uranium mining but are a part of the Radiation Protection Regulation VAC 5-481-600 which regulates human exposure to radiation sources in general. These regulated sources include diagnostic x-rays, other radiographic or tomographic systems, and brachytherapy. The regulations apply to persons licensed or registered by the agency to receive, possess, use, transfer, or dispose of sources of radiation. The Radiation Protection Programs (10 CFR 20.1101) and Definitions (10 CFR 20.1003) are applicable in the Commonwealth of Virginia (VAC 5-481-630). This regulation describes licensing requirements, the limits of human exposure to radiation, handling of equipment and reporting requirements for sources of radiation. The Commonwealth of Virginia will need to develop radiation protection regulations prior to issuing permits for uranium mining.

6.4 Mining Regulations Related to Uranium Mining

On-site worker health and safety regulations pertaining to specifically to radon daughter exposure monitoring are found in the MSHA mine worker safety regulations found in 30 CFR Part 57.5037. MSHA regulations are federal and are applicable to all mining activities in the U.S. However, the NAS (NAS, 2011) report titled “*Uranium Mining in Virginia*” references the International Commission on Radiological Protection (ICRP) recommendation for radon, which is more stringent than the MSHA requirement. Virginia regulation VAC 5-481-630 addresses radiation protection programs and occupational dose limits. Virginia defers to 10 CFR Part 20 – Standards for Protection Against Radiation. NRC agreement states (e.g., VA, CO, WA) have adopted NRC 10 CFR Part 20 as its radiation protection regulation.

6.5 NRC/Federal Regulations (10 CFR Part 20)

As an agreement state, Virginia has established programs to assume NRC regulatory authority under the Atomic Energy Act of 1954, as amended. Under this agreement the NRC relinquishes portions of its regulatory authority to license and regulate byproduct materials, source materials, and certain quantities of special nuclear material. However, Virginia's agreement with the NRC does not address uranium milling.

10 CFR Part 20 – “*Standards for Protection Against Radiation*” applies to all NRC licensed facilities and has been adopted by the Commonwealth of Virginia. The regulation is comprehensive and specifically addresses the following: radiation protection programs, occupational dose limits, radiation dose limits for individual members of the public, radiological criteria for license termination, surveys and monitoring, control of exposure from external sources in restricted areas, respiratory protection and controls to restrict internal exposure in restricted areas, storage and control of licensed material, precautionary procedures, waste disposal, records, reports, exemptions and additional requirements, and enforcement.

Occupational dose limits for adults are discussed in 10 CFR Part 20.1201. NRC licensed facilities are required to adhere to these dose limits except for planned special exposures under 10 CFR Part 20.1206.

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