

## **EXHIBIT G**

### **DEQ/DMME URANIUM STUDY: ENGINEERING DESIGN BEST MANAGEMENT PRACTICES**

# Uranium Study:

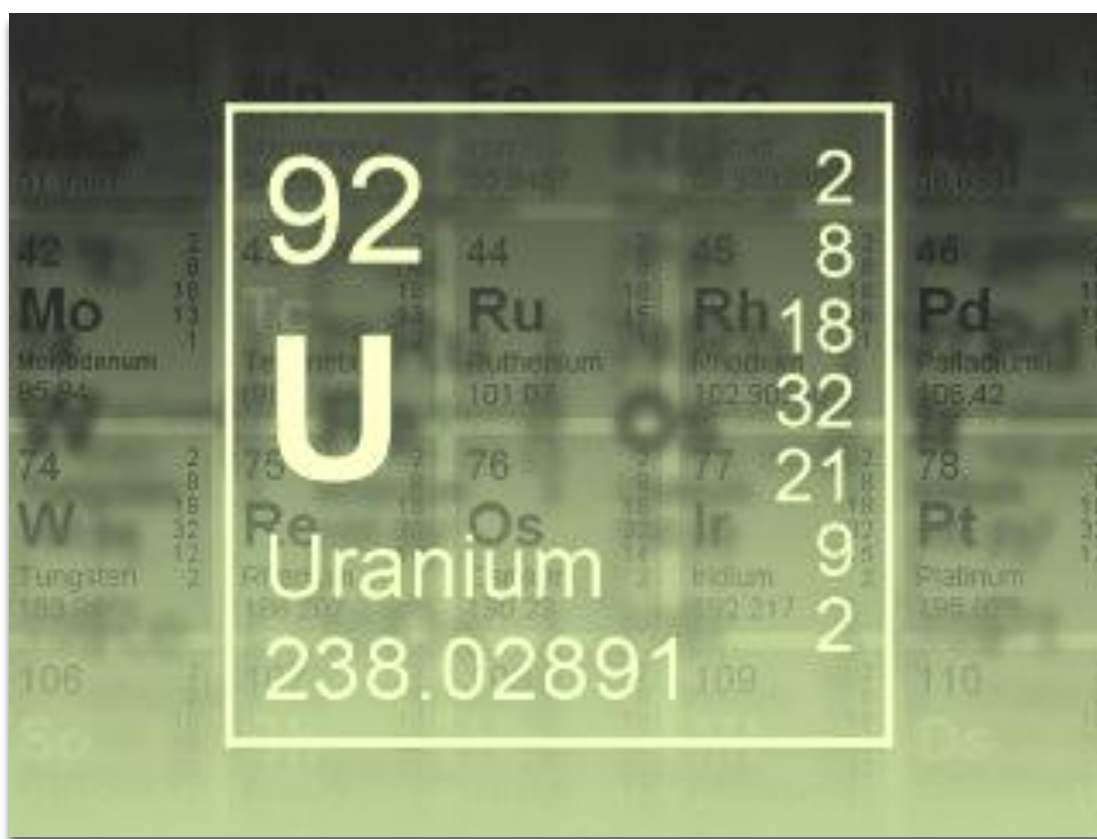
## Engineering Design Best Management Practices

### Commonwealth of Virginia

Department of Environmental Quality

Department of Mines, Minerals and Energy

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## ABBREVIATIONS

ACOE	U.S. Army Corps of Engineers
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
AST	Above-Ground Storage Tank
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
BMP	Best Management Practice
BSSC	Building Seismic Safety Council
CCR	Code of Colorado Regulations
CDPHE	Colorado Department of Public Health and Environment
CDRMS	Colorado Division of Reclamation Mining and Safety
CFR	Code of Federal Regulations
CMLRB	Colorado Mined Land Reclamation Board
CO	Colorado
COVERERP	Commonwealth of Virginia Radiological Emergency Response Plan
CWA	Clean Water Act
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulation Commission
GCL	Geo-Composite Liner
HAP	Hazardous Air Pollutant
HDPE	High-Density Polyethylene
IAEA	International Atomic Energy Agency
IBC	International Building Code
ICC	International Code Council
ISR	In Situ Recovery
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCE	Maximum Considered Earthquake
MSHA	Mine Safety and Health Administration
NAS	National Academy of Sciences
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NUREG	Nuclear Regulatory Commission Regulatory Guides

## ABBREVIATIONS (continued)

NSHMP	National Seismic Hazard Mapping Project
NSTS	National Source Tracking System
O&M	Operations and Maintenance
OAR	Oregon Administrative Rule
ODEQ	Oregon Department of Environmental Quality
ODGMI	Oregon Department of Geology and Mineral Industries
ODOE	Oregon Department of Energy
OR	Oregon
PGA	Peak Ground Acceleration
PM	Particulate Matter
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PUP	Precipitation Uncertainty Processor
RCW	Revised Code of Washington
RFP	Request for Proposal
SAP	Sampling and Analyses Plan
SPCC	Spill Prevention, Control, and Countermeasure
UL	Underwriters Laboratory
U.S.	United States
USGS	U.S. Geological Survey
UST	Underground Storage Tank
UWG	Uranium Working Group
VDEQ	Virginia Department of Environmental Quality
VDMME	Virginia Department of Mines, Minerals and Energy
WA	Washington
WAC	Washington Administrative Code
WES	Wright Environmental Services
WY	Wyoming
WYDEQ	Wyoming Department of Environmental Quality
WYDEQ-LQD	Wyoming Department of Environmental Quality, Land Quality Division
WYSEO	Wyoming State Engineer's Office

## 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 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 the engineering design best management practices (BMPs) for addressing risk and catastrophic events in mining and milling. These risks include catastrophic events, environmental factors, extreme flooding, landslides, seismic events, impacts to surface and groundwater, and vulnerability to attack. 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 VDEQ 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 Task A report. This report has been prepared to address Part F of Work Task B (B.2.f) and provides a discussion of engineering design best management practices. This report also addresses Part I of Work Task B (B.2.i) and discusses methods for addressing risks of catastrophic events.

## 1.2 Purpose and Scope

The purpose of this report is to respond to Work Task B.2.f and B.2.i in Contract EP881027, which assesses engineering designs and best management practices designed to prevent the release of radionuclides and other contaminants from mining into air, groundwater, and/or surface waters, including but not limited to:

- review of methods for addressing risks of catastrophic events;
- best management practices for minimizing the environmental effects of the failure of a waste containment facility;
- review of methods and practices for minimizing the risk of extreme flooding events;
- assessment of risks from landslides, debris flows, and slope failures;
- assessment of risks from seismic events;
- assessment of risks from the failure of on-site storage facilities;
- vulnerability analysis for security events; and
- review of criteria to develop an effective hydrogeological model for use at potential sites.

Based on a review of existing studies, existing regulatory programs, and emerging international standards, this report presents an initial analysis and recommendations for engineering design best management practices for assessing potential risks and catastrophic events.

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 METHODS FOR ADDRESSING RISK OF CATASTROPHIC EVENTS**

### **2.1 Introduction**

Accidents and natural disasters may interrupt the normal operations of a mine or mill site. With proper engineering design, quality construction, a comprehensive operations and maintenance (O&M) plan, and planning and training for accidents and natural disasters, these events should not result in releases of mine, mill, or related contaminants to the environment. Potential events that could occur at a mine or mill site that need to be accounted for in the design, construction, and operations include those of both natural and manmade origin. Some of these events are discussed in the following sections of this report.

#### **2.1.1 Natural Events**

Natural events may include weather and/or seismic events. Extreme weather events (e.g., severe rain, high wind, lightning, hail, flooding, forest/grass fires) may occur separately or may occur in various combinations, such as in a hurricane. Extreme weather events may occur in any season (e.g., tornados in the spring, hurricanes in the summer and fall, blizzards in the winter). Extreme weather events may be localized, such as a lightning strike which takes out a key piece of equipment, or regional, such as a hurricane or blizzard. Regional events may not only affect the facility, but may also damage public infrastructure and inhibit the ability of outside resources to assist in any required response.

The climate of an area generally determines the likelihood of certain types of weather events. Precipitation events lead to the necessity of design for prevention of flooding. The methods and practices for minimizing the risk of extreme flooding events are discussed in detail in Section 4.0 of this report.

The potential for seismic events is determined by the seismicity and geologic conditions of an area. Section 6.0 provides a detailed discussion of the methods for determining the potential for seismic events and best management practices to minimize the risk if a seismic event does occur.

#### **2.1.2 Manmade Events**

Manmade events may be accidental (e.g., spills, leaks, breaches, fires, explosions) or intentional (e.g., terrorism, eco-terrorism, cyber attacks). Accidents and attacks may be localized at one specific location of the mine/mill, but they may impact the overall ability of the facility to function by rendering key systems inoperable.

## 2.2 Regulatory Guidance

Mining of uranium is generally regulated by state agencies. The milling of uranium has historically been regulated by either the Nuclear Regulatory Commission (NRC) or state agencies under an agreement with the NRC (i.e., agreement states).

Regulations from the states of Wyoming, Colorado, Washington, Oregon and from the NRC were reviewed. Review of state regulations did not identify any specific or explicit discussion of design or management requirements addressing the risks of catastrophic events. 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) contains provisions for the development and implementation of both an "*Environmental Protection Plan*" and an "*Emergency Response Plan*." Although not an explicit requirement of these types of plans, the long-term stability of tailings disposal facilities mandated by the NRC and agreement states implies that this type of analysis be performed.

For uranium mills, the state of Colorado (6 Code of Colorado Regulations [CCR] 1007-1 Part 18, Appendix A) and the state of Washington (WAC 246-252-030) both contain the NRC Technical Criterion 5A (10 Code of Federal Regulations [CFR] Part 40, Appendix A), which qualitatively states: "*A surface impoundment must be designed, constructed, maintained, and operated to prevent overtopping resulting from normal or abnormal operations, overfilling, wind and wave actions, rainfall, or run-on; from malfunctions of level controllers, alarms, and other equipment; and from human error.*" NRC guidance generally indicates that mill facilities must be designed for the most extreme precipitation events. Recent NRC license applicants in the arid west have designed restricted areas to contain all precipitation from the probable maximum precipitation (PMP) storm, a theoretical maximum precipitation event for the site-specific area.

For uranium mines, operational and reclamation design standards would be established by the regulating state or commonwealth for both operational and long-term (reclamation/post-closure) stability and environmental protection. Different states have different requirements for design of operational conditions (e.g., surface water flows). The states of Colorado and Wyoming provide guidance for the design flows of hydraulic structures based on the return interval of the rainfall event, though the bases identified differ significantly.

- **Colorado:** The state of Colorado's *Rules and Regulations for Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010, Rule 6.3.3(2)(c)) states that the mine plan must:

*"...include design details demonstrating the capacity of ditches and impoundment structures to contain operating solutions and the volume of water generated by a one hundred (100) year 24-hour rainfall event."*

- **Wyoming:** The Wyoming Department of Environmental Quality Land Quality Division (WYDEQ-LQD) provides minimum standards for temporary diversions and culverts in their Guideline No. 8 (*Hydrology*) (WYDEQ-LQD, 2005, Part III.B.1):

*“Minimum standards require that temporary diversion channels be designed for the 2-yr, 6-hr event or a duration that yields a higher peak flow.”*

The guideline goes on to recommend that the design event recurrence interval be selected based on the structure's expected lifetime and an appropriate probability of failure for the function of the diversion. Recommended design event return periods are listed in Table 2-1.

**Table 2-1      Design Event Return Periods**

<b>Life of Diversion</b>	<b>Storm Event Return Period</b>
< 3 yrs	10 yr
3-10 yrs	25 yr
11-20 yrs	50 yr
>20 yrs	100 yr

## 2.3 Discussion of Impacts

Some natural disasters can be predicted far enough in advance (e.g., hurricanes, blizzards) to help prepare the mine or mill for the extreme event, thereby limiting the consequences of potential damage to the facility. Other natural disasters, such as a tornado or earthquake, or manmade disasters from accidents or vandalism, occur with little or no warning.

Mine or mill site facilities need to be designed, constructed, and operated such that damage to facilities does not result in a release to the environment. Damage to site facilities that occurs during catastrophic events should be evaluated through the quick performance of pre-designed inspections. Any damage identified through the inspection process will be prioritized for repair and appropriate remedies determined. The permitting process could include provisions for inspection of the site by agency personnel following natural or manmade events to ensure confidence in a safe re-start.

The nature and extent of any impacts from a catastrophic event would be determined through the execution of an approved characterization study. The study may include sampling of air, surface water, groundwater, soils, sediment, stream/lake sediment, and aquatic/terrestrial flora and fauna. The results of the sampling should be evaluated using pre-approved risk assessment methods and



compared to pre-established risk levels. Remediation may be required in areas where the risks exceed the pre-established levels.

The permitting process should require the development of an emergency response plan. As part of the plan development, the proposed mine and/or mill operator should undertake a process to assess the risks associated with natural and manmade events. For natural events, the process should consider both the probability that the event will occur (e.g., recurrence interval for precipitation, flood, earthquake) and the severity of the consequences of the event. The severity of the consequences should be assessed both geographically (e.g., on-site, local, regional) and temporally (e.g., based on the half-life of any radionuclides potentially involved).

Precipitation and flooding analyses for design are discussed in further detail in Section 4.0. Seismic hazard analyses are commonly performed to assess seismic risk. The two types of analyses used are deterministic and probabilistic. These are discussed in detail in Section 6.0.

With respect to acts of vandalism, as discussed by the International Atomic Energy Agency (IAEA, 2007), the probabilistic distribution of natural events (i.e., the larger the event, the lower the frequency of occurrence) may not hold true. There is essentially no known model for assessing frequency of manmade events or impacts from manmade events.

## **2.4 Best Management Practices**

The responsibility of management of any type of facility, including owner/operators of uranium mines and mills, is to design, construct, plan, and train for a variety of potential events that may threaten worker health and safety, public health and safety, or the environment through an uncontrolled release. By requiring sufficient planning, rigorous design, high quality construction, adequate training, and diligent operational monitoring and maintenance, the probability that a catastrophic event will result in a release to the environment can be minimized and, in the event of a release, the consequences minimized through a collaborative response involving the appropriate local, commonwealth, and federal resources.

The permitting and licensing process should include the preparation of an emergency response plan. The plan should be reviewed and approved by applicable local, commonwealth, and federal agencies. The plan should be periodically reviewed (i.e., annually or when significant changes to facilities or operations are made) and, if appropriate, revised and re-approved. The content and procedures of the plan should draw upon those in the Commonwealth of Virginia Radiological Emergency Response Plan (COVRERP) and other emergency response plans developed for the Commonwealth's other nuclear facilities to ensure consistent agency response, if needed.



### **3.0 MINIMIZATION OF BOTH LONG-TERM AND SHORT-TERM ENVIRONMENTAL EFFECTS OF THE FAILURE OF A WASTE CONTAINMENT FACILITY**

#### **3.1 Introduction**

During mining and milling operations, facilities are required to control liquid and solid waste material. The types of waste containment facilities are unique to each mining and milling operation. With proper engineering, construction, operation, and inspection, these facilities will not allow the unintended release of solid and/or liquid material.

Though unlikely to occur with proper engineering, operation, and inspection, containment failures are possible. A containment failure may consist of a “chronic” failure such as a leaking liner or pipe, ongoing air emissions, or ongoing spillage resulting from haulage between the mine and the processing facility. With this type of failure, the failure may occur for some period of time before it is detected by an applicable monitoring program.

Alternatively, a containment failure may consist of a “one time” failure event such as a pipe rupture, a waste dump failure, an ore truck overturning. The source of these events is easier to identify than the chronic failures listed above, and the impacts are often recognized immediately.

This section discusses the potential impacts of containment failures and regulatory, engineering, and operational practices that will serve to minimize the risk of a containment failure and the resulting impact. This discussion is based on review of guidance documents from Colorado, Washington, Oregon, Wyoming, and the NRC. Wyoming is not an agreement state and therefore falls under the NRC guidance for the containment of radioactive waste.

#### **3.2 Impacts of Containment Failures**

A failure of a containment system can have an effect on surface water, groundwater, air quality, and nearby soils. The degree of the impact is a function of the mode of failure, the nature of the impacted material, and the type of material released.

##### **3.2.1 Surface Water**

While controlled releases to surface waters may be allowed under strict permit or license conditions, uncontrolled releases can result in surface water impacts. Potential sources of uncontrolled releases to surface water include:

- Mining:
  - infiltration into and subsequent seepage from ores and mine waste;
  - loss of containment (leaks, spills, etc.) of fuels, cleaning solvents, etc.;
  - inadequate storm water design and controls; and
  - leakage or overflow (liquid and sediment) from lined ponds (mine water storage or storm water).
- Milling
  - loss of containment (leaks, spills, etc.) of fuels, mill reagents, process vessels and lines, mill laboratory wastes, etc.;
  - inadequate storm water design and controls;
  - leakage or overflow (liquid and sediment) from lined ponds (process water or storm water); and
  - leakage from tailings impoundments or heap leach pads.

The nature of potential surface water impacts depends on the type of release, the timeliness of corrective action and, if necessary, remediation, and the site-specific hydrogeologic and geochemical conditions. In contrast to groundwater flow rates, surface water flow rates are typically much faster (on the order of 100s to 10,000s of feet per day). These higher flow and transport rates typically do not afford much response time for corrective action and once materials are released, they can make their way into and along surface water systems rapidly.

Surface water impacts are often the result of overflow or failure of a containment system (i.e., storm water plan failure, process or waste pond failure, etc.). When there is an overflow of a containment system, it is usually in response to a large precipitation event, often in combination with poor design, construction, and/or inspection and maintenance activities. Failures of containment systems that impact surface waters are generally observed at the time of failure or shortly thereafter. As noted above, surface water generally travels much further in a shorter amount of time compared to groundwater. The materials may spread quickly, but may also be diluted and attenuated by surface flows.

Guidance documents from Colorado, Washington, Wyoming, and the NRC relate to surface water impacts:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 5B) states the following will be considered with respect to surface water quality. Washington regulations (Washington Administrative Code [WAC] 246-252-030, Criterion 5) and Colorado regulations (6 CCR 1007-1, Part 18, Appendix A) contain similar language.

*“Potential adverse effects on hydraulically-connected surface water quality, considering:*

- (i) The volume and physical and chemical characteristics of the waste in the licensed site;*
  - (ii) The hydrogeological characteristics of the facility and surrounding land;*
  - (iii) The quantity and quality of ground water, and the direction of ground water flow;*
  - (iv) The patterns of rainfall in the region;*
  - (v) The proximity of the licensed site to surface waters;*
  - (vi) The current and future uses of surface waters in the area and any water quality standards established for those surface waters;*
  - (vii) The existing quality of surface water including other sources of contamination and the cumulative impact on surface water quality;*
  - (viii) The potential for health risks caused by human exposure to waste constituents;*
  - (ix) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and*
  - (x) The persistence and permanence of the potential adverse effects.”*
- **Wyoming:** The Wyoming Hard Rock Mining Permit Handbook (WYDEQ-LQD, 2012) states that the applicant should “describe potential impacts to water resources from mining activities...”.

### 3.2.2 Groundwater

Groundwater impacts can result from numerous potential sources including:

- Mining:
  - dewatering of adjacent groundwater wells;
  - changes to groundwater quality from surface and underground mining due to oxidation and other geochemical changes;
  - infiltration into and subsequent seepage from ores and mine waste;
  - loss of containment (leaks, spills, etc.) of fuels, cleaning solvents, etc.; and
  - leakage from ponds (mine water storage or storm water).

- Milling
  - infiltration into and subsequent seepage from ores stockpiled on mill sites;
  - loss of containment (leaks, spills, etc.) of fuels, mill reagents, process vessels and lines, mill laboratory wastes, etc.;
  - well casing leakage and line leaks from in situ recovery (ISR) well fields; and
  - leakage from lined ponds (process water or storm water), tailings impoundments or heap leach pads.

The nature of these impacts depends on the type of release, the timeliness of corrective action and, if necessary, remediation, and the site specific hydrogeologic and geochemical conditions. Groundwater flow rates are usually relatively slow (on the order of a few 10<sup>th</sup>s of feet to 10s of feet per year), typically allowing time for corrective action and remedial actions to be designed, approved, and implemented before public exposure becomes likely. However, some fractured bedrock systems can have flow rates much greater.

The potential for groundwater impacts makes robust baseline groundwater characterization essential for mine and mill applications. These characterizations allow advance understanding of potential pathways, transport rates, and potential impacts.

The following guidance documents from Colorado, Washington, Wyoming, and the NRC pertain to groundwater impacts:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 5B) states the following will be considered with respect to groundwater quality. Washington regulations (WAC 246-252-030, Criterion 5) and Colorado regulations (6 CCR 1007-1, Part 18, Appendix A) contain similar language.

*“Potential adverse effects on ground-water quality, considering:*

- (i) The physical and chemical characteristics of the waste in the licensed site including its potential for migration;*
- (ii) The hydrogeological characteristics of the facility and surrounding land;*
- (iii) The quantity of ground water and the direction of ground water flow;*
- (iv) The proximity and withdrawal rates of ground water users;*
- (v) The current and future uses of ground water in the area;*
- (vi) The existing quality of ground water, including other sources of contamination and their cumulative impact on the ground water quality;*
- (vii) The potential for health risks caused by human exposure to waste constituents;*

(viii) *The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;*

(ix) *The persistence and permanence of the potential adverse effects.”*

- **Wyoming:** The Wyoming Hard Rock Mining Permit Handbook (WYDEQ-LQD, 2012) states that the applicant should “describe potential impacts to water resources from mining activities...”

### 3.2.3 Air Quality

Air quality standards are established on a site-by-site basis and are usually based on modeled hazardous air pollutant (HAP) levels identified in the air permit as well as radon levels and radionuclide particulate levels (40 CFR 61, Subpart b). Fugitive dust and hazardous air pollutants (e.g., NO<sub>x</sub>, SO<sub>2</sub>, CO, VOC, SVOC, ozone) are also potential issues and should be addressed as part of the Clean Air Act permit. The Wright Environmental Services Air Quality Monitoring Report (WES, 2012a) addresses air quality in more detail. Exceedances of the air quality standards are measured at the mine permit boundary or radiation control boundary and, in the case of radionuclides, at the nearest downgradient receptor. Air quality standards are generally met throughout operations through implementation of best management practices and emissions largely cease as soon as reclamation is completed and the sources are contained.

### 3.2.4 Soil

Windblown contamination of surface soils and haulage spills can have a large impact on closure and clean up requirements. Windblown soils can result in bioaccumulation of elevated metals and radionuclide concentrations in plants and animals. The impact of bioaccumulation of contaminants is beyond the scope of this report and will be addressed in other reports. Windblown soil may also impact surface water channels and bodies of water. It is important for the operator to collect baseline soils data prior to the start of operations to establish baseline conditions. The baseline data allow the regulators and operator to evaluate the impact to downgradient soils from windblown tailings and ore and impacts to soils from spillage of fuel and/or other materials.

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 8) states the following: *“The greatest potential sources of offsite radiation exposure (aside from radon exposure) are dusting from dry surfaces of the tailings disposal area not covered by tailings solution and emissions from yellowcake drying and packaging operations.”* Washington regulations (WAC 246-252-030, Criterion 8) and Colorado regulations (6 CCR 1007-1 Part 18, Appendix A) contain identical language.

### 3.3 Probability of Occurrence

The regulations reviewed for this report (CO, WA, OR, WY, NRC) do not address the probability of failure of containment systems. Regulations are commonly written based on a predetermined factor of safety that must be achieved or a return interval for storms of precipitation events that must be designed for. Methods for addressing extreme flooding events are addressed in Section 4.0. The current practice is to limit risk through engineering design, operational controls, and monitoring, as discussed below.

### 3.4 Minimizing Risk

The current regulatory framework seeks to minimize risk through a variety of controls including proper site selection, a comprehensive monitoring program, engineering design controls, and operational/institutional controls. This section provides a discussion of these general BMPs, along with the regulatory guidelines. An additional discussion providing BMPs specific to tailings impoundments is provided in Section 3.5.

#### 3.4.1 Site Selection

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, Colorado, and Wyoming 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 Part 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..."*
- **Washington:** Washington regulations (RCW 78.56.090) address siting criteria:
    - (1) In the processing of an application for an initial waste discharge permit for a tailings facility pursuant to the requirements of chapter 90.48 RCW, the department of ecology shall consider site-specific criteria in determining a preferred location of tailings facilities of metals mining and milling operations and incorporate the requirements of all known available and reasonable methods in order to maintain the highest possible standards to insure the purity of all waters of the state in accordance with the public policy identified by RCW 90.48.010...*
    - (3) The primary screening phase will consist of, but not be limited to, siting criteria based on considerations as to location as follows:*
      - (a) Proximity to the one hundred year floodplain, as indicated in the most recent federal emergency management agency maps;*
      - (b) Proximity to surface and ground water;*
      - (c) Topographic setting;*
      - (d) Identifiable adverse geologic conditions, such as landslides and active faults..."*

### 3.4.2 Monitoring and Reporting Program

One of the key components to minimizing the long-term and short-term effects of a failure of a waste containment facility is requiring that the applicant develop an adequate monitoring and reporting program. The monitoring program must include the collection of an adequate set of baseline environmental data. Without good baseline data, it is very difficult for the regulatory agency and the operator to determine the extent of or if any environmental impacts have occurred as a result of mining activity. During construction and operation, ongoing monitoring



is required to verify the effectiveness of containment measures. A clear mechanism for emergency reporting should also be established.

Regulatory guidance for the NRC and for the states of Colorado and Washington applies to monitoring and reporting.

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 7, 8A) states the following with respect to monitoring. Washington regulations (WAC 246-252-030, Criterion 7, 8A) and Colorado regulations (6 CCR 1007-1, Part 18, Appendix A) contain similar language.

*“Criterion 7 – At least one full year prior to any major site construction, a preoperational monitoring program must be conducted to provide complete baseline data on a milling site and its environs. Throughout the construction and operating phases of the mill, an operational monitoring program must be conducted to measure or evaluate compliance with applicable standards and regulations; to evaluate performance of control systems and procedures; to evaluate environmental impacts of operation; and to detect potential long-term effects.”*

*“Criterion 8A – Daily inspections of tailings or waste retention systems must be conducted by a qualified engineer or scientist and documented. The licensee shall retain the documentation for each daily inspection as a record for three years after the documentation is made. The appropriate NRC regional office as indicated in Appendix D to 10 CFR Part 20 of this chapter, or the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC, 20555, must be immediately notified of any failure in a tailings or waste retention system that results in a release of tailings or waste into unrestricted areas, or of any unusual conditions (conditions not contemplated in the design of the retention system) that is not corrected could indicate the potential or lead to failure of the system and result in a release of tailings or waste into unrestricted areas.”*

- **Colorado:** Colorado requires the following emergency notification if a failure of a key facility occurs (CMLRB, 2010, Rule 8, Section 8.1):

*“Operators shall notify the Office, as soon as reasonably practicable, but no later than twenty-four (24) hours, after the Operator has knowledge of a failure or imminent failure of any of the following:*

*(a) any impoundment, embankment, stockpile or slope that poses a reasonable potential for danger to human health, property or the environment;*

*(b) for a designated mining operation, any Environmental Protection Facility designed to contain or control designated chemicals or process solutions as identified in the permit;*

*(c) for in situ leach mining operations, any structure designed to prevent, minimize, or mitigate the adverse impacts to human health, wildlife, ground or surface water or the environment; and*

*(d) for in situ leach mining operations, any structure designed to detect, prevent, minimize, or mitigate adverse impacts on ground water.”*

#### **3.4.2.1 Air Monitoring**

With respect to air monitoring, the following regulatory language can be found:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 8) states the following with respect to air monitoring. Washington regulations (WAC 246-252-030, Criterion 8) and Colorado regulations (6 CCR 1007-1, Part 18, Appendix A) contain similar language.

*“Criterion 8 – 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. ...The greatest potential sources of offsite radiation exposure (aside from radon exposure) are dusting from dry surfaces of the tailings disposal area not covered by tailings solution and emissions from yellowcake drying and packaging operations. During operations and prior to closure, radiation doses from radon emissions from surface impoundments of uranium or thorium byproduct materials must be kept as low as is reasonably achievable.*

*Checks shall be made and logged hourly of all parameters (e.g., differential pressure and scrubber water flow rate) which determine the efficiency of yellowcake stack emission control equipment operation. The licensee shall retain each log as a record for three years after the last entry in the log is made. It must be determined whether or not conditions are within a range prescribed to ensure that the equipment is operating consistently near peak efficiency; corrective action shall be taken when performance is outside of prescribed ranges. Effluent control devices shall be operative at all times during drying and packaging operations and whenever air is exhausting from the yellowcake stack.”*

NRC Regulatory Guide 4.14, Revision 1 (*Radiological Effluent and Environmental Monitoring at Uranium Mills*) (NRC, 1980b) provides additional guidance with respect to monitoring. The radiological impact will be addressed in more detail in other reports.

#### 3.4.2.2 Groundwater Monitoring

With respect to groundwater monitoring, the following regulatory language can be found:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 7A) states the following with respect to groundwater monitoring. Washington regulations (WAC 246-252-030, Criterion 7) and Colorado regulations (CCR 1007-1, Part 18, Appendix A) contain similar language.

*“Criterion 7A – ...The licensee shall establish a detection monitoring program needed for the Commission to set the site-specific ground-water protection standards in paragraph 5B(1) of this appendix. For all monitoring under this paragraph the licensee or applicant will propose for Commission approval as license conditions which constituents are to be monitored on a site specific basis. A detection monitoring program has two purposes. The initial purpose of the program is to detect leakage of hazardous constituents from the disposal area so that the need to set ground-water protection standards is monitored. If leakage is detected, the second purpose of the program is to generate data and information needed for the Commission to establish the standards under Criterion 5B...”*

There are no standards that indicate the number of groundwater monitoring wells that must be installed. Criterion 5B of the NRC regulations cited above (as well as the corresponding Colorado and Washington regulations) states:

*“The Commission will also establish the point of compliance and compliance period on a site specific basis through license conditions and orders. The objective in selecting the point of compliance is to provide the earliest practicable warning that the impoundment is releasing hazardous constituents to the ground water. The point of compliance must be selected to provide prompt indication of ground-water contamination on the hydraulically downgradient edge of the disposal area. The Commission shall identify hazardous constituents, establish concentration limits, set the compliance period, and may adjust the point of compliance if needed to accord with developed data and site information as to the flow of ground water or contaminants, when the detection monitoring established under Criterion 7A indicates leakage of hazardous constituents from the disposal area.”*

NRC Regulatory Guide 4.14, Revision 1 (*Radiological Effluent and Environmental Monitoring at Uranium Mills*) (NRC, 1980b) provides additional guidance with respect to monitoring. The radiological impact will be addressed in more detail in other reports.

### 3.4.3 Engineering Controls

A primary means of containing the wastes from mine and mill sites is by proper engineering of such facilities. All facilities and monitoring systems must be designed by licensed professionals and constructed, maintained, and monitored by qualified personnel. The design bases for the engineering controls are developed to mitigate the risk to a level considered acceptable. Careful consideration of the requirements for design of these controls is essential to ensuring the level of protection deemed necessary. For example, all storm water facilities must be designed to withstand extreme flooding events, as discussed in Section 4.0 below. Likewise, all embankments and other facilities must be designed in accordance with appropriate seismic criteria, as discussed in Section 6.0. A full discussion of all of the required engineered structures or the engineering principles and standards that are required is beyond the scope of this report.

The current regulatory framework is structured to use design principles to control risk and does not quantify risk. Following are examples of regulatory language:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 5A) states the following with respect to surface facilities. Washington regulations (WAC 246-252-030, Criterion 5) and Colorado regulations (CCR 1007-1, Part 18, Appendix A) contain similar language.

*“5A(4) – A surface impoundment must be designed, constructed, maintained, and operated to prevent overtopping resulting from normal or abnormal operations, overfilling, wind and wave actions, rainfall, or run-on; from malfunctions of level controllers, alarms, and other equipment; and from human error.*

*5A(5) – When dikes are used to form the surface impoundment, the dikes must be designed, constructed, and maintained with sufficient structural integrity to prevent massive failure of the dikes. In ensuring structural integrity, it must not be presumed that the liner system will function without leakage during the active life of the impoundment.”*

### 3.4.4 Operational and Institutional Controls

A variety of operational and institutional controls can be implemented to contain mine and mill constituents. The monitoring and inspection of mine and mill facilities and well defined control boundaries including air monitoring, groundwater monitoring, and surface water monitoring will allow the regulatory agencies and the operators to identify adverse trends in a timely manner. Identifying and mitigating adverse trends and impacts in a timely fashion reduces corrective

action response time as well as remedial action costs and generally results in reduced impact to public health, safety, and the environment.

Limiting the amount of hydrostatic head on a waste containment liner system will reduce the flux rate of potential liner leaks. Recent NRC license applications have limited the head on the liner systems to two feet. This can be accomplished through the use of drains and leachate collection systems. Though this is not a regulation, it is now considered a BMP. Washington state regulatory guidance (RCW 78.56.100, Subsection 1.a.iii) indicates that *“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...”*.

The use of institutional controls such as signage and site security will also help reduce the risk of system failure.

### 3.4.5 Dust Mitigation Procedures

During operations, dust suppression and filters are used to reduce the potential for offsite air emissions. Flooding of the impoundment (i.e., keeping a large pool of water on tailings) and limiting the size of the exposed heap-leach pad being leached will also help to reduce the potential for dust and radon emissions for the site. The actual impact to the air is naturally mitigated very quickly as soon as the source is removed. It should be noted that dust emissions are potentially less in wetter parts of the country such as Virginia than in the arid west due to higher average moisture contents of soils and waste materials.

To reduce the risk of mine and mill constituent migration through air transport (fugitive dust), dust control measures are required by NRC and the agreement states:

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 8) states the following with respect to dust control. Washington regulations (WAC 246-252-030, Criterion 8) and Colorado regulations (CCR 1007-1, Part 18, Appendix A) contain similar language.

*“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. 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. Consideration must be given in planning tailings disposal programs to methods which would allow phased covering and reclamation of tailings impoundments because this will help in controlling particulate and radon emissions during operation. 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.”*

### 3.4.6 Waste Containment Liners

The states of Washington and Colorado along with the NRC require that uranium mill tailings facilities and other impoundments be constructed with liner and leak detection systems.

- **NRC, Washington, Colorado:** The NRC (10 CFR Part 40, Appendix A, Criterion 5A) states the following with respect to liners. Washington regulations (WAC 246-252-030, Criterion 5) and Colorado regulations (6 CCR 1007-1, Part 18, Appendix A) contain similar language.

*“5A(1) – The primary ground-water protection standard is a design standard for surface impoundments used to manage uranium and thorium byproduct material. Unless exempted under paragraph 5A(3) of this criterion, surface impoundments (except for an existing portion) must have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the impoundment to the adjacent subsurface soil, ground water, or surface water at any time during the active life (including the closure period) of the impoundment. The liner may be constructed of materials that may allow wastes to migrate into the liner (but not into the adjacent subsurface soil, ground water, or surface water) during the active life of the facility, provided that impoundment closure includes removal or decontamination of all waste residues, contaminated containment system components (liners, etc.), contaminated subsoils, and structures and equipment contaminated with waste and leachate. For impoundments that will be closed with the liner material left in place, the liner must be constructed of materials that can prevent wastes from migrating into the liner during the active life of the facility.*

*5A(2) – The liner required by paragraph 5A(1) above must be—*

*(a) 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;*

*(b) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift; and*



*(c) Installed to cover all surrounding earth likely to be in contact with the wastes or leachate.”*

- **Washington:** Washington requires that the liner design be provided in an engineering design report (RCW 78.56.100, Subsection 1.a.ii):

*“(ii) The tailings facility shall have a containment system that includes an engineered liner system, leak detection and leak collection elements, and a seepage collection impoundment to assure that a leak of any regulated substance under chapter 90.48 RCW will be detected before escaping from the containment system. The design and management of the facility must ensure that any leaks from the tailings facility are detected in a manner which allows for remediation pursuant to chapter 90.48 RCW. The applicant shall prepare a detailed engineering report setting forth the facility design and construction. The applicant shall submit the report to the department of ecology for its review and approval of a design as determined by the department. Natural conditions, such as depth to groundwater or net rainfall, shall be taken into account in the facility design, but not in lieu of the protection required by the engineered liner system...”*

The best liner systems constructed with good quality assurance/quality control measures still have allowable leakage rates (see EPA 40 CFR 264.222). This is discussed further in Section 3.5.2 of this report. It is possible to calculate the allowable leakage rate for a liner system as part of radioactive materials license applications.

### 3.4.7 Secondary Containment

The use of a double liner system for uranium mill waste management including liquid process wastes, tailing impoundments, and heap-leach pads is required by the NRC regulations as well as those of Colorado and Washington. The NRC and agreement states also require a compacted clay or geo-composite liner (GCL) under the double liner system to capture any effluent that might escape the double liner. Secondary containment is also required for all mill processes and reagents to contain spills from fuel tanks, mining fluids, milling fluids, etc.

### 3.4.8 Covers

To control surface migration of the tailings solids, the long term leaching of tailings constituents to the groundwater system, and emanation of radon from the tailings to the atmosphere, a low infiltration cover system is generally required (NUREG-1623) (NRC, 2002). Cover systems are also required for mine waste rock in Colorado and Washington. Washington regulations (RCW 78.56.100, Subsection 1.b.iii) require *“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.”* The amount

of infiltration through the cover can be analyzed by completing unsaturated flow analyses using local climate data. The cover design is discussed in more detail in the report titled “*Uranium Study: Safe Disposal of Mine and Mill Wastes*” (WES, 2012b).

### 3.4.9 Diversion Channels

To reduce the potential for overtopping of impoundments or erosion of cover systems, the use of diversion channels is required for uranium mills and is commonly required by states for uranium mines. Depending on the state regulations, the operational diversion channels for mines are sized based on the 100-year storm or a series of precipitation events while diversion channels for mills are sized based on the PMP, the 100-year storm plus the PMP, or a series of precipitation events. The use of diversion channels also reduces the amount of water that will flow over a section, thus reducing the infiltration into material and reducing the potential for sediment transport off site. Wyoming statutes (Title 35-11-406(b)(xiv)) require that the applicant provide “*the methods of diverting surface water around the affected lands where necessary to effectively control pollution or unnecessary erosion.*” Storm water diversion is discussed further in the following section.

NRC Regulatory Guide 3.11 (NRC, 2008b) addresses diversion channel design for tailings impoundments. Section 2.2.2 of the guideline states: “*Any channels that are needed to protect against flooding and erosion of embankments or tailings should be designed to safely pass a PMF with minimal, if any, damage to the channel. The essential criterion is that no release of tailings or contaminated materials should occur during a PMF, with the recognition that onsite personnel can repair minor damage within a short period of time. For example, a channel could be designed to pass only a 100-year flood, so long as the PMF does not result in the release of contaminated material.*”

## 3.5 Tailings Impoundments

Tailings impoundments are usually located within or adjacent to the mill area and collect the processed material left over from the uranium extraction process. Tailings impoundments include a variety of features including embankments, liners, pipelines, and collection systems. This section discusses measures to properly design, construct, and manage mill tailings impoundments to minimize the risk of impoundment failure.

In NRC Regulatory Guide 3.11.1 (NRC, 1980a), the NRC states: “*Causes of latent danger inherent in such works arise from site conditions, hydrologic and hydraulic features, types and qualities of the structures, operation and maintenance, and influence of the environment... Of these causes, the majority lie within the boundaries of modern technology and can be avoided.*” Table 1 in the Regulatory Guide (NRC, 1980a) provides a summary of uranium mill tailings releases between the years of 1959 to 1979, including the type of incident and the cause of the release. With respect to these historic releases, the Regulatory Guide states: “*Most failures have*



*resulted from gradually worsening defects (due to design, construction, operation, or lack of maintenance) that were either undiscovered or misjudged.”*

Tailings are regulated by the NRC (or the agreement state) and are to be isolated from the surrounding environment. Regulatory guidelines from the NRC, Wyoming, Colorado, and Oregon are discussed:

- **NRC:** NRC regulations pertaining to tailings impoundments are provided in 10 CFR Part 40, Appendix A. Applicable regulations are also addressed in NUREG-1620 (NRC, 2003b). In addition, NRC Regulatory Guide 3.11 (NRC, 2008b) titled “*Design, Construction, and Inspection of Embankment Retention Systems at Uranium Recovery Facilities*” provides detailed guidance for tailings facilities. Section B.1 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Because the prime functions of the retention system are to store radioactive solids and/or to provide temporary storage of contaminated water for clarification and evaporation, they system must be designed and constructed to remain stable for its intended life. It must provide the required storage at any given time, and it must provide sufficient control of seepage to prevent unacceptable contamination of adjacent land, waterways, and ground waters. It must also be designed to be resistant to wind and water erosion during and after facility operation.”*

- **Wyoming:** The state of Wyoming is a non-agreement state and as such tailings impoundments are regulated by NRC regulations as outlined in 10 CFR Part 40, Appendix A.
- **Colorado:** Within Colorado, tailings are regulated through the Department of Public Health and Environment (CDPHE) Hazardous Materials and Waste Management Division under 6 CCR 1007-1. The CDPHE utilizes the Code of Federal Regulations with regard to protection of the environment. In particular 40 CFR 264.221 (*Design and Operating Requirements*) relates to liners for tailings. The CDPHE will utilize these regulations and, depending on the situation, may integrate additional measures if deemed necessary.
- **Oregon:** The state of Oregon is an agreement state, like Colorado, but does not have the authority to regulate mill tailings. Their regulations (Division 92, Statutes 345-092-0010 and following) subrogate authority directly to the NRC rules and regulations and is handled very similar to Wyoming via 10 CFR Part 40, Appendix A.

### 3.5.1 Tailings Impoundment Embankments

Tailings embankments designed using sound engineering principles coupled with routine inspections and leakage prevention measures provide safe, long-term retention of tailings

materials. NRC Regulatory Guide 3.11 (NRC, 2008b) provides detailed guidance with respect to the design and construction of tailings embankments. Following is a summary of guidance provided in the various sections of Regulatory Guide 3.11 (NRC, 2008b). The basic design criteria are typically drawn from NRC 10 CFR Part 40, Appendix A.

#### **3.5.1.1 Field Exploration and Laboratory Testing**

A comprehensive field investigation program is required to properly design tailings impoundments in general and tailings embankments in particular. Section B.1.2 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Subsurface investigations at the site of the retention system and at possible borrow areas need to be of adequate scope to determine the suitability of the foundation and the availability and characteristics of embankment materials. Borings should be drilled along the axis of the retention structure and at critical locations perpendicular to the axis to establish geologic cross sections and ground-water conditions. Generally, borings should extend to a depth in the natural soils at least equal to the height of the planned embankment section...”*

As a part of the field investigation program, laboratory testing is required to characterize the materials. Section B.1.3 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Testing soil samples of foundation and embankment materials from the field investigation should result in detailed knowledge of such physical and mechanical properties as classification, gradation, shear strength, consolidation, permeability, sedimentation, compaction, piping and cracking susceptibility, and wind-water erosion characteristics.”*

#### **3.5.1.2 Engineering Design and Analysis**

Engineering design of tailings embankments should consider a variety of criteria including slope stability, settlement, etc. Section B.2 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Design analysis should consider stability, settlement, seepage, hydrologic analyses, liner stability, and liner compatibility. Specifically, the design must ensure that retention system failure will not occur. Historical records...indicate that most failures associated with tailings retention systems have been caused by overtopping by flood waters, erosion, piping in the retention embankment or the foundation, foundation failure, slope failure, or liquefaction.”*

Each of the potential failure mechanisms pertaining to tailings embankments can be addressed through proper engineering design and analysis.

Slope stability analyses are required to ensure a constructed tailings embankment will maintain the required factors of safety under a variety of conditions. Section B.2.1.1 of Regulatory Guide 3.11 (NRC, 2008b) provides a discussion of the various methods of analysis that can be

used to evaluate the geotechnical stability of embankment slopes including methods for static analysis and seismic analysis. Regulatory Guide 3.11 (NRC, 2008b) also addresses the various loading conditions for which stability analyses are necessary including: 1) end of construction, 2) partial pool with steady seepage, 3) maximum storage pool with steady seepage, and 4) earthquake loading. Section C.2.e of Regulatory Guide 3.11 (NRC, 2008b) provides minimum factors of safety for each of these loading conditions.

If the field exploration program and laboratory testing identify the presence of liquefiable soils, an analysis of the liquefaction potential of the soils is required. Section B.2.1.2 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Liquefaction impacts on stability need to be considered, if potentially liquefiable soils exist below the site of a retention system. Evaluation of liquefaction potential should include laboratory testing, in situ testing, and comparisons to similar soil deposits...”*

*“If liquefaction potential exists at a retention system site, additional subsurface investigation may be necessary. Once all testing is complete, a factor of safety against liquefaction should be calculated for each critical layer that may liquefy...”*

Settlement analysis of the foundation soils underlying a tailings embankment is required to ensure successful long-term performance of the embankment. Analyses should be performed to determine the anticipated rate and magnitude of settlement. Section B.2.1.3 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“If the foundation beneath an embankment retention system consists of layers of compressible soils or weathered rock, or if the bedrock profile is very irregular, differential settlements could result from uneven loading or variable thicknesses in the compressible soils. Total settlement and differential settlements may cause cracking and/or excessive strain in the embankments or other retention system components that could lead to system failure.*

*...After total and differential settlement analyses have been performed, the engineered components of the waste retention system, such as geotextiles, geomembranes, clay liners, drainage layers, leachate collection piping, and waste piping, should be analyzed for tensile strain. The analysis should verify that the components can maintain their integrity when subjected to the induced strain associated with the settlement determined in the total and differential settlement analyses. If analysis indicates that total and differential settlement along any cross-section is likely to damage an engineered component, or to cause the engineered component to be unable to meet the minimum design criteria, then the retention system must be redesigned to eliminate the adverse effects of total and differential settlement. Methods such as overbuilding, surcharging, removal of the material causing the problem, or engineered reinforcement can be used to mitigate the effects of settlement.”*

Depending on the unique conditions at each site, additional engineering analyses may be required to design the tailings embankments. These analyses may include, but are not limited to, seepage analyses, hydrostatic uplift potential, and/or the potential for soil collapse, expansion, or piping.

### **3.5.2 Tailings Impoundment Liners**

Tailings impoundments are required to have liners to prevent the migration of tailings waste to the surrounding environment. Section B.2.2.4.2 of Regulatory Guide 3.11 (NRC, 2008b) states: *“An embankment retention system for uranium recovery wastes is required to have a liner to prevent the migration of wastes to surrounding soil, ground water, or surface water during its operation and closure period. The design of a liner system should consider subgrade material, type of liner system, liner system protection, and leak detection. A complete liner system should also address anticipated installation techniques and operating practices...”*

#### **3.5.2.1 Liner Subgrade**

The liner subgrade should be properly characterized by the field exploration and laboratory testing program. Section 2.2.4.2 of Regulatory Guide 3.11 (NRC, 2008b) states: *“Proper design and understanding of the subgrade soils is very important to the success of a liner system. Design of the subgrade should consider the available soils, focusing on their gradation and moisture/density relationships. The subgrade surface needs to be competent and able to withstand the anticipated construction traffic.”*

In 10 CFR Part 40, Appendix A, Criterion 5A(2)(b), the NRC states that liners should be placed *“upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift...”*

Settlement analysis of the subgrade material should be performed in order to determine the potential for differential settlement and to ensure it will not damage the liner system.

#### **3.5.2.2 Liner System Selection, Construction, and Protection**

The liner system should be chemically and physically compatible with the tailings material. Regulatory Guide 3.11 (NRC, 2008b) states: *“The choice of the liner system should consider several factors. A key factor is the liner material’s physical and chemical inertness when exposed to the waste materials within the retention system. The chemical qualities of the tailings, slurry, and/or liquid wastes must be assessed to determine the impacts on liners and/or the environment, if contamination resulting from seepage or surface water runoff occurs.”* According to 10 CFR Part 40, Appendix A, Criterion 5A(2)(a), the liner must be *“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, stress of installation, and the stress of daily operation...*”

The synthetic components of a liner system should be carefully designed and tested. Current approaches to the design of liner retention systems with geosynthetics are provided in Lupo and Morrison (Lupo and Morrison, 2005 and 2007) and Koerner (Koerner, 2005). The puncture resistance of a synthetic liner system should be demonstrated through appropriate material selection and testing. Likewise, hydraulic conductivity testing will demonstrate the liner material meets the requirements. Section 4.4.3(9) of NUREG-1620 (NRC, 2003b) addresses liner testing:

*“Tests should show conclusively that the liner will not deteriorate when subjected to the waste products and expected environmental and temperature conditions at the site. Applicant test data and all available manufacturers test data should be submitted with the application for this purpose. For clay liners, tests, at a minimum, should consist of falling head permeameter tests performed on columns of liner material obtained during and after liner installation. The expected reaction of the impoundment liner to any combination of solutions or environmental conditions should be known before the liner is exposed to them. Field seams of synthetic liners should be tested along the entire length of the seam. Representative sampling may be used for factory seams. The testing should use state-of-the-art test methods recommended by the liner manufacturer. Compatibility tests that document the compatibility of the field seam material with the waste products and expected environmental conditions should be submitted for staff review and approval...”*

In addition to proper design and testing, synthetic liner systems must be carefully constructed to prevent damage to the liner. Installation must be performed by an experienced liner installation contractor, and thorough quality assurance practices must be employed. Section B.3 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“Installation of a synthetic liner system should focus on minimizing liner damage. Damage can occur in the form of wrinkles, improper seaming techniques, poor synthetic panel orientation, and punctures caused by construction equipment. The potential for wrinkle development can be minimized by orienting panels properly, seaming within the allowable range of temperatures, and compacting the subgrade properly. Synthetic liner manufacturers often provide specific guidance on proper techniques for minimizing wrinkles. Seams typically constitute the weakest portion of a synthetic liner system. Therefore, the layout of the synthetic panels should minimize the location of seams in high-stress areas. Punctures can be minimized by following manufacturer recommendations for allowable ground pressures and minimum protective cover requirements for construction equipment working on a synthetic liner. Quality assurance practices during synthetic liner installation need to be rigorous, and a leak location survey after synthetic liner installation may be beneficial.”*



After installation, constructed liner systems are susceptible to damage from ultraviolet radiation, foot traffic, construction equipment, animals, wind, and other factors. Therefore, measures must be employed to protect liner systems during the operation life of the facility. Section B.2.4.2 of Regulatory Guide 3.11 (NRC, 2008b) and Section 4.4.3(9) of NUREG-1620 (NRC, 2003b) describe the measures that can be used to protect liners including soil covers, sandbags, venting systems, diversion ditches, and fencing.

### **3.5.2.3 Bottom Liners and Leak Detection Systems**

Bottom liners and leak detection systems are required below tailings impoundments. In 10 CFR Part 40, Appendix A, Criterion 5E(1), the NRC discusses the installation and testing of bottom liners:

*“(1) 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. This is in addition to the groundwater monitoring program conducted as provided in Criterion 7. 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. Tests must be run for a sufficient period of time to reveal any effects if they are going to occur (in some cases deterioration has been observed to occur rather rapidly after about nine months of exposure)).”*

In 10 CFR Part 40, Appendix A, Criterion 5A(5), the NRC states: “...it must not be presumed that the liner system will function without leakage during the active life of the impoundment.” Section C.1.d of Regulatory Guide 3.11 (NRC, 2008b) states: “Unless exempted under the regulations in Criterion 5A(3) of Appendix A to 10 CFR Part 40, liners and leak detection systems need to be included in the design of retention systems per 10 CFR Part 40, Appendix A, Criteria 5A(1), 5A(2), and 5E(1), and considering EPA requirements in 40 CFR 264.221.”

Section B.2.2.4.2 of Regulatory Guide 3.11 (NRC, 2008b) provides the following guidance with respect to leak detection systems for tailings impoundments:

*“A leak detection system is required with a synthetic liner. The leak detection system should be designed to identify the approximate locations of leaks so repairs can be made and to isolate leaks so that they can be controlled. The leak detection system generally consists of either a highly permeable soil or synthetic material such as a geonet located immediately beneath the synthetic liner. This highly permeable layer should be designed to drain to sumps where the leakage can be monitored. Consideration should be given to developing a contoured grading plan that has a series of peaks and valleys for the liner and leak detection system to identify the approximate location of any leak. The design of a leak detection system also should establish an*

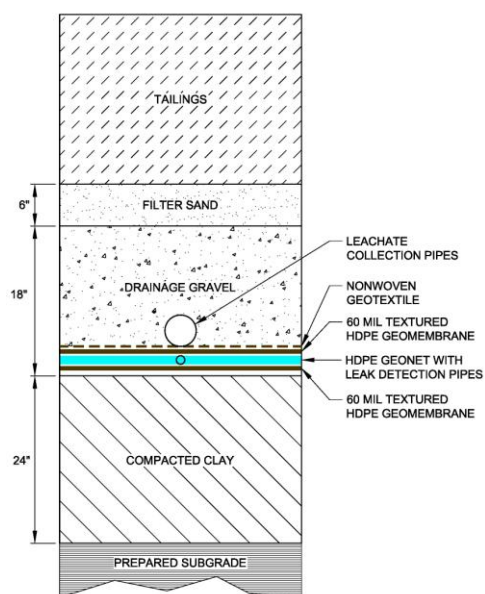
*allowable leakage rate (ALR). The ALR should take into account anticipated defect rates in the synthetic layer, hydraulic head conditions on the liner system, and flow rates within the detection layer. If leakage is found in the detection system at a rate greater than the ALR, remedial action is necessary.”*

Although care is taken to ensure a stable impoundment and liner system that is designed and constructed according to required standards, unforeseen problems and deficiencies may lead to leakage. Therefore, leak detection systems are designed to drain to a sump where the leakage can be monitored and pumped back to operational or holding ponds.

#### **3.5.2.4 Example Liner System**

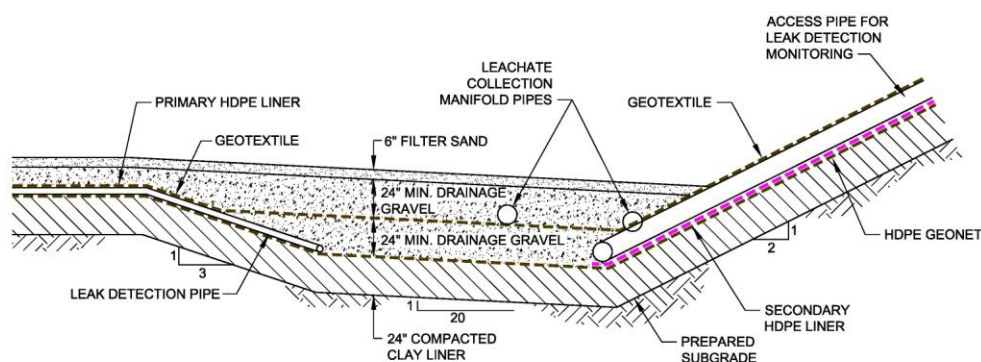
A liner system was recently designed for a uranium tailings facility in the arid western United States (U.S.). The liner system consisted of multiple components as shown on Figure 3-1 and listed (from bottom to top):

- prepared subgrade material;
- compacted clay liner with a maximum permeability of  $1 \times 10^{-7}$  cm/sec;
- 60-mil high-density polyethylene (HDPE) secondary geomembrane;
- HDPE geonet and 3-inch diameter perforated piping as the leak detection system;
- primary 60-mil HDPE geomembrane;
- cushioning layer of nonwoven geotextile material;
- gravel bedding with 4-inch to 8-inch diameter piping as the leachate collection system; and
- filter sand to prevent migration of tailings into the underlying gravel.



**Figure 3-1 Example Liner System for Tailings Impoundment**

The liner system was designed so that both the leachate collection piping and the leak detection piping drained to sumps with separate collection areas. The floor of the tailings impoundment was graded to drain to individual areas so that leaks could be isolated for repair. Figure 3-2 shows a cross section through the leak detection sump.



**Figure 3-2 Example Sump for Leak Detection System**

### 3.5.3 Tailings Pipelines

Pipelines that convey tailings to the tailings disposal facility are designed to contain the material and isolate it from the environment. However, problems can occur that cause leaks to develop. NRC Regulatory Guide 3.11.1 (NRC, 1980a) indicates that pipe ruptures or leakage can occur due to abrasion from the coarse sand fraction of the tailings, from air entrainment in the pipeline, or from a variety of other causes. All of these factors can contribute to potential pipe failure which can lead to damage to other components of a tailings impoundment and/or impacts to



groundwater or surface water. Consequently, close monitoring of all pipes and fittings by qualified personnel should be performed during operation of the facility.



**Figure 3-3 Tailings Discharge Piping**

Visual inspection alone, however, may not be adequate to identify leaks outside of the inspector's vision. Therefore, providing alternative means of containing and alerting personnel to a leak is important. NRC Regulatory Guide 3.11.1 (NRC, 1980a) indicates that alarm-triggering flow rate sensors installed at the nozzle outlets are widely used to detect ruptures, pipe clogging, or other slurry flow irregularities. Flow restrictors and flow shutoffs can also be used to monitor the pressure within the pipeline in various ways. The sensors can monitor pressure decreases over time, length of time for the pipeline to reach operating pressure, and combinations of increases and decreases in pressure. When a leak is suspected, a flow restrictor reduces the flow through the pipe to levels well below the usual flow rate until the leak is identified. If a leak is detected, a flow shutoff can completely cut off flow in the pipeline or can even shut down the pump. Automatic flow restrictors and shutoffs are permanently installed directly into the pipeline or the pump housing.

Automated internal, vapor, or interstitial pipeline monitoring systems can also be installed that will sound an alarm, flash a signal on a console, or call a phone number, depending on the sophistication of the system. These sensors can be combined with automatic shutoff systems so that when the monitor detects a suspected release, the pipeline system can be automatically shut down.

Within a pipe trench, two or more liners and a leachate collection and removal system between these liners can be installed to contain any leakage. The recently licensed Piñon Ridge Mill site in Montrose County, Colorado is using double-walled HDPE piping in buried locations. Advantages to this type of pipe include protection from impacts, exposure to weather and

sunlight degradation, as well as thermal effects of freezing and expansion from high temperatures.

If a leak is detected, the flow should be stopped to assess the severity of the leak and the degree of impact to adjacent soils. Any noticeable leakage should be contained, if this has not already occurred. A written report summarizing the problem and corrective actions taken should be prepared. Within the document, the operator must specify a procedure for complying with cleanup requirements. Liquid and other constituents from the leak must be cleaned up and disposed of in a proper manner. Fluids may be transported to the tailings impoundment, if appropriate.

### **3.5.4 Tailings Impoundment Covers**

A properly designed and constructed reclamation cover over the tailings impoundment will reduce the risk of impoundment failure. The NRC provides regulations pertaining to reclamation covers in 10 CFR Part 40, Appendix A, Criterion 6(1):

*“In disposing of waste byproduct material, 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...”*

The NRC addresses final reclamation cover slopes and vegetative or rock covers for erosion protection in 10 CFR Part 40, Appendix A, Criterion 4:

*“(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. The broad objective should be to contour final slopes to grades which are as close as possible to those which would be provided if tailings were disposed of below grade; this could, for example, lead to slopes of about 10 horizontal to 1 vertical (10h:1v) or less steep. In general, slopes should not be steeper than about 5h:1v. Where steeper slopes are proposed, reasons why a slope less steep than 5h:1v would be impracticable should be provided, and compensating factors and conditions which make such slopes acceptable should be identified.*

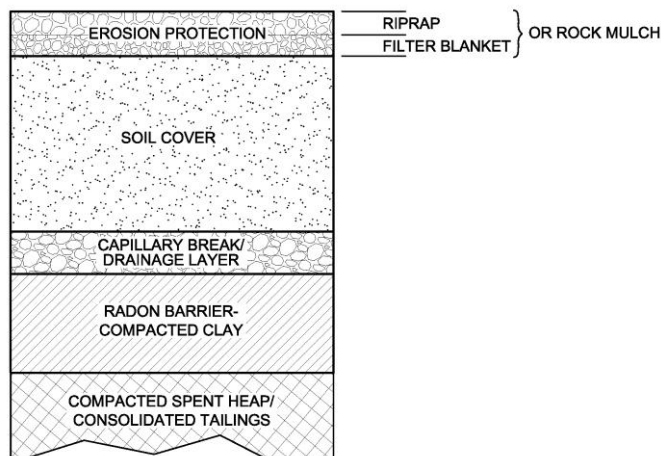
*(d) A full self-sustaining vegetative cover must be established or rock cover employed to reduce wind and water erosion to negligible levels.*

*Where a full vegetative cover is not likely to be self-sustaining due to climatic or other conditions, such as in semiarid and arid regions, rock cover must be employed on slopes of the impoundment system. The NRC will consider relaxing this requirement for extremely gentle slopes such as those which may exist on the top of the pile.”*

Appendix A of 10 CFR Part 40 and NUREG-1620 (NRC, 2003b) provide additional guidelines with respect to reclamation cover design and construction criteria, including those pertaining to seepage and radon emanation through the cover.

Figure 3-4 shows an example of a reclamation cover system recently designed for a uranium heap leach facility in the western U.S. The components of the cover system include (from bottom to top):

- compacted spent heap material or consolidated tailings;
- a compacted clay layer to limit infiltration and to act as a radon barrier;
- a gravel layer to act as a capillary break and drainage layer;
- a thick soil cover to reduce infiltration, provide a plant growth medium, and provide for frost protection for the radon barrier; and
- an erosion protection layer.



**Figure 3-4 Example Cover System for Uranium Tailings or Heap Leach Facility**

### 3.5.5 Operations, Inspection and Maintenance

All operating tailings impoundments should have a detailed operations plan that describes various operational requirements including appropriate water/solids ratio in the tailings, freeboard requirements for the impoundment, etc. Also, a comprehensive monitoring and maintenance program is required to ensure successful operation of mine and mill facilities. With respect to tailings impoundments, Section C.4 of Regulatory Guide 3.11 (NRC, 2008b) states:

*“A detailed, systematic inspection and maintenance program should be established to detect and repair damage that might lessen the integrity of the retention system. Generally, visual inspections performed on a regular basis and supplemented by adequate instrumentation are acceptable. A detailed checklist should be developed and followed to document the observations of each significant feature. The inspection program should use photographs to compare previous and present conditions. In addition, the program should include radiometric and water quality surveys.”*

Section B.4 of Regulatory Guide 3.11 (NRC, 2008b) presents guidelines for daily, monthly, and quarterly inspections, as well as special inspections such as unscheduled inspections conducted *“after the occurrence of significant earthquakes, hurricanes, tornadoes, floods, intense local rainfalls, or other unusual events.”* Section B.4.b of Regulatory Guide 3.11 (NRC, 2008b) also states:

*“Daily inspections of tailings or waste retention systems should be planned, conducted, evaluated, and documented under the direction of an experienced professional who is thoroughly familiar with the investigation, design, construction, and operation of these types of facilities. The licensee should retain documentation (i.e., a record) of each daily inspection for 3 years after the documentation is made.”*

*“The inspection and maintenance program should start at the beginning of construction and continue at least through the operation of the facility.”*

## 4.0 METHODS AND PRACTICES FOR MINIMIZING THE RISK OF EXTREME FLOODING EVENTS

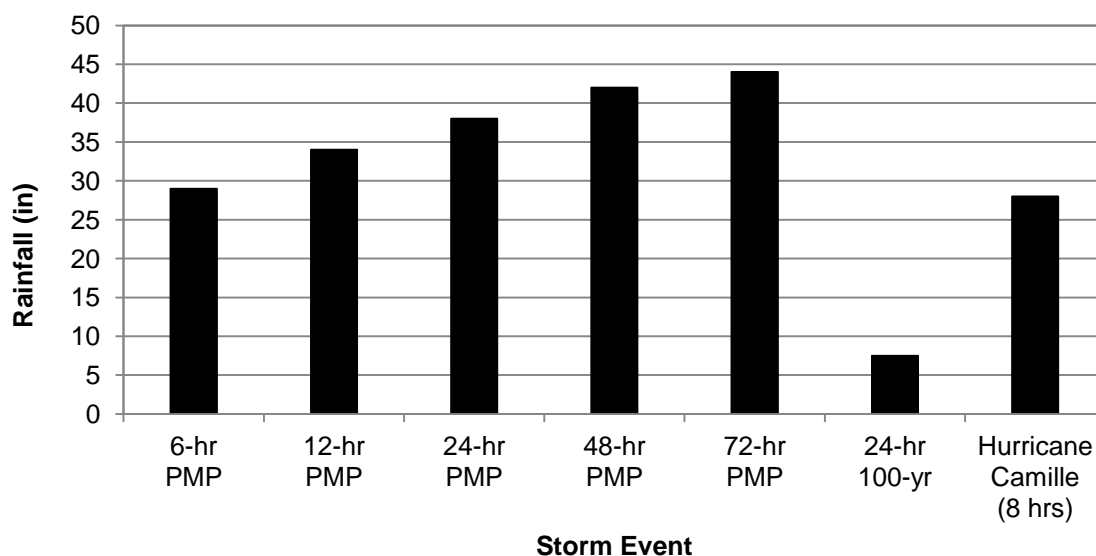
### 4.1 Introduction

An extreme flooding event may be characterized as an infrequent severe hydrologic occurrence that has the potential to cause extensive damage to property and corresponding infrastructure. This type of event is generally a lower recurrence event (e.g., 50-year, 100-year, 200-year, etc.) and can occur when critical climatic conditions converge. From a design standpoint and in an effort to ensure stability of a mine, different design events are appropriate for different structures. In the case of a mining operation (ISR or conventional), diversion design is often tied to the life of the facility and the probability of exceedance during that life. Culverts under roads may be designed for events ranging from the 2-year to 25-year event, whereas a permanent stream diversion may be designed for the 100-year event. In the case of a milling operation, the design event would be the PMP or the PMP plus additional storm events. The NRC regulations in 10 CFR 40 Appendix A, Criterion 8 reference the Environmental Protection Agency (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...”*

In the case of milling operations, while discharges are technically allowed under NRC and EPA regulations when discharge water quality is protective of surface water quality, it is not common industry practice in the arid west to attempt to treat process water to a level protective of instream water quality. For milling operations in the arid west, diversion design is governed by the concept of no discharge of the process material (solids or liquids) even during catastrophic events (i.e., probable maximum precipitation events). To address “no discharge of the process material” the operator should consider the largest probable hydrologic event, which is termed the probable maximum flood (PMF), and is generated by the probable maximum precipitation PMP falling on the largest feasible area of the contributory watershed. Such an event can occur from the most severe combination of critical meteorological and hydrologic conditions reasonably possible in a particular region. Such meteorological conditions may include, but are certainly not limited to hurricanes, thunderstorms, extreme snowmelt, and rainfall on snow.

The PMP is defined as the greatest depth of precipitation for a given storm duration that is physically possible for a geographic location. Addressing extreme storm events and their corresponding impacts is important to maintaining integrity of the mine facility and adequate containment of its tailings. For the Commonwealth, National Oceanic and Atmospheric

Administration (NOAA) Atlas 14, Volume 2 (NOAA, 2006) provides precipitation data that can be used in the computation of various storm events. In addition, the NOAA Hydrometeorological Report No. 51 (NOAA, 1978) is used to compute a PMF. Report No. 51 (NOAA, 1978) shows that the highest PMP values in Virginia are in the southern portion of the commonwealth. The PMP near Pittsylvania County, Virginia is 29 inches (6 hr), 34 inches (12 hr), 38 inches (24 hr), 42 inches (48 hr), and 44 inches (72 hr). These PMP rainfall values are shown graphically on Figure 4-1. For comparison purposes, the rainfall total for the 100-year, 24-hour storm event is also shown (7.5 inches) (Virginia Department of Conservation and Recreation, 1999). The rainfall total for hurricane Camille is also shown. According to Williams and Guy (Williams and Guy, 1973), the 1969 hurricane Camille was the likely the worst recorded natural disaster in central Virginia's history, and recorded rainfall totals were as high as approximately 28 inches occurring over a period of about 8 hours.



**Figure 4-1 Summary of Rainfall Values for Pittsylvania County**

The U.S. Army Corps of Engineers (ACOE) defines the PMF as the hypothetical flood that is considered to be the most severe reasonably possible event, based on comprehensive hydro-meteorological application of the Precipitation Uncertainty Processor (PUP) and other hydrologic factors favorable for maximum flood runoff, such as sequential storms and snowmelt. Precipitation associated with a hurricane and/or tropical storm would be reflected within this definition. For the Commonwealth of Virginia, NOAA Atlas 14, Volume 2 (NOAA, 2006) provides precipitation data to compute various storm events. In addition, the NOAA Hydrometeorological Report No. 51 (NOAA, 1978) is used to compute a PMF. Additional precipitation may be gathered from each individual state's weather service.



## 4.2 Methods and Practices for Uranium Mining and Milling

### 4.2.1 Site Selection Criteria

The NRC states in 10 CFR Part 40, Appendix A (Technical Criteria – Criterion I) that 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.” Extreme precipitation events are a major catalyst in creating disturbance and dispersion of contaminants. Accounting for the potential of extreme flooding events is important when addressing site selection. Although some of the site selection criteria discussed below may not specifically be referenced to extreme precipitation events by state and federal regulations, one should always intuitively consider how an extreme event may impact their site.

#### 4.2.1.1 Surface Hydrology

Site selection should ensure that adequate information is available to develop hydrologic parameters (10-, 25-, 50-, 100-year, or PMP) for the site. Hydrologic conditions will lead to forces that will impact disturbance and dispersion of contaminants. To the extent possible, sites should be selected so as to have the smallest possible contributory watershed area. Such sites would be at or near the top of local drainage divides and/or would not be located in floodplains or flood-prone areas (NRC, 2008b, Regulatory Guide 3.11). Utilizing this criterion will help avoid the need for diversion channels or extensive riprap protection to prevent erosion of the toes and slopes of the embankments. In addition, surface water flow should be evaluated in the area to make sure mill and tailings do not adversely impact streams and lakes. This criterion becomes more prevalent when considering extreme hydrologic events.

- **Wyoming:** The WYDEQ-LQD Guideline No. 8 (*Hydrology*) (WYDEQ-LQD, 2005) does not specifically address the PMP, but does provide guidelines for determining flow rates for the mine plan as well as criteria pertaining to surface water flow.
- **Colorado:** The CDPHE Hazardous Materials and Waste Management Division (6 CCR 1007-1) provides guidelines for surface hydrology parameters. Additional guidelines are contained in 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). Section 7.3.1 (3) indicates “the design storm event may be the 2-year, 24-hour storm event up to the PMP event plus the 10-year, 24-hour storm event.”
- **NRC:** 10 CFR 40 Appendix A provides guidance for the siting of the mill and tailings disposal area. The facilities should be located in a topographic location where the upstream watershed area is minimized. In the case of the mill, it is



paramount to divert undisturbed runoff around the disturbed area to avoid any mixing of mill water with runoff. The smaller the upstream watershed area the less significant will be the diversion issues. The mill site should also be located outside of a floodplain or flood-prone area.

#### **4.2.1.2 Climate (Hurricanes, Tropical Storms, and Extreme Events)**

Extreme weather events are synonymous with hurricanes, tropical storms, and so called “acts of God.” Hurricane Camille, for example, produced significant precipitation (>100-year recurrence interval) in the Commonwealth causing massive slope failures and flooding conditions throughout the state. Understanding the characteristic climate of a site assists in the planning for potential problems from extreme flooding events. Events like this would require determining the 50-year and 100-year storm events as well as the PMP for the area. The following is a general discussion that provides guidance for designing a uranium mine or mill to protect against severe weather events.

#### **4.2.1.3 Soils and Vegetation**

Understanding the various classifications of soils on a mine or mill and tailings site is important since it provides valuable insight as to how soils will interact with heavy precipitation. Information pertaining to seepage, infiltration, swelling, etc. will aid in developing designs that will ensure full containment of water from the mill site. A useful source for soils information can typically be found in site specific Environmental Assessment (EA) / Environmental Impact Statement (EIS) documents performed for the specific site or earlier work performed at nearby sites having similar soil conditions.

- **Wyoming:** State Statute 35-11-428 (i) suggests that information pertaining to soils and vegetation “*consistent with the extent and nature of the proposed surface disturbance*” including descriptions of the soil and vegetative cover be included in the application. The WYDEQ-LQD Guideline No. 2 (*Vegetation*) (WYDEQ-LQD, 1997) provides guidance for performing vegetation inventories. The WYDEQ LQD Guideline No. 1 (*Topsoil and Overburden*) (WYDEQ-LQD, 1994a) provides information pertaining to soils.

- **Colorado:** The Mineral Rules and Regulations: *Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010) provide the following information:

6.4.9 EXHIBIT I – Soils Information: Requires the definition of the general type, thickness and distribution of soil over the affected land.

6.4.10 EXHIBIT J – Vegetation Information: Requires descriptions of present vegetation types including quantitative estimates of cover and height for the principal species; relationship of present vegetation types to soil types.

- **Oregon:** Regulation 345-022-0022 (Soil Protection) states: “The Council must find that the design, construction and operation of the facility, taking into account mitigation, are not likely to result in a significant adverse impact to soils including, but not limited to, erosion...”
- **NRC:** NRC regulation (10 CFR Part 40, Appendix A, Criterion 5A (3c)) indicates that soils should be identified between the impoundment and groundwater and surface water. Also, Part 5A (3d) suggests that all other factors that would influence the quality and leachate produced and the ability for it to migrate to groundwater or surface water should also be defined.

#### ***4.2.1.4 Rainfall Catchment Areas Located Upstream of Mill and Tailings***

The NRC in Criterion 4 (a) of 10 CFR Part 40, Appendix A, requires that rainfall catchment areas located upstream from a mill or tailings disposal location must be minimized in order to decrease the erosion potential as well as the size of floods which could erode or wash out portions of the mill or tailings disposal area. Basically, impoundments must be located as far upstream as possible in a watershed in order to minimize the amount of runoff that could reach the mill and tailings site.

- **Wyoming, Colorado, and Oregon:** All have adopted the NRC rule above with little if any apparent modifications.

### **4.2.2 Design Criteria**

#### ***4.2.2.1 Remoteness***

In general, remoteness can be used for the design criteria associated with mining and milling operations. If such an operation is near a populated area, higher return period events may need to be considered for the design of diversions or sediment control features than if the structure were in a remote area. In every case, the applicant should consider the facility’s relationship or proximity to potential flooding areas. Criterion 4 of NRC 10 CFR 40 Appendix A states that the “*primary emphasis must be given to isolation of tailings or wastes.*”

- **Wyoming:** Section 3 of Guideline No. 8 (*Hydrology*) (WYDEQ-LQD, 2005) discusses probable hydrologic consequences of mining and reclamation operations. Depending on the probable consequences of mining on surface water and groundwater in the area, WYDEQ may impose additional remoteness constraints on the development of a site. Such constraints may include distances to schools, houses, lakes, and streams. With respect to the latter, additional design criteria may be implemented if there is reason to believe that the proximity of a site to a water body

(surface and ground) may be detrimental. An example would be potential inundation or encroachment from flood flows from an adjacent stream.

- **Colorado:** Colorado regulations (6 CCR 1007-1 Part 18) discuss remoteness as it relates to populated areas. The regulations state that the following should be considered in selecting between alternative sites: “...hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from ground water sources, and the potential for minimizing erosion, disturbance and dispersion by natural forces over the long term.” In general and to the extent possible, a mine or milling facility should be located where there is not a large population and design events should be selected which ensure the long-term protection of the nearby population.
- **Oregon:** The Oregon Department of Environmental Quality (ODEQ), Division 120 (Hazardous Waste Management) has additional criteria of remoteness. The Division established a “supplemental siting and permitting procedure for most types of hazardous waste” disposal facilities. The regulations (OAR 340-120-0010 and 340-120-0015) provide the following guidance:
  - guidance relating to proximity to urban areas, parks, etc.;
  - groundwater protection;
  - waste facilities should be at least one quarter of a mile from flood hazard areas, coastal shorelands, beaches, and dunes;
  - in general, for uranium mills, Oregon would default to the NRC regulations 10 CFR Part 40, Appendix A.
- **NRC:** NRC 10 CFR Part 40, Appendix A (Technical Criteria – Criterion 1) suggests that in order to meet the goal of permanent isolation of tailings, an important consideration in design and ultimate construction of these types of facilities is to locate them in as remote a location as possible and away from populated areas. Remoteness will help ensure that current or future encroachment from population areas will not create instability to tailings impoundment locations.

#### 4.2.2.2 *Minimizing Erosion, Disturbance and Dispersion of Waste Materials*

Factors affecting erosion include climate, soil characteristics, topography, and ground cover. Evaluating the site in relation to these factors helps to define the site’s potential for erosion. Erosion occurs when soil particles are loosened from the ground by raindrop impacts and flow forces. Erosion develops and occurs in the following manner:

- **Sheet Erosion:** Transport of loosened soil particles by surface runoff that has not developed into a concentrated rate of flow.
- **Rill Erosion:** Flow becomes concentrated within small paths.

- **Gully Erosion:** Increased accumulation of water flow creates small channels or gullies.

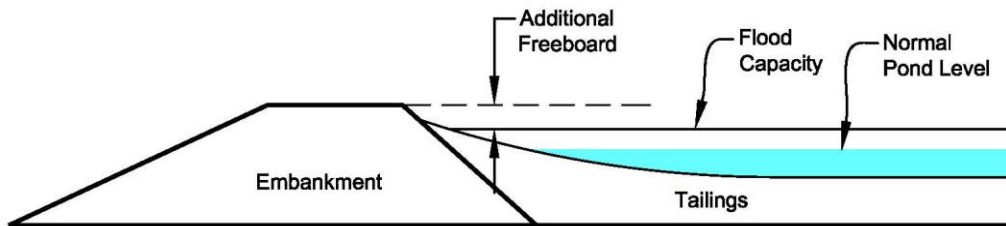
Through these processes, soil is removed from the ground surface and transported downstream from its original location where it eventually settles once the water velocity slows to a point where captured soil particles are allowed to settle from the flow. Although erosion is a natural process, activities such as mining and/or milling provide avenues where runoff can be concentrated resulting in an increase in soil erosion. Extensive degradation at a mine or mill facility could jeopardize stability of mine waste materials or a tailings impoundment. If this potential is not minimized, site failure may occur resulting in the release of solids or liquids. Degradation of the mine and/or mill location will create sediment runoff into creeks, stream, rivers, and lakes downstream from the project. Diversions of undisturbed runoff around the mine and/or mill facilities are critical to ensure that the volume of water crossing the site is minimized. Diversion designs are generally a reflection of the life of the mine (e.g. 100-year 24-hour criteria for mine life greater than 20 years) or may reflect the nature of the materials upon which runoff may come into contact (e.g., PMF diversion for a mill tailings facility).

Protection becomes more critical when precipitation from extreme events becomes part of the analysis. Designing to resist this type of force is crucial to operational and reclamation success. Erosion countermeasures must be capable of working in minor storm events as well as extreme events.

- **Wyoming:** Guideline No. 8 (*Hydrology*) (WYDEQ-LQD, 2005) discusses erosion. Appendix 2 of the guideline provides recommendations for minimizing sediment release from a site.
- **Colorado:** Colorado regulations (6 CCR 1007-1 Part 18, Criteria 3, 4A, 4C, and 4D) address erosion of tailings facilities. Measures include armoring (riprap), especially if vegetative cover is or will be scarce. In arid locations, vegetation may not take hold as quickly as desired, causing armoring to be more prevalent in design and reclamation. Rock armor is essential in final closure and decommissioning.
- **Oregon:** The Department of Environmental Quality discusses erosion regulations within OAR 340-041-0004 (Antidegradation). The Oregon Department of Energy provides guidelines in OAR 345-092 (Standards for the Siting of Uranium Mills in Oregon). Essentially, the policy protects from unnecessary further degradation from point and non-point sources of pollution.
- **NRC:** Within the Technical Criterion 1 of 10 CFR Part 40, Appendix A, the recommendation is to minimize erosion over the long term. Consequently, erosion countermeasures must be designed to resist forces of a PMF event. Countermeasures include riprap, established vegetation, and other erosion protection measures.

#### 4.2.2.3 Adequate Freeboard in Impoundments to Prevent Overtopping During Storm Events

It is essential in the design stage of tailings impoundments that water balance calculations consider average and extreme production and hydrologic conditions to prevent loss of freeboard and loss of liquids or solids during tailings disposal operations. The total freeboard is the vertical height between the waterline and the top of the embankment crest. Figure 4-2 shows a schematic of a tailings impoundment and associated freeboard.



**Figure 4-2 Schematic of Tailings Impoundment and Freeboard**

Factors to consider include the duration of high water levels, wind fetch (important during hurricane and tropical storm events), maximum precipitation above the operating levels, and the ability of the embankment to resist erosion from waves.

- **Wyoming:** Wyoming defers to NRC standards for tailings impoundment freeboard. Additional freeboard requirements for liquid impoundments and reservoirs are provided by the Wyoming State Engineer's Office (WYSEO) and reflect Mine Safety and Health Administration (MSHA) guidance, as applicable.
- **Colorado:** Freeboard requirements within Colorado directly meet or exceed NRC standards. At the recently permitted Piñon Ridge Mill Facility (Montrose County, Colorado) the applicant's design showed 3 feet of freeboard for all tailings embankments.
- **Oregon:** Similar to Colorado and clearly defers to the NRC.
- **NRC:** 10 CFR Part 40, Appendix A, Criterion 5A(4) states: "A *surface impoundment must be designed, constructed, maintained, and operated to prevent overtopping resulting from normal or abnormal operations, overfilling, wind and wave actions, rainfall, or run-on; from malfunctions of level controllers, alarms, and other equipment; and from human error.*"

#### 4.2.2.4 Dam Stability to Prevent Breaching during Storm Events

Impoundments function as a dam, even though the impoundment may not meet the requirements of state or federal dam programs. As such, the impoundment may be scrutinized similarly to a traditional dam to ensure stability. A document provided by the ACOE (ACOE, 1979) entitled

*“Recommended Guidelines for Safety Inspections of Dams”* provides information pertaining to important considerations of dams. An additional resource is published by the EPA (EPA, 1994b) entitled, *“Design and Evaluation of Tailings Dams.”* Information in the report includes tailings design, construction, stability, and water control and management. The Federal Energy Regulation Commission (FERC) also inspects dams and has provided inspections at NRC facilities.

- **Wyoming:** The Wyoming State Engineer’s Office must always be contacted regardless of the size of embankment proposed for an impoundment. Typically, the WYSEO will define the type of stability analysis required. Dam facilities greater than 19.9 feet high or greater than 20 acre-feet capacity fall under a special category requiring specific design criteria and certification. For a uranium mill impoundment, the NRC would oversee inspection as Wyoming is a non-agreement state.
- **Colorado:** *“Where there is the potential for off-site impacts due to failure of any geologic structure or constructed earthen facility, which may be caused by mining or reclamation activities, the Applicant shall demonstrate through appropriate geotechnical and stability analyses that off-site areas will be protected with appropriate factors of safety incorporated into the analysis.”* An applicant may be required to provide engineering stability analyses for proposed final reclaimed slopes, waste piles, embankments, and ore leach facilities. An applicant may also be required to provide engineering stability analyses for certain slope configurations that will occur during operations.
- **Oregon:** Department of Environmental Quality regulation OAR 340-043-0100 (Physical Stability of Retaining Structures and Emplaced Mine Materials) states: *“(1) Permit applicants must demonstrate to the Department that the design of chemical processing facilities and waste disposal facilities is adequate to ensure the stability of all structural components of the facilities during operation, closure and post closure. (2) Retaining structures, foundations and mine materials emplacements shall be designed by a qualified, registered professional...”* Additional guidelines are in Department of Geology and Mineral Industries regulation OAR 632-035-0025 (Requirements for an Operating Permit Application). If a dam is higher than 10 feet and stores more than 9.2 acre feet of water, approval from the Water Resources Department is required. For uranium mills, Oregon will defer to the NRC regulations and guidelines.
- **NRC:** The NRC Regulatory Guide 3.11 (NRC, 2008b) states: *“This guide describes engineering practices and methods generally considered by the U.S. Nuclear Regulatory Commission (NRC) to be satisfactory for the design, construction, and inspection of embankment retention systems used for retaining liquid and solid wastes*



*from uranium recovery operations.”* Ultimate dam stability will be gauged on how the impoundment is anticipated to work under extreme weather conditions at mill sites.

### 4.2.3 Operational Criteria

#### 4.2.3.1 Protection of Ore and Waste Stockpiles from Erosion

Stockpiled material can leach into the ground from rainfall or flow away from the stockpile. Protecting this material from erosion and leaching is required. The degree of protection is generally commensurate with the hazardous nature of the materials. Mine waste stockpiles can be protected with berms and ditches. Ore stockpiles at a mill and wastes from processing require a higher level of protection including engineered diversions and double liners with leak detection systems.

- **NRC, Wyoming, Colorado, and Oregon:** Common to the NRC, Colorado, Wyoming and Oregon, stockpiled material must have parameters in place that restrict penetration of fragments (metals, radionuclides) into the underlying soils and ultimately into groundwater. Methods used include liners, concrete foundations, and compaction of soils (particularly clay) of stockpile areas (NRC, 10 CFR Part 40, Appendix A, Criterion 5H).

At a mill site, a drainage system must be in place to catch runoff from the stockpiled location to ensure minimal runoff potential to the surrounding environment. Drainage is conveyed to evaporation ponds or other locations for proper treatment and disposal. Depending on the risk, the drainage network should consider extreme events.

#### 4.2.3.2 Stream Diversions and Collection Ponds to Redirect Surface Flow around Facilities

The siting of the mine (to the extent possible) and more importantly the mill and tailings facilities should be located in a topographic location where the upstream watershed area is minimized. In the case of both the mine and the mill, it is paramount to divert undisturbed runoff around disturbed areas to avoid mixing of mining and/or milling water with natural runoff. The smaller the upstream watershed area, the less significant will be the diversion issues.

- **NRC, Wyoming, Colorado, and Oregon:** The NRC, Colorado, Wyoming, and Oregon adopt the criteria that channel conveyance and storage should accommodate the 100-year 24-hour rainfall event for the siting area with adequate freeboard. Such diversions and collection ponds within a mill area should be evaluated against the 1,000-year rainfall event under bank full/pond full conditions with zero freeboard.



Design of channels to accommodate flows should consider erosive properties of anticipated velocities within conveyances. Typically, design velocities should be around 3 feet per second for the 100-year event to minimize erosion. One of the technical difficulties in the PMF requirement around mills and mines is the size of the required diversion and its behavior during normal (or more typical) events. The channel's propensity for sedimentation must also be addressed by the design engineer.

#### 4.2.3.3 Facility Inspection and Maintenance

- **NRC, Wyoming, Colorado, and Oregon:** The NRC, Colorado, Wyoming, and Oregon refer to the guidelines documented in 10 CFR Part 40, Appendix A, Criterion 8A: *“Daily inspections of tailings or waste retention systems must be conducted by a qualified engineer or scientist and documented. The licensee shall retain the documentation for each daily inspection as a record for three years after the documentation is made.”* Colorado and Oregon have regulations that provide state representatives with access to mill and tailing sites for inspection.
- **Colorado:** Section 3.2 (Inspection and Monitoring) of the *Mineral Rules and Regulations: Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010) provides additional information relating to Colorado inspections for mines.

Routine maintenance should always occur to prevent failures and possible contamination problems from occurring. This is especially important when protecting a facility from potential extreme hydrologic events. A poorly maintained facility may survive a normal hydrologic event, but may fail during an extreme event. Inspections and maintenance should be consistent and well documented.

#### 4.2.3.4 Best Management Practices for Erosion and Sedimentation Control

In general:

- Erosion resistant features (riprap, concrete, etc.) should be placed in conveyance locations, such as channels and pipe inlet and outlet locations, where velocities may contribute to erosion.
- Embankment slopes on a tailings pond should be designed to minimize erosion.
- If seeding is in place along these slopes, placement of wattles along the slopes will reduce erosion along the same slopes.
- Along steep slopes or very long slopes, it is common to use methods such as contour ditches, terracing, benching, and installation of erosion resistant features (riprap, etc.) to minimize erosion.
- Vegetation establishment minimizes erosion and enhances sedimentation control.

- Strategic location and sizing of a sediment basin captures sediment in runoff.

Each method of managing erosion and sedimentation should be evaluated with respect to the nature of the materials and different runoff events including and where applicable the most extreme events. Measures will have to be fairly resistant to extreme hydrologic/hydraulic forces.

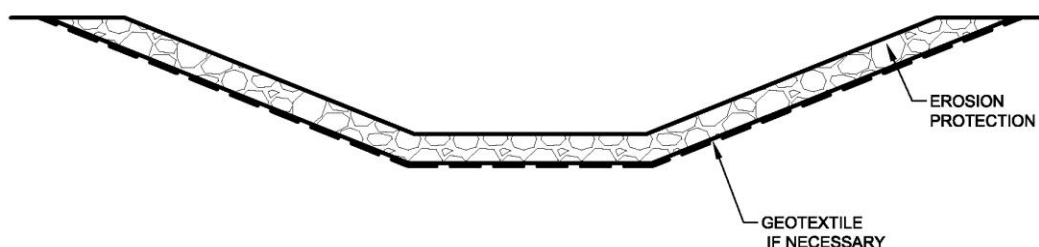
#### 4.2.4 Closure and Post-Closure Considerations

Reclamation requirements at most mines require long-term stabilization and isolation of mine wastes. Acid-forming and toxic materials are isolated from both surface water and groundwater. Waste dumps are graded and covered by suitable overburden and topsoil. The entire mine area is generally topsoiled and revegetated in a manner to return the land to an approved post mining land use. The following sections will only address closure and post closure considerations for uranium milling facilities.

##### 4.2.4.1 Diversion of Surface Water

- **NRC:** 10 CFR Part 10 Appendix A, Criterion 5E(3) addresses design to accommodate flows from extreme events to ensure adequate dewatering measures can be satisfactorily performed.
- **Wyoming, Colorado, and Oregon:** In general, Colorado, Wyoming, and Oregon utilize techniques similar to those defined in the NRC regulations for the closure and decommissioning of tailings and processing facilities. Aside from the general criteria for closure and post closure considerations, how these relate to extreme precipitation events is the primary concern.

The final site should be protected from flows, especially extreme flows. Diversion channels will direct storm water around these locations and must be maintenance free. The area around the facility must be graded in a manner to prevent channeling of flows. An example diversion channel detail is shown on Figure 4-3.



**Figure 4-3 Example Diversion Channel Detail**

#### 4.2.4.2 *Removal of Liquids and Decommissioning/Reclamation of Processing Ponds*

- **NRC, Wyoming, Colorado, and Oregon:** For the NRC, Colorado, Wyoming, and Oregon, guidelines require that sludge and other water within ponds be removed and disposed of in an approved manner. Liners must be removed and disposed of in an approved location and soils under the liners need to be tested for contamination and treated accordingly. If more than one pond contains water, transferring water to a single pond may allow for temporary storage while the remaining ponds are closed and decontaminated. Following the closure of the other ponds, the final pond can be closed. Remaining liquid within the pond may need to be pumped to a location for transport to a treatment/disposal location. For a single evaporation pond, freeboard must be provided to account for additional precipitation during the remaining evaporation period.

#### 4.2.4.3 *Recontouring/Revegetation*

With respect to mill and tailings disposal sites, final reclamation and closure must meet NRC or agreement state requirements which include a radon barrier followed by a rock mulch or vegetative cover to ensure that no erosion will occur over the long term. Contouring should provide gradual slopes away from the mill or tailings. With respect to mining, final reclamation and grading should be performed to meet specified post-mining land use requirements. Upon final grading, both mines and mill/tailings sites should be revegetated. Revegetation provides stability to the soil and reduces the potential for erosion. Accomplishing this objective provides a more stable area that will be able to withstand extreme flooding events. Slopes and overall topography will be less susceptible to erosion once vegetation is established.

- **NRC:** 10 CFR Part 40, Appendix A, Criterion 4(d) states that “*all impoundment surfaces must be contoured to avoid areas of concentrated surface runoff or abrupt or sharp changes in slope gradient. In addition to rock cover on slopes, areas toward which surface runoff might be directed must be well protected with substantial rock cover (rip rap). In addition to providing for stability of the impoundment system itself, overall stability, erosion potential, and geomorphology of surrounding terrain must be evaluated to assure that there are no ongoing or potential processes, such as gully erosion, which would lead to impoundment instability.*”
- **Wyoming:** WYDEQ-LQD Guideline No. 6 (*Noncoal, Application for a Permit to Mine or an Amendment*) (WYDEQ-LQD, 1994c) discusses grading and revegetation for mines in Section IV.
- **Colorado:** Section 3.1.10 (Revegetation) of the *Mineral Rules and Regulations: Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010) provides information related to this topic. Additional regulations (6 CCR 1007-1 Part 18,

Criterion 4D) discuss vegetative covers. If a vegetative cover cannot be established or self-sustaining because of climate, a rock cover will be required.

- **Oregon:** OAR 345-095-0118 (Mine Reclamation) and 345-095-0120 (Tailings Disposal) provide vegetation guidelines.

#### 4.2.4.4 *Post Closure Monitoring*

Beyond closure of a mill facility, continued monitoring is required to ensure the site remains stable.

- **NRC:** NRC guidelines (10 CFR Part 40, Appendix A, Criterion 12) state: *“The final disposition of tailings, residual radioactive material, 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 responsible for long-term care of the disposal site to confirm its integrity and to determine the need, if any, for maintenance and/or monitoring.”*
- **Wyoming and Oregon:** Wyoming and Oregon rely on NRC guidelines for monitoring mills.
- **Colorado:** Colorado adheres to the NRC guidelines cited above.
- **Oregon:** The following regulations of the Department of Geology and Mineral Industries address post-closure issues: OAR 632-037-0070 (Reclamation and Closure Plan) and OAR 632-037-0130 (Reclamation and Mine Closure Standards).

For extreme precipitation events, each state is concerned that the site is not disturbed by intense storm events. Following a large event, inspection may be made to monitor how the site responded.

## 5.0 THE POTENTIAL FOR LANDSLIDES, DEBRIS FLOW, AND SLOPE FAILURE

### 5.1 Introduction

A landslide is generally defined as the rapid movement of rock, soil, or debris down a slope. The potential for a landslide to occur depends on the characteristics of a particular site or area. These characteristics include site geology, soil and rock properties, groundwater and surface water conditions, weather patterns, slope geometry, etc. Once a site is characterized, the probability of occurrence can be determined through engineering analyses and the potential risks can be managed appropriately.

### 5.2 Geology/Site Characterization

In order to assess the potential for landslides or debris flows, the site must be evaluated to determine the geologic and geotechnical properties. The geology of a site can be defined using U.S. Geological Survey (USGS) maps and other published information. A field investigation is also important in order to observe and characterize the soil and rock properties. Generally, a field investigation involves drilling geotechnical borings and collecting soil and/or bedrock samples. These samples are usually sent out for laboratory testing to further refine the soil and/or rock properties.

- **NRC:** The NRC regulations discuss geology and site characterization in general terms for milling.

Appendix A to 10 CFR Part 40 discusses site characterization in regards to tailings disposal system proposals. The regulation requires the operator to provide information for the underlying soil and geologic formation. Specifically, the information must be collected from borings and field survey methods within the impoundment area and surrounding areas. Both field and laboratory testing should be performed.

NUREG-1623 (NRC, 2002) outlines general guidelines for reclamation design submittals. An operator is expected to submit soil types and characteristics and surficial and bedrock geology along with site geomorphological characteristics.

NRC Regulatory Guide 3.11 (*Design, Construction, and Inspection of Embankment Retention Systems at Uranium Recovery Facilities*) (NRC, 2008b) discusses requirements for a subsurface investigation at the site where the retention system is planned to be located. Specifically, borings should be drilled across the site at critical locations to establish geologic sections and groundwater conditions. Borings should extend to a depth that equates to the height of the embankment, with a minimum

depth of 15 feet. This investigation should produce information on classification, physical and chemical properties, location and extent of soil and rock strata, and groundwater conditions.

NUREG-1620 (NRC, 2003b) details requirements for investigation of stratigraphic features including orientation, occurrence, thickness, composition, age, depositional environment, and interrelationships. The guide also provides suggestions for review of structural and tectonic features, geomorphic features, and seismicity and ground motion. Reviewers are asked to review geotechnical stability information including exploration data, laboratory methods, test results, physical properties, geotechnical parameters of materials, and groundwater conditions for the site material, borrow material, and tailings.

- **Colorado:** The Colorado Mined Land Reclamation Board *Mineral Rules and Regulations for Hard Rock, Metal, and Designated Mining Operations* (CMLRB, 2010) specify a baseline site characterization which includes physiographic, geologic, hydrogeologic, surface water, and groundwater conditions.

The CDPHE regulations (6 CCR 1007-1) require that the underlying soils and geology be characterized in terms of thickness, uniformity, shape, and orientation of underlying strata. Borings, field testing, and a field survey must be performed.

- **Wyoming:** The WYDEQ-LQD Guideline No. 1 (*Topsoil and Overburden*) (WYDEQ-LQD, 1994a) recommends an extensive soil survey including mapping, soil sampling, and soil analysis. It also discusses geology data collection.

Guideline No. 4 (*In-Situ Mining*) (WYDEQ-LQD, 1994b) Part III requires a geologic assessment, which involves investigation of the regional geology and a field investigation.

- **Washington:** Washington regulations (RCW 78.56) (*Metals Mining and Milling Operations*) outline the requirements for potential tailings facility locations. The requirements for a technical site investigation include soil, hydrologic, and geologic characteristics.

### 5.3 Probability of Occurrence

The probability of a landslide or debris flow is based on several factors including soil and rock characteristics, geology, slope configuration, water conditions, slope geometry, and seismic potential. Generally, the most widely used method for determining the probability of a landslide is through slope stability analyses.

Slope stability analyses are usually performed with two-dimensional modeling software. These programs usually give results as a factor of safety against sliding or as a deformation of the slope. In practice, a target factor of safety of 1.5 is often used.

Most agency guidelines focus on the stability of mine or mill embankments, pit slopes, and tailings piles. Selected guidelines are summarized in the following sections.

- **NRC:** The NRC regulation 10 CFR Part 61.13 specifies licensing requirements for land disposal of radioactive wastes. Technical analyses must be performed for long-term stability of the disposal site based on natural processes including erosion, mass wasting, slope failure, settlement, infiltration, and surface run-off.

10 CFR Part 61.56 continues the stability discussion by requiring waste to be structurally stable. It should maintain physical dimensions and its form under conditions such as loading, moisture intrusion, and internal factors such as radiation effects.

Appendix A to 10 CFR Part 40 discusses stability in regard to embankments and impoundments. The regulation states that “*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.*” They recommend slopes no steeper than 5 horizontal to 1 vertical or less (5H:1V). In addition, the regulation discusses stability in terms of avoiding abrupt or sharp changes in grade to avoid concentrated areas of runoff.

NRC Regulatory Guide 3.11 (NRC, 2008b) outlines in detail the stability and failure analyses they recommend for the design of embankment retention systems. The guide suggests the use of computer programs for ease of calculation but also recommends checking computed results with another program or hand calculations. The regulation details the static analysis methods including limit equilibrium methods (friction circle method, method of slices, wedge method, etc.), deterministic versus probabilistic analyses, and finite element methods. It also outlines dynamic (seismic) stability analyses.

- **Colorado:** The CMLRB (CMLRB, 2010) *Rules and Regulations for Hard Rock, Metal, and Designated Mining Operations* (Section 3.1.5) provides a discussion of stability. The guide suggests the operator must provide adequate compaction of waste materials for stability, and grading should control erosion to protect from slides. Maximum slopes should be no steeper than 2 horizontal to 1 vertical (2H:1V). Section 6.5 of the rules and regulations is the geotechnical stability exhibit. This section requires the applicant to provide an evaluation of geologic hazards which



could affect the impoundment, slope, embankment, highwall, or waste pile in terms of destabilization. Also, slope stability analyses should be provided for reclaimed slopes, highwalls, waste piles, embankments, and ore leach facilities. These analyses should include slope angles and configurations, compaction and density, physical characteristics of earthen materials, pore pressure information, slope height, post-placement use of site, and information on structures or facilities which could be affected by slope failure. The applicant must show that off-site facilities will be protected from failure at the facility with an appropriate factor of safety, determined by the CMLRB office.

- **Wyoming:** Wyoming guidelines do not mention stability analyses as related to landslides or debris flows.
- **Washington:** Washington regulations (RCW 78.56.090) (*Metals Mining and Milling Operations*) state that a slope stability analysis must be performed for tailings facility sites prior to selection.

## 5.4 Risk Management

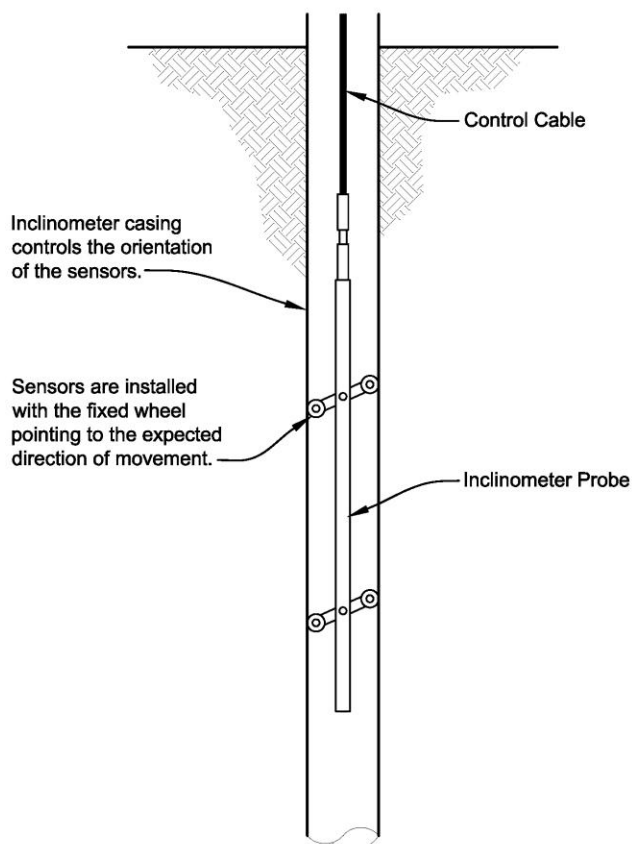
The NRC and state guidelines do not specifically outline risk management procedures for landslides and debris flows. However, most guidelines specify the requirement for site characterization and stability analyses. Slope stability analyses and engineering designs, if performed properly, will help prevent or at least minimize the risk for landslides and debris flows. However, risk management systems can be implemented to further enhance safety as outlined below.

### 5.4.1 Monitoring Systems

Mine and mill waste storage facilities have plans in place to inspect the highwalls and embankments for signs of cracking and movement. In the event of observed movement, monitoring systems may be put in place to measure the amount of movement. The most commonly used monitoring systems are piezometers and inclinometers. Piezometers monitor fluctuations in groundwater level and the main types of piezometers include vibrating wire, pneumatic, and standpipe. Inclinometers are used to monitor slope movement and can be manual or automated. Figure 5-1 shows the instrumentation for a dedicated inclinometer monitoring system installed at the crest of an open pit mine in the western U.S. The system includes the use of dedicated in-place inclinometers to monitor the slope for movement, as shown on Figure 5-2.



**Figure 5-1 Inclinometer Monitoring System**



**Figure 5-2 Inclinometer used to Monitor Slope for Movement**

### **5.4.2 Stabilization Measures**

The regulatory guidance relies on appropriate engineering design to provide stable slopes. Unstable slopes can be stabilized by a variety of methods including buttressing, soil nails, excavation of material at the head of the slope, or lowering of pore water pressures in the slope. Rockfall barriers or screens can be used to mitigate rockfall hazards.

## 6.0 THE POTENTIAL FOR SEISMIC EVENTS

State and federal governments have recognized the need to incorporate an analysis of the potential for seismic events into the preliminary and reclamation design of uranium mining and milling operations. The following discussion includes a review of historic seismicity in the Commonwealth of Virginia, a discussion of the seismic design criteria contained in the International Building Code (IBC), a comparison of the requirements for seismic hazard analysis for various states and the NRC, a description of methods for seismic hazard analysis, and best management practices for completing a seismic hazard analysis.

### 6.1 Historic Seismicity in Virginia

Crone and Wheeler (Crone and Wheeler, 2000) report that seven Class A, B, or C seismic zones or features exist in Virginia. Class A features have geologic evidence that demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed for mapping or inferred from liquefaction or other deformational features. Class B features have geologic evidence that demonstrates the existence of a fault or suggests Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A. Class C features have geologic evidence that is insufficient to demonstrate (1) the existence of tectonic fault, or (2) Quaternary slip or deformation associated with the feature (Crone and Wheeler, 2000). One Class A seismic zone (Central Virginia Seismic Zone) exists between Charlottesville and Richmond and one Class B fault system (Pembroke Faults) exists near Blacksburg. The remaining five features are Class C features. The Crone and Wheeler (Crone and Wheeler, 2000) report was part of a national effort by the USGS to compile published geological information on Quaternary faults, folds, and earthquake-induced liquefaction in order to develop an internally consistent database. A key objective of this compilation is to provide a comprehensive database of Quaternary features that might generate strong ground motion and should, therefore, be considered in assessing seismic hazard.

Virginia is considered to have a moderate level of risk from earthquakes (Sibol et al., 2007). The first documented earthquake in Virginia was February 21, 1774 when a strong earthquake was felt over much of Virginia and southward into North Carolina. Many houses were moved considerably off their foundations at Petersburg and Blandford (von Hake, 1977). The largest earthquake to originate in Virginia occurred on May 31, 1897. The epicenter was in Giles County, where on May 3, an earlier tremor at Pulaski, Radford, and Roanoke had caused damage (von Hake, 1977). Minor tremors continued in the epicentral region from time to time until June 6. Other disturbances felt on June 28, September 3, and October 21 were probably aftershocks.

In 1977, several seismographs were installed and operated by Virginia Polytechnic Institute and State University (Virginia Tech) and the Virginia Department of Mines, Minerals and Energy – Division of Mineral Resources. From 1978 through 1993, over 160 earthquakes were detected in and around Virginia. Twenty-six of those earthquakes were felt by local residents. This averages out to about ten earthquakes per year of which one or two are felt (Sibol et al., 2007). Earthquake activity to note includes the 1981 Scottsville, Virginia earthquake sequence in which three felt earthquakes with magnitudes of 3.4, 3.2, and 2.9 occurred within an eight minute period. A series of 11 small (magnitude 1.5-2.2) shallow earthquakes were strongly felt in Richmond in the winter of 1986-1987. One of the most persistent areas of activity is in Carroll County, Virginia. Since 1978, five small felt earthquakes have occurred near Hillsville, Virginia (Sibol et al., 2007).

An earthquake occurred on August 23, 2011 within the "Central Virginia Seismic Zone." The Central Virginia Seismic Zone has produced small and moderate earthquakes since at least the 18th century. Previous seismicity in the Central Virginia Seismic Zone has not been causally associated with mapped geologic faults (USGS, 2012). Previous, smaller, instrumentally recorded earthquakes from the Central Virginia Seismic Zone have had shallow focal depths (average depth about 8 km). They have had diverse focal mechanisms and have occurred over an area with length and width of about 120 km, rather than being aligned in a pattern that might suggest that they occurred on a single causative fault (USGS, 2012). Figure 6-1 shows the epicentral region of the August 23, 2011 earthquake.

The August 23, 2011 earthquake caused moderately heavy damage in a rural region of Louisa County southwest of Mineral. Widespread light to moderate damage occurred from central Virginia to southern Maryland including the Washington D.C. area and the Washington Monument. Minor damage was reported in parts of Delaware, southeastern Pennsylvania, and southern New Jersey (USGS, 2012).



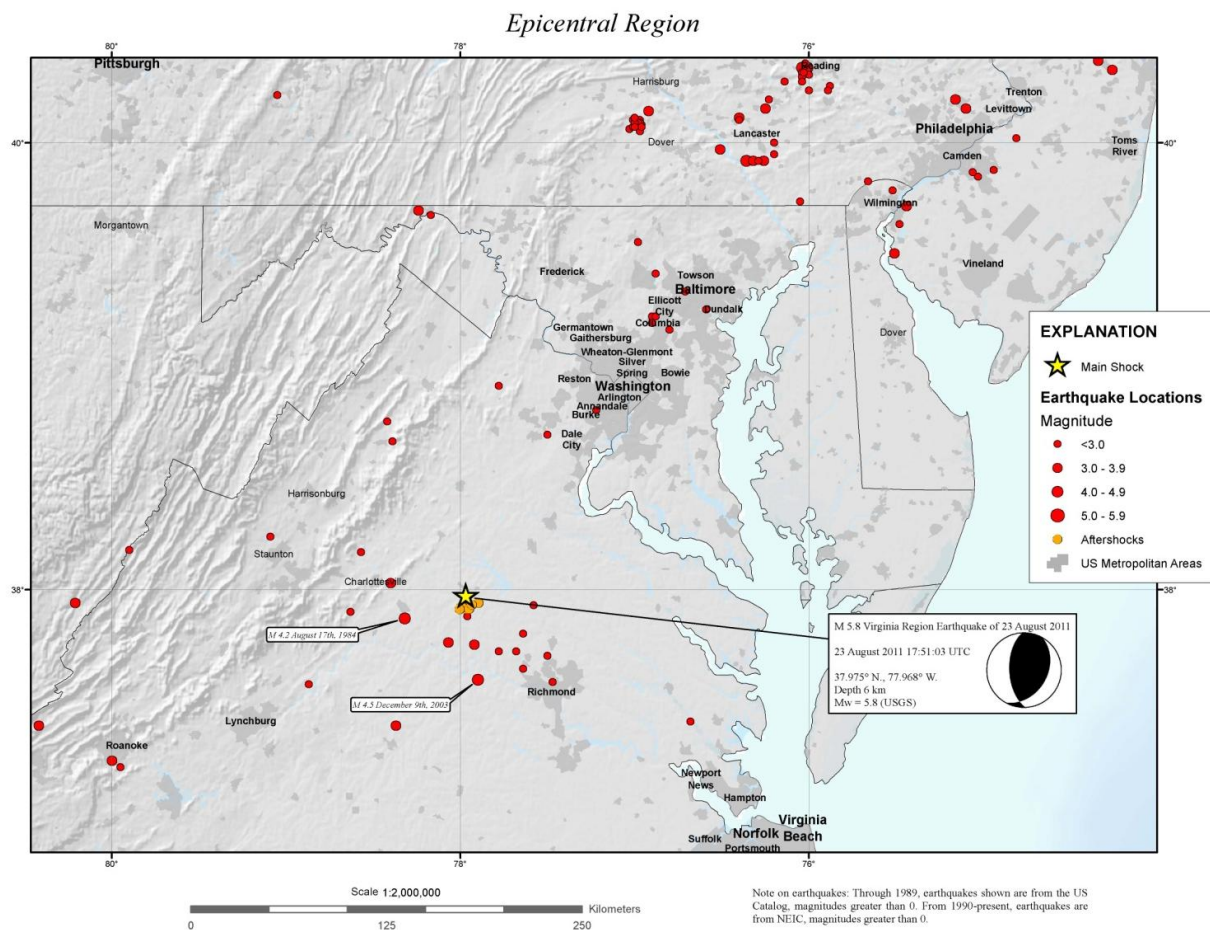


Figure 6-1 Epicentral Region of the August 23, 2011 Earthquake (from USGS, 2011)

## 6.2 Regulatory Requirements

- **International Building Code:** Section 1613 of the International Building Code (International Code Council, Inc., 2012) specifies that every structure shall be designed to resist the effects of earthquake motions. Section 1613.3 outlines the options for determining the maximum considered earthquake (MCE) spectral response accelerations. The Code gives the option of determining the MCE from figures contained in the IBC. The figures were developed utilizing a probabilistic hazard analysis. The Code also states that the MCE can be obtained from a seismic parameter program developed by the USGS in cooperation with the Building Seismic Safety Council (BSSC) and the FEMA.

The Code specifies that all buildings and structures be designed for ground motion associated with a 2 percent probability of exceedance in 50 years. The Code

recommends a structure be designed for the level of ground motion corresponding to the design earthquake. The design earthquake is determined as two-thirds of the maximum considered earthquake ground motion with adjustments to account for the soil profile. It should be noted that the term “maximum considered earthquake” is only used by the building codes and building code documents to define the 2%/50 year earthquake motion. It is the event considered to be applicable to building code design, and is based on probabilistic methods. The term is often confused with “maximum credible earthquake” which is discussed below.

- **NRC:** Seismic regulations for uranium mines and mills are included in NRC code Appendix A to 10 CFR Part 40 “Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content.” NRC code Appendix A to Part 40 of 10 CFR requires that an impoundment not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. The term "maximum credible earthquake" means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology, seismology, distance from a causative fault, and specific characteristics of local subsurface material. NRC code Appendix A to Part 40 also specifies that control of residual radioactive material be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

In addition, NUREG-1620 (NRC, 2003b) provides guidance regarding seismic hazard analyses that need to be completed for reclamation plans.

- **Wyoming:** Title 35 Chapter 11 of the Wyoming Environmental Quality Control Act regulates all types of mining in Wyoming. No specific information was provided regarding seismic hazard analyses required for mining. The WYDEQ-LQD’s non-coal rules and regulations also provide no specific information. However, the *Hard Rock Mining Permit Handbook* (WYDEQ-LQD, 2012) includes a statement that permits should include a discussion of the regional and local seismology. The handbook also states that a professional geologist or professional engineer must certify the interpretations.
- **Colorado:** Colorado 6 CCR 1007-1 Part 18 states that an impoundment may not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. As used in this criterion, the term "capable fault" has the same meaning as defined in Appendix A of 10 CFR Part 100. In addition, the code states that control of



radiological hazards should be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

The Colorado Division of Reclamation, Mining and Safety Hard Rock Rules state that where there is the potential for off-site impacts due to failure of any geologic structure or constructed earthen facility, which may be caused by mining or reclamation activities, the applicant shall demonstrate through appropriate geotechnical and stability analyses that off-site areas will be protected with appropriate factors of safety incorporated into an analysis. The potential for seismic activity should be included in this analysis.

- **Washington:** Under Washington regulations (RCW 78.56.090), siting criteria should take into consideration identifiable adverse geologic conditions such as active faults and the technical site investigation should include a local and structural geology evaluation including seismic conditions. Under Washington code (RCW 70.121.030), any person who proposes to operate a uranium or thorium mill within the state of Washington must submit 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. Washington code (WAC 246-252-030) addresses reclamation criteria related to disposition of uranium mill tailings or wastes. Criterion 4 states that the impoundment shall not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. As used in this criterion, the term "capable fault" has the same meaning as defined in Section III (g) of Appendix A of 10 CFR Part 100. Washington code (WAC 246-252-030) also states that an earthen cover or approved alternative must be placed over tailings or wastes at the end of milling operations and that the design must be effective for 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.

## 6.3 Seismic Hazard Analyses

Site specific seismic hazard analyses are typically conducted using a deterministic analysis, probabilistic analysis, or both. Both deterministic and probabilistic methods have a role in seismic hazard and risk analyses performed for decision making purposes. The approach for each site should be chosen according to the nature of the project and also be calibrated to the seismicity of the region under study, including the quantity and quality of the data available to characterize the seismicity (Bommer, 2002).

### 6.3.1 Deterministic Analyses

A deterministic analysis can be used to determine the peak ground acceleration (PGA) for each earthquake attenuated to the site. A deterministic approach develops a scenario for a particular

earthquake with a specified size, produced in a specified location, and which is assessed based on ground motion at the site of interest. The first step in a deterministic analysis is to identify any seismic sources (faults, geologic structures, etc.) that may affect the site. The sources can be identified as points, lines, areas, or volume, depending on the source type and the possibility to define them geologically. The next step in the analysis is to determine the control earthquake for each seismic source. This can be the expected earthquake, maximum credible earthquake, or any type of earthquake. Earthquake magnitude and epicentral intensity are commonly used to define the size of the earthquake. The distance between the source and the study location needs to be specified. The next step is to determine the earthquake's ground motion in the study location. This is done by estimating the intensity, displacement, velocity, or acceleration of land for different epicentral distances utilizing attenuation equations.

In addition, earthquakes sometimes occur that are not associated with a known geologic structure. These events are termed “background events” or “floating earthquakes” and can also be evaluated in a deterministic analysis. Evaluation of background events allows for potential low to moderate earthquakes that are not associated with tectonic structures to be considered in the seismic hazard of the site. Background earthquakes are typically evaluated deterministically by placing the largest earthquake that can be assumed to occur, that is not associated with a known fault, at a specified distance from the site. The ground motion for this earthquake is then determined.

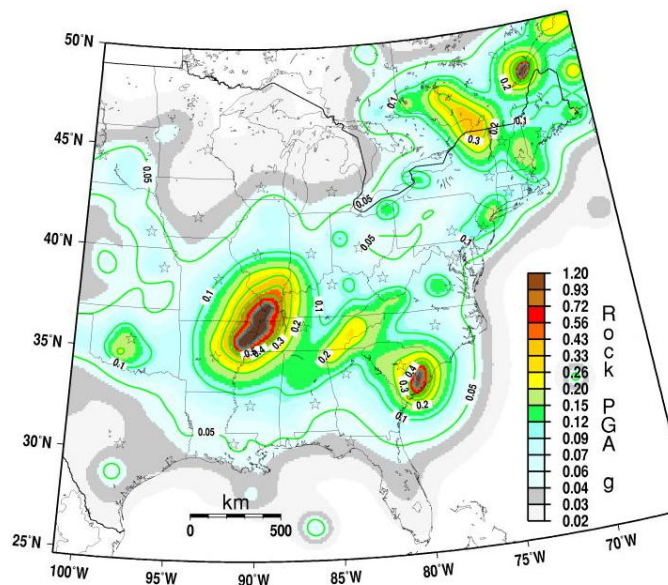
### **6.3.2 Probabilistic Analyses**

A probabilistic analysis consists of four basic steps which partially overlap the deterministic analysis. The first step is to define the seismic sources. It is generally similar to the deterministic analysis except that the sources are explicitly defined as having a constant seismic potential. Sources may vary from line sources to seismotectonic regions. The “background event” in a probabilistic analysis can be defined as an aerial source zone. The next step in the analysis is to define recurrence seismic characteristics for each source. A recurrence relationship indicates the probability of a given size earthquake, with the epicenter anywhere in the source, within a timeframe to take place. The next step is to estimate the earthquake effects at the site location utilizing attenuation curves. The final step consists of integrating the entire range of magnitudes and distances for each seismic source to obtain probabilistic hazard values in the form of cumulative distributions for parameters that describe the movement of land. The effects of all earthquakes of various sizes, produced in different locations and different seismic probabilities are integrated into a single curve, which expresses the probability of exceedance in a specified time period.

### **6.3.3 Seismic Hazard Analyses Programs**

There are many computer programs available with which to complete a site specific seismic hazard analysis. EZ-FRISK and FRISK88M are two examples that are commercially available

from Risk Engineering/Fugro, however, there are numerous others. In addition, the USGS website has many tools available for online seismic hazard analyses (see <http://earthquake.usgs.gov/hazards/apps/>). The USGS and IBC both provide seismic hazard maps that can be used if a site specific analysis is not required. The IBC maps were discussed earlier. Recent research by the USGS has focused on producing national and regional maps of probabilistic earthquake ground shaking. These maps integrate the results of research in historical seismicity, paleoseismology, strong motion seismology, and site response. The maps take into account all the possible locations and magnitudes that can happen in alternative future hypothetical earthquake histories. The maps have been produced by the USGS staff since the early 1970's. The USGS National Seismic Hazard Mapping Project (NSHMP) developed these maps by incorporating information on potential earthquakes and associated ground shaking obtained from interaction in science and engineering workshops involving hundreds of participants, review by several science organizations and state surveys, and advice from two expert panels. The most recent probabilistic hazard maps (Peterson et al., 2008) represent an update of the 2002 seismic hazard maps. Figure 6-2 shows an example seismic hazard map for the central and eastern southeastern U.S.



**Figure 6-2 Example Seismic Hazard Map (from Peterson et al., 2008)**

The National Seismic Hazard Maps represent assessment of the “best available science” in earthquake hazards estimation for the U.S. USGS probabilistic seismic hazard maps are revised approximately every six years to reflect newly published or thoroughly reviewed earthquake science and to keep pace with regular updates of the building code. As of the year 2000, all U.S. model building codes incorporated ground motion hazard maps derived from the USGS studies. The maps are available at:

<http://earthquake.usgs.gov/hazards/apps/http://earthquake.usgs.gov/hazards/apps/>.

## 6.4 Best Management Practices

With regard to completing a seismic hazard analysis for a particular uranium operation the following BMPs should be considered:

- Review of the USGS Quaternary Fault and Fold databases to determine site specific seismic sources;
- Review of the USGS Earthquake database to determine the earthquakes that have taken place within a specified distance of the site;
- Perform a literature search to determine any additional seismic sources that may not be included on the USGS website;
- Take into consideration the IBC maximum considered earthquake at the site when completing a seismic hazard analysis for that location;
- Take into consideration the NRC regulations for seismic evaluations;
- Complete both a deterministic and probabilistic analysis for the site. The two methods can complement one another to provide additional insights to the seismic hazard or risk. Emphasis will be given to one analysis over another based on the specific characteristics of the site;
- If a site specific analysis is not required, another option is to use a tool available on the USGS website. One tool in particular was developed using the 2008 update source and attenuation models of the NSHMP (Petersen et al., 2008). The tool is an interactive deaggregation tool that can calculate ground motions for the following spectral periods anywhere in the conterminous United States: 0.0 second (PGA), 0.1 second, 0.2 second, 0.3 second, 0.5 second, 1.0 second, and 2.0 second. The tool is available at <https://geohazards.usgs.gov/deaggint/2008/index.php> and more information regarding the tool is available at <https://geohazards.usgs.gov/deaggint/2008/documentation.php>.

## 7.0 POTENTIAL IMPACTS TO SURFACE WATER AND GROUNDWATER FROM ON-SITE STORAGE

### 7.1 Introduction

This section discusses regulations related to the on-site storage of potentially hazardous materials used in the mining/milling process. These materials include fuel, lubricants, solvents, waste oil, washing detergents, etc. that are used in the mining/milling process. Regulations are in place to prevent the contamination of surface water and groundwater due to use of these materials.

The potential impacts to surface water and groundwater from the mining/milling facilities themselves (i.e., ore stockpiles, waste rock piles, tailings impoundment) were discussed previously in Section 3.0.

### 7.2 Storage Tanks

The majority of mining and milling operations utilize on-site storage tanks to store a variety of materials used during operations. In general, the EPA regulates above ground storage tanks (ASTs) and underground storage tanks (USTs) and the regulations are administered by the individual states. The majority of tanks utilized in mining and milling operations are above ground.

#### 7.2.1 Indoor Storage Tanks

Indoor storage tanks utilized in the mining industry typically contain fluids that are used for milling operations. Following is a discussion of state and federal regulations pertaining to indoor storage tanks.

- **Wyoming:** ASTs are regulated by the Wyoming Department of Environmental Quality (WYDEQ) within their Storage Tank Program. Regulation of ASTs occurs only if the tank dispenses gasoline or diesel fuel directly to the public and the owner has a Wyoming Department of Transportation license to collect state fuel taxes. Otherwise, regulation defaults to federal legislation, such as regulations defined by the EPA (see below).
- **Colorado:** Storage tanks are regulated by the Colorado Division of Labor and Employment, Division of Oil and Public Safety (7 CCR 1101-14). Article 3 in the regulations addresses ASTs. Prior to installation of an AST, an owner is required to submit an application to construct an AST, at which time the applicant is given guidance regarding state and federal regulations that will govern their project. Sections 3 and 5 of Article 3 of 7 CCR 1101-14 address performance standards for tanks:

- Section 3-3-2 (*Design and Construction of Tanks*) provides information pertaining to the appropriate tank material for the type of material stored, secondary containment tanks, and spill prevention measures.
- Section 3-3-8 (*Location and Installation of ASTs at Bulk Plants*) discusses regulations pertaining to storage where the internal pressures do not exceed 2.5 psi. Table 6 in the regulation defines tank capacity along with the placement distance from property.
- Section 3-3-10 (*Normal Venting*) provides venting requirements for tank installations.
- Section 3-3-14 (*Installation of Tanks Inside Buildings*) provides detailed regulations pertaining to tanks constructed within enclosed structures.
- Section 3-3-15 (*Standards for Piping, Valves and Fittings*) provides regulations that ensure proper connection and conveyance of fluids.
- Section 3-5 (*Release Detection*) provides regulations related to inspection and testing of primary and secondary containment systems in order to detect leaks.
- **Oregon:** The ODEQ Land Quality Division regulates tanks. However, ASTs are not covered by the ODEQ program. Certain ASTs are regulated by the Oregon State Fire Marshal's Office.
- **Environmental Protection Agency:** Section 311(b)(3) of the Clean Water Act (CWA) prohibits the discharge of oil or hazardous substances to navigable waters of the U.S. Section 502(7) of the CWA defines navigable waters as the waters of the U.S. In addition, the EPA's interpretation of navigable waters has traditionally included all streams, creeks, lakes, wet meadows, mudflats, sand flats, ponds and other drainages connected to any tributary system in a river basin.

### 7.2.2 Outdoor Storage Tanks

The predominant consideration of outdoor storage tanks relates to weather factors, such as precipitation and wind. The following regulations provide guidance specific to outdoor storage tanks.

- **Wyoming:** See discussion in Section 7.2.1.
- **Colorado:** Regulations discussed in Section 7.2.1 are also relevant to outdoor storage tanks. In addition, 7 CCR 1101-14 Article 3 provides information that specifically addresses outdoor storage tanks:
  - Section 3-4-2(b) (*Remote Impounding*) provides guidelines for remote impounding of fluids, including minimum slope requirements, allowance for precipitation, and capacity of impoundment area.



- Section 3-4-2(c) (*Impounding Around Tanks by Diking*) provides guidelines for dike impoundments including dimensions, storage capacity, sloping, and material requirements.
- Section 3-4-3 (*Operation and Maintenance of Corrosion Protection*) addresses methods to protect tanks, pipes and other appurtenances from corrosion which could ultimately lead to failure. Corrosion of outdoor storage tanks can be accelerated by the elements.

In terms of outdoor storage tank construction, secondary containment must also account for the addition of rainfall into the storage area. Accounting for this moisture is in addition to the anticipated chemical spillage. Although not specifically defined in Article 3 of 7 CCR 1101-14, conservatism leads to using the PMP to determine additional storage requirements. For information pertaining to the PMP, see Section 4.0 of this report.

- **Oregon:** See discussion in Section 7.2.1.
- **Environmental Protection Agency:** For storage tanks located outdoors, EPA regulations state:
  - “*Secondary Containment (e) (2) (ii). Any bulk storage facility storage container (e.g., tanks, oil-water separators, etc.) must have secondary containment for the entire contents of the largest single container with sufficient freeboard to allow for precipitation; or an alternate system like the ones listed in 40 CFR 112.7(c)(1). The volume of freeboard should be sufficient to contain the rainfall from a 100 year, 24-hour storm event. If the facility is located in a state with the potential for large amounts of rainfall, the secondary containment structures should accommodate these greater amounts of precipitation.* Refer to:
  - [http://www.epa.gov/emergencies/docs/oil/spcc/example\\_construct\\_containment.pdf](http://www.epa.gov/emergencies/docs/oil/spcc/example_construct_containment.pdf) for examples and guidance in determining secondary containment and precipitation.

### 7.3 Spill Prevention Control and Countermeasure (SPCC) Plan

Regulations issued by the EPA under the Clean Water Act Section 311(j) (40 CFR Part 112) require facilities that store oil or chemicals in significant amounts to prepare Spill Prevention Control and Countermeasure (SPCC) Plans and to adopt measures to keep accidental releases from reaching the waters of the U.S. The regulation applies to both mines and mills and details the equipment, manpower, procedures and steps to prevent, control, and provide adequate countermeasures to a release. It should be noted that Wyoming, Colorado, and Oregon refer to EPA regulations unless otherwise noted in their regulations. SPCC Plans ensure that facilities utilize containment and other countermeasures that would prevent releases that could potentially



reach navigable waters. Whether the licensee/permittee has an indoor or outdoor tank, any bulk storage (tank) facility must have a written site-specific SPCC Plan which details the facility's compliance with 40 CFR Part 112. The SPCC Plan must comply with the following:

- be kept on site;
- be certified by a Registered Professional Engineer;
- have full management approval;
- conform with all SPCC requirements set forth within *40 CFR part 112*;
- discuss spill history;
- discuss anticipated spill migration; and
- be reviewed every three years.

Specific elements to include in the SPCC Plan are found in 40 CFR 112.7. General requirements include:

- **Diversiory Structures:** All SPCC-regulated facilities, including bulk storage facilities, shall have contaminant spill structures in place to prevent spills and contaminated runoff from reaching storm drains, streams (perennial or intermittent), ditches, rivers, groundwater, bays, and other navigable waters. Secondary containment must be in place to account for primary containment failure. The regulation lists dikes, berms, curbing, culverts, gutters, trenches, absorbent material, retention ponds, weirs, booms, and other barriers or equivalent preventive systems. Because SPCC requirements are performance-based, alternative forms of spill containment may be allowed, assuming the proposed alternative provides protection that is equivalent to systems listed in 40 CFR 112.7(c). Whatever material or method is used for secondary containment, it must be sufficiently impervious to contain spilled material. It should be verified that secondary confinement material will not be compromised by the material being confined.
- **Tank Material:** The tank material must be suitable for the storage purpose and for the conditions of storage (e.g., pressure, physical and chemical properties, and temperatures). Industry standards relative to tank construction, material, installation, and use should be applied. Refer to relevant portions of industry standards from organizations such as the American Petroleum Institute (API), National Fire Protection Association (NFPA), Underwriters Laboratory (UL), or American Society of Mechanical Engineers (ASME). State or local regulations (and some other federal regulations) may require the use of these standards.

- **Secondary Containment:** Any bulk storage facility storage container (e.g., tanks, oil-water separators) must have secondary containment for the entire contents of the largest single container with sufficient freeboard to allow for precipitation (outdoor tanks). In general, the volume of freeboard should be sufficient to contain the rainfall from a 100-year, 24-hour storm event. However, if the facility is located in a state that has the potential for large rainfall intensity, the secondary containment structures should accommodate these greater amounts of water.
- **Aboveground Storage Tanks:** Periodically, qualified personnel should examine each AST for integrity of the tank(s). Inspection personnel may use techniques such as x-ray or radiographic analysis to measure wall thickness and detect cracks and crevices in metal; ultrasonic analysis to measure shell metal thickness; hydrostatic testing to identify leaks caused by pressure; visual inspection to detect cracks, leaks, or holes; magnetic flux eddy current test used in conjunction with ultrasonic analysis to detect pitting. The outside of the tank should be checked for signs of deterioration, leaks that might cause a spill, and accumulated oil inside diked areas. AST tank bottoms may be subject to extensive corrosion, which may go undetected during visual inspections. A tank also may fail due to surface corrosion. Pitting creates a high potential for AST failure. Holes may form in rusty tanks causing the tank to leak. Corrosion can be minimized by taking measures appropriate for the type of tank installation and foundation (e.g., dielectric coatings, carefully engineered cathodic protection, and double-bottom tanks).
- **Tank Foundations:** The foundation and supports for each tank should be examined. If a tank sits on a foundation, it should be examined for large gaps between the foundation and the tank bottom and for crumbling or excessive cracking in a concrete foundation. Storage tank foundations should be assessed to determine if they provide adequate support for the tank. If the tank sits directly on the ground, it should be examined for large gaps between the ground surface and the tank bottom.
- **Documentation:** All leaks must be documented on an inspection form and reported to the person in charge of spill prevention at the mine and/or mill facility. Leaks should be immediately repaired.
- **Level Monitoring:** Level gauging systems should be selected that are in accordance with good engineering practices. Some larger tanks may require gauges and high-level alarms as the fail-safe system.
- **Pumping:** Pumping systems are required to pump spill material to a backup location if a leak were to occur.

## 8.0 VULNERABILITY ANALYSIS FOR SECURITY EVENT

### 8.1 Introduction

This section discusses potential uranium mine and mill security concerns and measures and controls that are implemented to prevent security events from occurring.

Security of radiation sources is a top priority for the NRC to prevent their use by terrorists. Although to date there have been no specific credible threats against uranium mills and mines, the NRC remains vigilant to the security of sources of radioactive material. According to the NRC, since September 11, 2001, the focus of U.S. security for radiation sources has been increasingly on the prevention of the theft of radioactive materials and the subsequent malicious use as a “dirty bomb” or a radiation exposure device.

The NRC works with domestic and international organizations on a variety of initiatives to make sources less vulnerable to terrorists. The information included in this section is based on NRC guidance which references the numerous international security instruments in place that provide technical guidance for security events involving radioactive material including: *Convention on the Physical Protection of Nuclear Material* (IAEA, 1980, amended 2005), the *Code of Conduct on the Safety and Security of Radioactive Sources* (IAEA, 2000); the *Supplementary Guidance on the Import and Export of Radioactive Sources* (IAEA, 2012), the *United Nations Security Council Resolution 1373* (UN, 2001) and *1540* (UN, 2004); and the *International Convention for the Suppression of Acts of Nuclear Terrorism* (UN, 2005).

The NRC or agreement states have implemented comprehensive security measures that are appropriate for facilities where radioactive material is produced, housed, or utilized and the risk posed by the materials. The NRC and its agreement state partners conduct regular inspections of material licensees to ensure safety and security requirements are met.

The National Source Tracking System (NSTS) is a database that the NRC has developed to track the most risk-significant sources. In addition to its security function, the NSTS has been useful in the NRC’s response to natural disasters such as floods or hurricanes by informing regulators where sources were located so their safety and security could be ensured.

The NRC and its agreement states have imposed a comprehensive, multi-layered security program to protect radioactive source materials. The NRC’s security program allows the licensee to develop a security program that is specifically tailored to their facility. This allows an operator to develop and implement a facility-specific security plan based on their assessment of possible security events.

Key elements of the NRC security program are found in their *Backgrounder on the Protection and Security of Radiation Sources* (NRC, 2012) and are listed below:

- background checks including fingerprinting to ensure that those that have access to radioactive material are trustworthy and reliable;
- personnel access controls to areas where radioactive material is stored or used;
- security plans or procedures designed to detect, deter, assess and respond to unauthorized access attempts;
- coordination and response planning between licensees and local law enforcement agencies;
- coordination and tracking of shipments of radioactive material; and
- security barriers to discourage theft of portable devices containing radioactive material.

The IAEA *Implementing Guide for Security of Radioactive Sources* (IAEA, 2009) recommends that facility-specific security plans be developed considering the following:

- definition of the system objectives and requirements;
- facility characteristics;
- target identification;
- threat assessment and risk management;
- consequence analysis;
- vulnerability assessment;
- performance tests; and
- contingency plan.

A vulnerability assessment, also known as a security survey or security assessment, is a method for evaluating protective security systems on a facility-specific basis. It is a systematic appraisal of the effectiveness of a security system for protection against an assessed threat. The vulnerability assessment can be specific or general in nature, can be conducted by the operator or regulatory body, and can be used to help the development of regulations for demonstrating regulatory compliance of a facility.

The following physical security measures are implemented to prevent unauthorized access to a licensed facility. These measures have been identified by the IAEA as best practices for physical

protection to prevent terrorism, theft, and general vandalism to equipment and administrative information.

- access control;
- uranium shipment control;
- radiation monitoring of vehicles and containers;
- facility perimeter control; and
- training of security staff.

## 8.2 Mine and Mill Security

Security events of concern to the NRC at uranium mines and mills are predominantly related to theft, sabotage, unauthorized access, and illegal transfer of the milled uranium. The IAEA has identified the following possible security concerns at uranium mines and mills:

- misuse of operating mines and mills;
- understatement of uranium production over long periods of time;
- understatement of uranium production during a short period of time;
- theft of significant quantities of uranium during a period of production transition; and
- theft from facility or during transport.

The IAEA has identified the following BMPs for mines and mills for the effective management of uranium accounting:

- evaluation of feasible scenarios of uranium theft and quantities involved;
- establish effective management of uranium accounting;
- clear delineation of staff responsibilities;
- separate functions of accounting staff from facility operations;
- establish record system including procedures, electronic accounting records, inventory changes and operating records;
- establish measurement system including procedures, calibration, sampling, quality control of measurement results and analysis of measurement uncertainties;
- establish material balance areas and key measurement points for effective calculations of uranium balance and flow;
- automate accounting system;

- establish procedures for regular physical inventory taking, material balance evaluation, shipping/receiving differences, and material; and
- establish accounting for procedures for transition periods in regular uranium production.

At uranium mines, there are a variety of security concerns that are not unique to uranium mining but are applicable to mining operations in general. These include, but are not limited to, the following:

- theft of equipment or supplies;
- theft of explosives;
- trespassing leading to injury due to pit walls or other hazardous mine conditions;
- vandalism or misuse of mine equipment or vehicles;
- vandalism to chemical/petroleum storage tanks resulting in product releases that could have environmental impacts;
- vandalism or theft of monitoring or sampling equipment; and
- vandalism or theft of computers or mine records.

Likewise, at uranium mills, there are security concerns that are not unique to uranium milling but apply to milling or industrial processing in general. These include, but are not limited to:

- theft of equipment or supplies;
- trespassing leading to injury due to milling equipment or hazardous substances;
- vandalism or misuse of mill equipment or vehicles;
- vandalism to chemical/petroleum storage tanks;
- vandalism to piping systems;
- vandalism or theft of monitoring or sampling equipment; and
- vandalism or theft of computers, mill records, or uranium accounting records.

Prudent mine or mill operators will anticipate these security concerns and develop a comprehensive security plan to protect their facility, equipment, and the public. The security plan should consider fencing, gates, security cameras, security guards, regular patrols by mine personnel, etc.



## **9.0 CRITERIA TO DEVELOP AN EFFECTIVE HYDROGEOLOGICAL MODEL FOR USE AT POTENTIAL SITES**

This section discusses the use of hydrogeological models which are commonly used to simulate groundwater and related hydrologic conditions in the subsurface. The use of a hydrogeological model is not required by any regulatory agency as part of the permitting/licensing process for a mine or mill operator. However, a groundwater model can be a useful tool to characterize the groundwater conditions at a site and to predict the effect of mining on groundwater and surface water.

### **9.1 Regulatory Precedent**

Environmental permitting for mining projects typically does not require hydrogeological models, which are often referred to as groundwater flow and transport models. The WYDEQ allows the use of groundwater flow models, formulas, or other technically justified methods for defining the “area of review” and monitoring well spacing for in-situ leaching projects (WYDEQ-LQD, 1994b). The level of sophistication used in estimating drawdown and other impacts should be proportional to the complexities of the hydrogeologic system (WYDEQ-LQD, 2005 and NRC, 2003c). This implies that groundwater models may be needed for complex hydrogeologic conditions, but that analytical methods are acceptable for general conditions. This is consistent with NRC 10 CFR 51.45 which requires that the affected environment must be described, but it does not require numerical models for the analysis.

The complexity of modern projects, groundwater systems, and restoration has resulted in the increasing use of groundwater flow and transport models. As a practical matter the use of computer models is a best management practice, but they are not required. This section provides information to consider if hydrogeological models are used for groundwater system characterization and predictions. A summary of references and standards used in developing an effective hydrogeological model is presented in Table 9-1.

### **9.2 Introduction**

Hydrogeological models are commonly used to simulate groundwater and related hydrologic conditions in areas surrounding mining projects. These models are used for a variety of purposes that may include regulatory permitting, development and evaluation of mine plan of operations, monitoring plans, and mine closure plans. There are three major issues related to groundwater in mining projects that are commonly addressed: (1) mine dewatering requirements; (2) stability of pit walls or developments; and (3) environmental impacts on groundwater levels and on groundwater quality, during mining and post-mining periods (Martinez and Ugorets, 2012). During the environmental permitting phase of a mining project hydrogeological models, which

are often referred to as groundwater flow and transport models, are used for predicting mining-related hydrologic impacts.

Each mining project and the affected environment are unique. The objectives and methods used in groundwater modeling are likewise unique. It is therefore difficult and ineffective to establish rigid requirements or criteria for model development. This section outlines standard technical issues that should be addressed and industry standard criteria for the developing acceptable models. These criteria are guidelines and need to be considered in context with the specific project and hydrogeologic environment.

The acceptability of a hydrogeologic model and its predictions are most commonly determined during a technical review process. Qualified, subject-matter experts commonly provide technical reviews of the conceptual model, numerical model, input data, related analyses, and simulation results. Regulatory agency staff and/or independent third party reviewers can fulfill the technical review responsibilities. Model developers are then provided the opportunity to address concerns and issues identified by the technical reviewers. An effective model is developed during this process that allows regulatory agencies to confidently evaluate the project.

The EPA uses scientific peer review to provide the main mechanism for independent evaluation of environmental models used by the Agency (EPA, 2009). Peer review provides an independent, expert evaluation that fulfills the following primary purposes:

- to evaluate whether the assumptions, methods, and conclusions derived from environmental models are based on sound scientific principles;
- to check the scientific appropriateness of a model for informing a specific regulatory decision;
- to provide information helpful for choosing among multiple competing models for a specific regulatory application; and
- to identify the limitations of existing models.

The references in this section provide guidelines and criteria for development of effective hydrogeological models and their subsequent technical review. It is the responsibility of the technical reviewer to determine whether project specific conditions were addressed and simulated in an appropriate manner and that the results are reasonable.

The primary steps to develop an effective groundwater model are identified in EPA (EPA, 1992b) and ASTM D5447-04 and this section generally follows these steps:

- define the study objectives;
- develop a conceptual model;
- select a computer code;
- construct the groundwater flow model;
- calibrate the model and perform a sensitivity analysis;
- make predictive simulations; and
- document the modeling study.

### 9.3 Purpose and Objectives

An effective hydrogeologic model will have a clearly stated purpose and objectives that guides model development. Technical reviewers should use these objectives as a reference for evaluating the adequacy and effectiveness of the model (Reilly and Harbaugh, 2004). The purpose and objectives may include the following elements:

- The purpose of hydrogeologic models may be related to regulatory permitting, project design, project management, and/or addressing a specific problem. The project specific purposes should be clearly stated.
- A project description that focuses on the project facilities and features that may impact the hydrogeologic environment. Conversely, the groundwater system may impact development of the project facilities and these interactions should be identified.
- Model objectives may include an assessment of potential impacts to the hydrologic system. Features, conditions, and areas that may be potentially impacted should be explicitly identified.
- Identifying objectives related to changes in groundwater quantity, flow paths, and water quality will guide modeling methods and approaches.
- The predictive period for the model should be identified and be consistent with regulatory needs.

### 9.4 Conceptual Model

A conceptual model that provides a consistent and integrated understanding of the groundwater system is needed to guide numerical model development and evaluation of its results.

Conceptual models evolve during the characterization and modeling process as greater understanding of the groundwater system is obtained. The conceptual model should be supported by data and analyses obtained during groundwater system characterization. Data commonly obtained to characterize groundwater systems is provided in ASTM D5474-93. A guide for characterization and conceptualization of groundwater systems is provided in ASTM D5979-96.

The source, occurrence, and movement of groundwater are described in the conceptual model. This includes a discussion of the hydrogeologic framework, which describes the extent, distribution, geometry, and properties of the hydrogeologic units and structures. Items to be considered in the conceptual model may include the following:

- groundwater basin boundaries;
- media type (e.g. fractured or porous media);
- water bearing hydrogeologic units;
- confining units and flow barriers;
- groundwater flow directions (horizontal and vertical gradients);
- groundwater recharge areas;
- groundwater discharge areas;
- surface-water bodies (lakes, ponds, rivers, streams, wetlands, etc.);
- groundwater and surface-water interactions;
- riparian vegetation including distribution, density, and groundwater discharge;
- pumping and injection wells;
- water budget; and
- other relevant natural and anthropogenic processes.

## **9.5 Modeling Approach and Computer Model Programs**

There are numerous modeling approaches to address hydrogeologic related problems. Regardless of the approach, a calibrated model is usually required to adequately simulate a hydrogeologic system and to evaluate potential impacts due to mining projects. There are numerous options for simulating hydrogeologic conditions and the appropriateness of the method depends on the specific application. Modeling approaches that can be used to address problems are discussed in Reilly and Harbaugh (Reilly and Harbaugh, 2004).

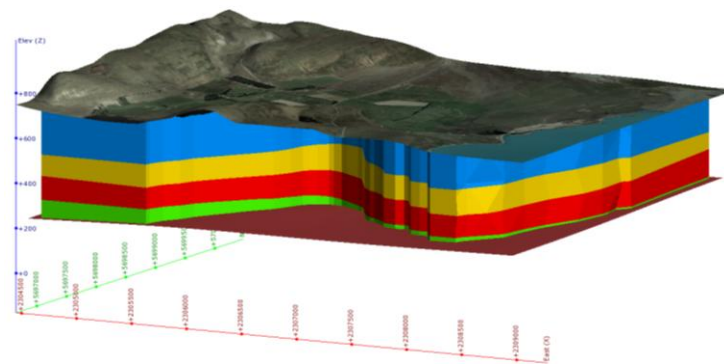
In general, computer modeling programs should (Reilly and Harbaugh, 2004):

- meet the modeling objectives;
- have appropriate assumptions and representations of the groundwater flow equations; and
- be able to simulate the important physical processes needed to adequately represent the groundwater system.

Criteria for identifying acceptable modeling programs include rigorous peer review, numerically accurate and verified results, and successful implementation on similar projects. There are no formally stated industry standards for modeling programs and there are too many options to list. Commonly used groundwater flow modeling programs that can be used for a variety of systems include the U.S. Geological Survey's finite difference code MODFLOW (Harbaugh, 2005), variations such as MODFLOW-SURFACT, and the finite element code FEFLOW (developed by the DHI Group). An extensive list of criteria to be considered when selecting groundwater modeling codes is provided in ASTM D6170-97. Simulation of contaminant transport and unsaturated zone conditions requires additional computer programs that typically rely on groundwater flow models to simulate the flow directions and rates.

### 9.5.1 Model Construction

Model construction is the process of creating a numerical or computer representation of the conceptual model. Hydrogeologic features and processes are defined by input data into the modeling programs. Figure 9-1 shows an example of a computer representation of a conceptual subsurface geological system.



**Figure 9-1 Computer Representation of a Conceptual Subsurface Geological System**

A fundamental aspect of numerical models is the representation of the real world by discrete volumes of material (Reilly and Harbaugh, 2004). The accuracy of the model is limited by the

size of the discrete volumes. The volumes are called cells in the finite-difference method, and the volumes are called elements in the finite-element method. Grid spacing in the x- and y-directions provides the horizontal dimension of model cells. Model layer thickness provides the vertical dimension of finite-difference model cells. Element sizes in finite-element models are irregular and are varied to provide more resolution near important features. In transient models, time is represented by discrete increments of time called time steps in most model programs. The size of the time steps also has an impact on the accuracy of a model. The issue of the size of the discrete volumes and time steps is discussed for the finite-difference method in Reilly and Harbaugh (Reilly and Harbaugh, 2004).

### **9.5.2 Boundary Conditions and Initial Conditions**

Appropriate boundary conditions are needed to accurately simulate natural processes related to model inflows and outflows at the external model boundaries, surface-water features, riparian vegetation, pit lakes, and related features. Boundary conditions are a mathematical expression of a state of the physical system that constrains the equations of the mathematical model (ASTM D5447-04). Identifying and appropriately simulating boundary conditions are extremely important for obtaining reliable results. Initial conditions provide starting hydraulic heads for transient simulations.

### **9.5.3 Hydraulic Properties and Model Input**

Each model cell or element must be assigned hydraulic properties and model specific values. The most common hydraulic properties are horizontal and vertical hydraulic conductivity (or transmissivity) and storage properties. Hydraulic property values are assigned in the model based upon geologic and aquifer testing data (ASTM D5447-04). Data obtained during characterization provides input needed to simulate recharge, springs, streams, lakes, riparian vegetation, pumping, and water quality (ASTM D5979-96).

Transient simulations require model inputs that change with time. For example, water-level, stream flow, evapotranspiration, recharge, and pumping may change with time. These changes need to be identified at an appropriate frequency to meet the modeling objectives and desired accuracy.

### **9.5.4 Model Calibration**

Model calibration is the process of adjusting hydraulic parameters, boundary conditions, and initial conditions within reasonable ranges to obtain a match between observed and simulated water levels, flow rates, or other calibration targets (ASTM D5447-04). Models are generally calibrated using manual trial-and-error or inverse-modeling techniques. Guidelines for effective model calibration can be found in Hill (Hill, 1998). Although Hill addresses inverse modeling



techniques most of the guidelines apply to all groundwater models. Additional criteria for effective model calibration can be found in ASTM D5981-96.

The criteria for determining whether the model calibration is acceptable depend on the application and the modeling objectives. Discussion on determining the adequacy of a model calibration is provided in several references. A guide for comparing the results of numerical groundwater flow models with observed site-specific information is provided in ASTM D5490-93.

### **9.5.5 Sensitivity Analysis and Uncertainty**

A sensitivity analysis is often conducted following model calibration. This analysis provides simulation results based on changes to the calibrated model's hydraulic properties or boundary conditions. A guide for performing a basic sensitivity analysis is provided in ASTM D5611-94. Sensitivity analysis is a method of evaluating the significance of uncertainty in model parameters. Sources of uncertainty and statistical methods for quantifying uncertainty are provided in NRC, 2004.

### **9.5.6 Predictions and Post-Audit**

Calibrated models are often used to make predictions of future groundwater conditions that will result from mining projects. The accuracy of these predictions depends in part on how well the simulated groundwater system represents the real-world natural and anthropogenic conditions that control the system. Model calibration and validation that the model adequately predicts historic conditions provides a measure of confidence in the future predictions.

Groundwater system monitoring after the project is implemented is critical for assessing the accuracy of the model predictions. Stresses applied to the groundwater system by mining projects may be greater than historical stresses used to calibrate the model. Monitoring the impact of the mining stresses provides a valuable data set for assessing model performance and for model improvements. Periodic groundwater model updates, that may include re-calibration, can be implemented using these monitoring data to continually improve model performance. It may take several years before groundwater system changes are observed and an effective post-audit can be conducted. Model updates are therefore typically performed every 5 to 10 years, which provides sufficient monitoring data to assess trends and impacts.

## **9.6 Model Documentation**

There are no formal criteria for documenting hydrogeologic model investigations. General guidelines that should be followed are provided in USGS (USGS, 1996), which is provided as an appendix in Reilly and Harbaugh (Reilly and Harbaugh, 2004). Additional guidance on documentation is provided in ASTM D5718-95 and ASTM D5447-04. The appropriate level of

documentation will vary depending on the project objectives and the complexity of the simulations. The general structure of a well-constructed report describing simulation is much the same as that for any investigative study. It should present: (1) the objectives of the study, (2) a description of the work that was done, (3) logical arguments to convey to the reader that the methods and analyses used in the study are valid, and (4) results and conclusions (USGS, 1996).

## 10.0 SUMMARY

### 10.1 Summary of Best Management Practices

The key BMPs and regulatory guidance applicable to the design, operation, and closure of uranium mining and milling facilities are provided in Tables 10-1 through 10-6. Each table summarizes key regulatory guidance and BMPs for separate aspects of uranium mining or milling, as follows:

- Table 10-1 addresses BMPs for design of uranium mines and includes a discussion of water storage ponds, embankments, seismic design, groundwater, surface water, air, and waste rock.
- Table 10-2 addresses the BMPs for design of uranium mills and includes a discussion of process ponds, tailings impoundments, heap-leach liners, ore stockpiles, embankments, seismic design, groundwater, process fluid delivery systems, surface water, and air.
- Table 10-3 addresses BMPs for mine operations and includes a discussion of water storage ponds, groundwater, surface water, air, and waste rock.
- Table 10-4 addresses BMPs for mill operations and includes a discussion of process ponds, tailings impoundments, heap-leach liners, embankments, groundwater, process fluid delivery systems, surface water, and air.
- Table 10-5 addresses BMPs for mine closure design and implementation and includes a discussion of water storage, embankments, seismic design, groundwater, surface water, and waste rock.
- Table 10-6 addresses BMPs for mill closure design and implementation and includes a discussion of process ponds, tailing impoundments, heap-leach liners, ore stockpiles, embankments, seismic design, groundwater, surface water, air, soils, and the mill facilities.

The tables are not intended to provide an exhaustive list of all BMPs or regulatory guidance applicable to the various phases of uranium mining and processing. Rather, they include representative examples which are included to aid the VDEQ and VDMME in decision making.

### 10.2 Selected Case Histories and Technical Articles

Selected case histories and technical articles related to uranium mining and milling are summarized in Table 10-7. These publications address a variety of aspects of uranium mining and milling. Many of these publications can be found in the proceedings of the annual Tailings and Mine Waste Conferences (Tailings and Mine Waste Conferences, 1996 through 2011). The

publications summarized in Table 10-7 represent a small sample of the substantial body of published technical information available on the topic of uranium mining and milling.

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## TABLES

**Table 9-1 Summary of References and Standards Used in Developing an Effective Hydrogeologic Model**

<b>Model Component</b>	<b>Applicable References and Standards</b>
Modeling Guidance Overview	<ul style="list-style-type: none"> <li>• BLM (2012)</li> <li>• EPA (2009), EPA 100-K-09-003</li> <li>• EPA (1994a), EPA 500-B-94-003</li> <li>• EPA (1992b), EPA 540-S-92-005</li> <li>• NUREG/CR-6948, Vol. 1</li> <li>• NUREG/CR-6805</li> </ul>
Purpose and Objectives	<ul style="list-style-type: none"> <li>• EPA (1994a), EPA 500-B-94-003</li> <li>• Reilly and Harbaugh (2004)</li> </ul>
Conceptual Model	<ul style="list-style-type: none"> <li>• EPA (1994a), EPA 500-B-94-003</li> <li>• ASTM D5979-96</li> <li>• Franke et al. (1987)</li> <li>• Reilly (2001)</li> </ul>
Modeling Approach and Model Programs	<ul style="list-style-type: none"> <li>• ASTM D6170-97</li> <li>• ASTM D5880-95</li> </ul>
Model Construction	<ul style="list-style-type: none"> <li>• Anderson and Woessner (1992)</li> <li>• Reilly and Harbaugh (2004)</li> </ul>
Boundary Conditions	<ul style="list-style-type: none"> <li>• ASTM D5609-94</li> <li>• Franke et al. (1987)</li> <li>• Reilly (2001)</li> </ul>
Initial Conditions	<ul style="list-style-type: none"> <li>• ASTM D5610-94</li> <li>• Franke et al. (1987)</li> </ul>
Hydraulic Properties and Model Input	<ul style="list-style-type: none"> <li>• ASTM D5447-04</li> <li>• ASTM D5979-96</li> <li>• NUREG/CR-6948, Vol. 1</li> </ul>
Model Calibration	<ul style="list-style-type: none"> <li>• Anderson and Woessner (1992)</li> <li>• ASTM D5490-93</li> <li>• Hill (1998)</li> <li>• Reilly and Harbaugh (2004)</li> </ul>
Sensitivity Analysis and Uncertainty	<ul style="list-style-type: none"> <li>• ASTM D5611-94</li> <li>• NUREG/CR-6843</li> <li>• NUREG/CR-6805</li> </ul>
Predictive Simulations and Post-Audit	<ul style="list-style-type: none"> <li>• ASTM D5447-04</li> <li>• NUREG/CR-6948, Vol. 1</li> </ul>
Documentation	<ul style="list-style-type: none"> <li>• ASTM D5718-95</li> <li>• EPA (1992b), EPA 540-S-92-005</li> <li>• USGS (1996)</li> </ul>



**Table 10-1 Guidance for Mine Design BMPs**

Item	BMP	Guidance
Water Storage Ponds	<u>Unlined or Single-Lined</u> : These ponds are commonly used to hold dust suppression water.	<ul style="list-style-type: none"> <li>CMLRB (2010), Section 3.1.6(5)</li> </ul>
Embankments	<u>Slope Stability</u> : Static and pseudostatic analyses are completed for proposed excavated and constructed slopes. The seismic coefficient used will be determined based on the life of the mine.	<ul style="list-style-type: none"> <li>CMLRB (2010), Section 6.5</li> </ul>
	<u>Surface Erosion</u> : Controlled by the placement of riprap or other erosion resistant materials .	<ul style="list-style-type: none"> <li>Washington RCW 78.56.090, Subsection (4)</li> </ul>
Seismic Design	<u>Return Interval</u> : The seismic coefficient used will be determined based on the life of the mine. Mine buildings are designed based on 2% probability of exceedance in 50 years.	<ul style="list-style-type: none"> <li>International Building Code (ICC, 2012)</li> </ul>
	<u>Site Acceleration</u> : Two-thirds of the peak acceleration is used in the pseudostatic analyses.	<ul style="list-style-type: none"> <li>DOE (1989)</li> </ul>
Groundwater	<u>Characterization</u> : Climatic conditions, important groundwater system processes, hydrogeologic properties of subsurface materials, flow paths, background water quality, and sensitive environmental features are determined.	<ul style="list-style-type: none"> <li>WYDEQ-LQD (2012)</li> <li>Washington RCW 78.44.091</li> <li>CMLRB (2010), Sections 3.1.6(4), 6.4.21, 8, 9</li> </ul>
	<u>Monitoring Systems</u> : Monitoring and testing wells are established based on local and regional geology, groundwater flow, and sensitive environmental features. Groundwater wells are installed to establish baseline water quality and piezometric surface. Point of compliance wells are commonly established along the mine perimeter.	<ul style="list-style-type: none"> <li>CMLRB (2010), Sec. 3.1.7</li> </ul>
	<u>Modeling</u> : Drawdown and potential migration of constituents of concern in the unsaturated and saturated zones are analyzed for mining and post-closure phases to determine the range of possible impacts on the groundwater system and the environment.	<ul style="list-style-type: none"> <li>CMLRB (2010), Sec. 3.1.7(6)(b)(i)(B)</li> </ul>
	<u>Mine Dewatering</u> : If mining will be below the water table, a dewatering plan is developed cooperatively with pit or tunnel design to ensure safe working conditions and geologic stability of the facilities. The dewatering plan should address: drawdown, mine water balance to include handling excess water, recycling water for dust control, mill and mining operations, treatment of water if needed.	<ul style="list-style-type: none"> <li>CMLRB (2010), Section 3.16(a)</li> </ul>
	<u>Pit Lake Model</u> : Geochemical and groundwater models are commonly used to predict the long-term pit lake water quality and potential for off-site migration.	<ul style="list-style-type: none"> <li>CMLRB (2010), Section 3.16(a)</li> </ul>

**Table 10-1 Guidance for Mine Design BMPs (continued)**

Surface Water	<u>Diversions Upstream</u> : Riprap lined channels are constructed to divert water around the proposed mine structures (e.g., waste rock piles, pits, embankments).	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• CMLRB (2010)</li> </ul>
	<u>Channelized Flow</u> : On-site flow is collected in channels and diverted around proposed waste rock piles, pits, adits, and other areas of high mineralization.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• CMLRB (2010)</li> </ul>
	<u>Sedimentation/Settlement Basins</u> : The channels to collect and divert surface flow are designed with basins of sufficient size to settle soil particles prior to discharge off site.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• CMLRB (2010)</li> </ul>
	<u>Riprap Design</u> : The channels are lined with riprap of sufficient size and thickness to withstand the effects of a precipitation event commensurate to the protection risk.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> </ul>
Air	<u>Haul Road Dust</u> : A plan to control dust commonly includes wetting, and/or the use chemical dust suppression or cover gravel.	<ul style="list-style-type: none"> <li>• Virginia issues Air Quality Permit specifying controls if required to achieve emission limits.</li> </ul>
	<u>Crushing and Conveyance</u> : To reduce dust, wetting and shrouding are common practices.	<ul style="list-style-type: none"> <li>• Virginia issues Air Quality Permit specifying controls if required to achieve emission limits.</li> </ul>
	<u>Radon</u> : Mine ventilation plan is required and real-time monitoring.	<ul style="list-style-type: none"> <li>• EPA 40 CFR 61 Subpart B - National Emissions Standards for Hazardous Air Pollutants (NESHAP)</li> </ul>
	<u>Toxic Air Pollutants (TAP)/Hazardous Air Pollutants (HAP)</u> : Emission inventory will specify what level of controls, if any, will be required.	<ul style="list-style-type: none"> <li>• Virginia issues Air Quality Permit specifying controls if required to achieve emission limits.</li> <li>• EPA 40 CFR 61</li> </ul>
Waste Rock	<u>Geochemical Analyses</u> : Characterization of the waste rock is completed to determine the potential for ARD and other leachates to occur.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• ADEQ (2004), Arizona Mining Guidance Manual</li> <li>• Washington RCW 78.56</li> </ul>
	<u>Handling Plan</u> : This plan generally includes methods of removal and storage of topsoil, placement of sub-ore grade rock, and placement of neutralizing material.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.56.100</li> </ul>
	<u>Mine Drainage</u> : Sampling of water quality and modeling of long-term water quality is conducted to determine water treatment options, if needed.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.56</li> </ul>
	<u>Minimize Ponding</u> : The surfaces of waste rock piles should be graded to facilitate drainage.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.56</li> </ul>

**Table 10-1    Guidance for Mine Design BMPs (continued)**

Waste Rock (continued)	<u>Minimize Run-On:</u> Diversion channels should be designed to reduce the potential surface flow onto the proposed waste rock piles.	<ul style="list-style-type: none"><li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li><li>• CMLRB (2010)</li><li>• Washington RCW 78.56</li></ul>
	<u>Minimize Footprint:</u> The footprint is minimized to reduce the potential for infiltration into the waste rock and underlying soil.	<ul style="list-style-type: none"><li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li><li>• CMLRB (2010)</li></ul>
	<u>Slope Stability:</u> Static and pseudostatic slope stability analyses are commonly conducted to assess slope stability for proposed stacking plans and layouts.	<ul style="list-style-type: none"><li>• Washington RCW 76.56.090, Subsection (4)</li><li>• CMLRB (2010), Section 6.5</li></ul>

**Table 10-2 Guidance for Mill Design BMPs**

ITEM	BMP	GUIDANCE
Process Ponds, Tailings Impoundments, and Heap-Leach Liners	<u>Liner</u> : The common practice to meet groundwater protection standards is double-lined containment with leak detection and an underlying GCL or clay liner.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> <li>• NUREG-7028</li> <li>• EPA 40 CFR 264.220; EPA 40 CFR 264.221</li> <li>• NRC Regulatory Guide 3.11, Section 2.2.4.2</li> <li>• Washington RCW 78.56.100</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5</li> </ul>
	<u>Leak Detection</u> : A collection system is designed between liners with sumps and instrumentation to monitor potential leaks and remove collected leakage.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5(E) and 8A</li> <li>• NUREG-7028, Section 8.2</li> <li>• EPA 40 CFR 264.221; EPA 40 CFR 264.222; EPA 40 CFR 264.223</li> <li>• NRC Regulatory Guide 3.11, Section B.2.2.4.2</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5E</li> </ul>
	<u>Leachate Collection System</u> : A collection system is designed and placed at the bottom of the tailings and heap-leach pads to limit the head on the liner.	<ul style="list-style-type: none"> <li>• NUREG-7028, Section 8.2</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5E(3)</li> </ul>
	<u>Liner Puncture</u> : Puncture testing of the liner system with site specific material and ore is generally completed for leach pads.	<ul style="list-style-type: none"> <li>• NUREG-7028</li> </ul>
	<u>Chemical Compatibility</u> : The proposed leachate should be tested with the clay liner or GCL to determine the effectiveness of the liner. The synthetic liner is commonly selected based on the manufacturer's specifications.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(2), Criterion 5E(1)</li> <li>• EPA 40 CFR 264.221</li> <li>• NRC Regulatory Guide 3.11</li> <li>• NUREG-1620</li> </ul>
	<u>Liner Durability Performance</u> : The performance of the synthetic liners varies based on process solution chemistry, exposure to UV radiation, and temperature extremes.	<ul style="list-style-type: none"> <li>• NUREG-7028, Section 8</li> <li>• Peggs (2003)</li> <li>• Colorado 6 CCR 1007-1 Criterion 5A(2)</li> </ul>
	<u>Leakage</u> : The allowable leakage rate for the liner system is commonly estimated as part of design.	<ul style="list-style-type: none"> <li>• EPA 530-R-92-DQ4</li> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(5)</li> <li>• NRC Regulatory Guide 3.11, Section B.2.2.4.2</li> </ul>
	<u>Wind Uplift</u> : A key trench is designed for the edge of the liner system to anchor the liner and prevent wind uplift of the liner. During installation, ballast may need to be placed on the liner to prevent uplift.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(2)(b)</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5A(2)(b)</li> </ul>

**Table 10-2 Guidance for Mill Design BMPs (continued)**

Ore Stockpiles	<u>Seepage</u> : Steps must be taken during stockpiling of ore to minimize penetration of seepage into underlying soils; suitable methods include lining and/or compaction of ore storage areas.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5H</li> <li>• Washington WAC 246-252-030, Criterion 5(q)</li> <li>• Colorado 6 CCR 1007-1 Appendix A, Criterion 5H</li> <li>• Washington WAC 246-252-030</li> </ul>
Embankments	<u>Slope Stability</u> : Static and pseudostatic slope stability analyses are completed.	<ul style="list-style-type: none"> <li>• NRC NUREG-1620</li> <li>• NRC Draft Regulatory Guide DG-3032</li> <li>• NRC Regulatory Guide 3.11, Section B.2.1, Section C.2</li> <li>• Washington RCW 76.56.090, Subsection (4)</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 4C</li> </ul>
	<u>Deformation</u> : Analysis of the potential deformation is completed.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(5)</li> <li>• NUREG-1623</li> </ul>
	<u>Seepage</u> : Analyses are completed to determine the potential seepage if there is a leak in the liner. An internal drain is often designed to reduce the potential seepage.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 3.11, Section B.2.2</li> <li>• Colorado 6 CCR 1007-1 Criterion 5A(5)</li> </ul>
	<u>Liquefaction</u> : Liquefaction impacts on stability need to be considered for tailings and if potentially liquefiable soils exist below the site of a retention system.	<ul style="list-style-type: none"> <li>• NUREG-1620, Section 2.4</li> <li>• NRC Draft Regulatory Guide DG-3032</li> <li>• NRC Regulatory Guide 3.11, Section B.2.1.2</li> </ul>
	<u>Settlement</u> : Analyses of the potential settlement of the foundation material is commonly completed.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 3.11, Section B.2.1.3</li> <li>• Colorado 6 CCR 1007-1 Criterion 5A(2)(b)</li> </ul>
	<u>Surface Erosion</u> : Evaluation of surface erosion of the downstream embankment face is conducted as necessary.	<ul style="list-style-type: none"> <li>• CMLRB (2010)</li> <li>• Washington WAC 246-252-030</li> <li>• NRC 10 CFR 40 Appendix A</li> <li>• Colorado 6 CCR 1007-1 Criterion 4D</li> </ul>
Seismic Design	<u>Return Interval</u> : The seismic coefficient used will be determined based on the life of the mill. Operational design will be based on 2% probability of exceedance in 50 years.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• International Building Code (ICC, 2012)</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 6</li> </ul>
	<u>Site Acceleration</u> : Two-thirds of the peak ground acceleration is used in the pseudostatic analysis.	<ul style="list-style-type: none"> <li>• DOE (1989)</li> </ul>
Groundwater	<u>Monitoring Systems</u> : Monitoring and testing wells are established based on local and regional geology, groundwater flow, and sensitive environmental features. Point of compliance wells are commonly established along the mine perimeter to monitor for potential off-site contaminant migration.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5B</li> <li>• CMLRB (2010), Section 3.1.7</li> </ul>
	<u>Well Spacing</u> : The monitoring wells are located based on geology and groundwater flow.	<ul style="list-style-type: none"> <li>• CMLRB (2010), Section 3.1.7(6)(b)(ii)</li> <li>• Colorado 6 CCR 1007-1 Criterion 5B</li> </ul>

**Table 10-2 Guidance for Mill Design BMPs (continued)**

Process Fluid Delivery Systems	<u>Secondary Containment</u> : A secondary containment system can be designed to contain potential leaks.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 3.11.1</li> </ul>
	<u>Data Acquisition &amp; Automation</u> : This system should be designed to monitor for potential leaks.	
Surface Water	<u>Diversions Upstream</u> : Diversion channels are designed to divert water around proposed heap-leach pads and tailings impoundments.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 4</li> <li>• NRC Regulatory Guide 3.11, Section 2.2</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Channelized Flow</u> : Designs are completed to collect flow in channels and divert it around tailings impoundments and heap-leach pads.	<ul style="list-style-type: none"> <li>• NUREG-1623</li> <li>• NRC Regulatory Guide 3.11, Section 2.2</li> </ul>
	<u>Sedimentation/Settlement Basins</u> : The channels to collect and divert surface flow are designed with basins of sufficient size to settle soil particles prior to discharge off site.	<ul style="list-style-type: none"> <li>• NUREG-1623, Appendix E</li> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(4)</li> </ul>
	<u>Riprap Design</u> : Riprap of sufficient size and thickness is designed that will withstand runoff from the PMP.	<ul style="list-style-type: none"> <li>• NUREG-1623, Appendix D and F</li> <li>• NRC Regulatory Guide 3.11, Section 2.2</li> </ul>
Air	<u>Dust</u> : Dust control is accomplished through wetting of the tailings and heap, and emissions control on the mill stacks.	<ul style="list-style-type: none"> <li>• Washington WAC 246-252-0303, Criterion 8</li> <li>• Colorado 6 CCR 1007-1, Appendix A Criterion 4B and 8</li> <li>• NRC 10 CFR 40 Appendix A, Criterion 8</li> </ul>
	<u>Radioparticulates</u> : Soil surveys are completed in the mill prior to construction of the mill area to determine background levels.	
	<u>Radon</u> : This is reduced by limiting active pond and heap size to 40 acres or less and the use of interim covers.	

**Table 10-3 Guidance for Mine Operation BMPs**

ITEM	BMP	GUIDANCE
Mine Water Storage Ponds	<u>Freeboard</u> : Should be maintained to prevent overtopping resulting from normal or abnormal operations, overfilling, wind and wave actions, rainfall, or run-on.	
Groundwater	<u>Sampling and Analyses Plan (SAP)</u> : Developed in agreement with the regulatory agency to identify contaminants that exceed background or baseline permit water-quality standards at point of compliance wells. Quarterly monitoring of monitoring wells is common. The monitoring frequency and number of wells may be adjusted based on the water-quality results.	<ul style="list-style-type: none"> <li>• CMLRB (2010), Section 3.1.7(7)</li> </ul>
	<u>Reporting</u> : Quarterly and annual water-quality monitoring reports are commonly required by the regulatory agency to ensure compliance with permit conditions.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criteria 7 and 8A</li> <li>• Washington WAC 246-252-030, Criteria 7 and 8A</li> <li>• Colorado 6 CCR 1007-1, Part 18, Appendix A</li> <li>• CMLRB (2010), Section 3.1.7(9)</li> </ul>
	<u>Modeling</u> : Groundwater flow and transport models are commonly updated every 5 years using historical monitoring data and additional subsurface data. These models are recalibrated to improve model fit to observed conditions and to improve flow paths and potential contaminant migration predictions.	
Surface Water	<u>Inspection and Maintenance</u> : Channels are inspected regularly to check for sediment or erosion.	<ul style="list-style-type: none"> <li>• CMLRB (2010)</li> </ul>
	<u>Sampling and Analyses Plan (SAP)</u> : This is developed in agreement with the regulatory agency. Collection of water samples may not be required or may only be required during high flow events.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994b), Guideline 4;</li> <li>• WYDEQ-LQD (2005), Guideline 8</li> <li>• CMLRB (2010), Section 6.4.21(11)(12)</li> </ul>
	<u>Reporting</u> : Quarterly and annual monitoring reports are commonly required by the regulatory agency.	



**Table 10-3 Guidance for Mine Operation BMPs (continued)**

Air	<u>Sampling and Analyses Plan (SAP)</u> : This is developed in agreement with the regulatory agency.	<ul style="list-style-type: none"> <li>Virginia issues a site-specific permit prior to construction and operation which specifies the sampling, reporting, and emission limits for each mine.</li> </ul>
	<u>Reporting</u> : Quarterly and annual monitoring reports are commonly required by the regulatory agency.	<ul style="list-style-type: none"> <li>Virginia issues a site-specific permit prior to construction and operation which specifies the sampling, reporting, and emission limits for each mine.</li> </ul>
	<u>Haul Road Dust</u> : Common practices include: wetting of the haul roads; the application of a chemical binder such as magnesium chloride; and the use of sacrificial road cover such as gravel.	<ul style="list-style-type: none"> <li>Virginia issues a site-specific permit prior to construction and operation which specifies the sampling, reporting, and emission limits for each mine.</li> </ul>
	<u>Crushing and Conveyance</u> : To reduce dust, wetting and shrouding are common practices.	<ul style="list-style-type: none"> <li>Virginia issues a site-specific permit prior to construction and operation which specifies the sampling, reporting, and emission limits for each mine.</li> </ul>
	<u>Radon</u> : Mine ventilation plan is required as well as real-time monitoring.	<ul style="list-style-type: none"> <li>EPA 40 CFR 61 Subpart B (NESHAP)</li> </ul>
Waste Rock	<u>Geochemical Analyses</u> : This is completed mainly to confirm ore grades during operations. However, depending on the operator's waste rock management plan, additional sampling may be completed to assist in reducing ARD and other leachates.	<ul style="list-style-type: none"> <li>WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>CMLRB (2010)</li> <li>ADEQ (2004), Arizona Mining Guidance Manual</li> <li>Washington RCW 78.56</li> </ul>
	<u>Handling Plan</u> : This plan generally includes methods of removal and storage of topsoil, placement of sub-ore grade rock, and placement of neutralizing material.	<ul style="list-style-type: none"> <li>WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>CMLRB (2010)</li> <li>Washington RCW 78.56</li> </ul>

**Table 10-4 Guidance for Mill Operation BMPs**

ITEM	BMP	GUIDANCE
Process Ponds, Tailings Impoundments, and Heap-Leach Liners	<u>Construction QA of Clay Liners</u> : Compacted clay liners or GCLs may be used. Hydraulic permeability of clay should be confirmed. Proper compaction, moisture conditioning, and hydration will improve liner performance.	<ul style="list-style-type: none"> <li>• NUREG-7028, Section 7, Section 10</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>
	<u>Construction QA of GCL Liners</u> : Prior to the placement of GCLs they should be tested for chemical compatibility to ensure the leachate will not impact the effectiveness of the liner. The hydration should be completed prior to covering. The GCL should not be allowed to free swell during hydration and should be covered quickly.	<ul style="list-style-type: none"> <li>• NUREG-7028, Section 7, Section 10</li> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>
	<u>Construction QA of Synthetic Liners</u> : Liner installation QA includes seam testing.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> <li>• NUREG-7028, Section 8, Section 10</li> <li>• NRC Regulatory Guide 3.11</li> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>
	<u>Inspections and Maintenance</u> : Daily inspections are completed and annual reports are generally made to the regulatory agency. Daily inspections include slumps, cracks, animal burrows, and other signs of movement. Monitoring of downgradient wells should also be completed to check for changes in groundwater levels that may be attributed to leaks.	<ul style="list-style-type: none"> <li>• NUREG-1620</li> <li>• NRC Regulatory Guide 3.11, Section B.4, Section C.4</li> <li>• Colorado 6 CCR 1007-1 Appendix A, Criterion 8A</li> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>
	<u>Freeboard</u> : Should be maintained to prevent overtopping resulting from normal or abnormal operations, overfilling, wind and wave actions, rainfall, or run-on.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5A(4)</li> </ul>
	<u>Monitoring of Leak Detection System</u> : The sumps should be monitored on a regular basis. Any leakage above the calculated leakage rate should be reported and acted upon.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 7</li> </ul>
	<u>Limitation of Operational Impoundment/Heap Area</u> : The active pond size is generally limited to 40 acres.	<ul style="list-style-type: none"> <li>• EPA 40 CFR 61, Subpart B (NESHAP)</li> </ul>
Embankments	<u>Construction QA</u> : The construction monitoring is normally completed by a third party engineering firm to confirm construction is in compliance with drawings and specifications.	<ul style="list-style-type: none"> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>
	<u>Inspection and Maintenance</u> : Daily inspections are completed and annual reports are generally made to the regulatory agency. Daily inspections include slumps, cracks, animal burrows, and other signs of movement.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 3.11, Section B.4 and C.4</li> <li>• Colorado 6 CCR 1007-1 Section 18.3.3</li> </ul>

**Table 10-4 Guidance for Mill Operation BMPs (continued)**

Groundwater	<u>Sampling and Analyses Plan (SAP)</u> : Developed in agreement with the regulatory agency to identify contaminants that exceed background or baseline permit water-quality standards at point of compliance wells. Quarterly monitoring of monitoring wells is common. The monitoring frequency and number of wells may be adjusted based on the water-quality results.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> <li>• NUREG-1569, Section 5.7.8</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 7</li> </ul>
	<u>Reporting</u> : Quarterly and annual water-quality monitoring reports are commonly required by the regulatory agency to ensure compliance with permit conditions.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Section 18.7.3</li> </ul>
Process Fluid Delivery Systems	<u>Inspection and Maintenance</u> : The system should be inspected daily for leaks and repaired as required.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 8</li> <li>• Washington WAC 246-252-030</li> </ul>
Surface Water	<u>Inspection and Maintenance</u> : Channels are inspected regularly, particularly following a storm/runoff event to check for sediment or erosion.	<ul style="list-style-type: none"> <li>• Washington WAC 246-252-030</li> <li>• NRC Regulatory Guide 3.11</li> </ul>
	<u>Sampling and Analyses Plan</u> : This is developed in agreement with the regulatory agency.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994b), Guideline 4; WYDEQ-LQD (2005), Guideline 8</li> <li>• NRC Regulatory Guide 4.14</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Reporting</u> : Quarterly and annual monitoring reports are commonly required by the regulatory agency.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 4.14</li> <li>• Washington WAC 246-252-030</li> </ul>
Air	<u>Sampling and Analyses Plan</u> : This is developed in agreement with the regulatory agency.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 1.111</li> <li>• EPA 520/1-89-002</li> <li>• NUREG-1569, Section 5.7.3, 5.7.7</li> </ul>
	<u>Reporting</u> : Quarterly and annual monitoring reports are commonly required by the regulatory agency.	<ul style="list-style-type: none"> <li>• NRC Regulatory Guide 4.14, Sections 2-6</li> </ul>
	<u>Dust/Control</u> : This is accomplished through wetting of the tailings and heap and emissions control on the mill stacks.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 8</li> </ul>
	<u>Interim Covers</u> : These covers are commonly placed to reduce the potential for dust from inactive sections of the heap-leach pad or impoundment and to reduce radon emissions.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 8</li> </ul>

**Table 10-5 Guidance for Mine Closure Design and Implementation BMPs**

ITEM	BMP	GUIDANCE
Mine Water Storage Ponds	<u>Liner Disposal</u> : The current practice is to bury the liner in the bottom of the pond with backfill.	
	<u>Surface Reclamation</u> : The surface of the buried pond is regraded to reduce the potential for erosion and revegetated in accordance with the operator's reclamation plan. The surface is generally revegetated.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994c), Guideline 6</li> <li>• WYDEQ-LQD (2006)</li> <li>• Noncoal Mine, Environmental Protection Performance Standards</li> <li>• CMLRB (2010)</li> </ul>
Embankments	<u>Slope Grading</u> : The operational slopes are flattened and slope stability analyses are completed to ensure long-term stability. The required factor of safety for slope stability is generally 1.5 for static conditions and 1.1 for pseudostatic analysis.	<ul style="list-style-type: none"> <li>• Washington RCW 76.56.090, Subsection (4)</li> <li>• CMLRB (2010) Section 3.1.5(7)</li> </ul>
	<u>Surface Reclamation</u> : The surface of the reclaimed slope is protected from erosion either by placement of riprap, sacrificial soil cover, or vegetation.	<ul style="list-style-type: none"> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.44.091</li> </ul>
	<u>Flatten Slopes</u> : Surface slopes are generally reduced to meet both slope stability and erosion requirements.	<ul style="list-style-type: none"> <li>• CMLRB (2010)</li> <li>• Washington RCW 76.56.090, Subsection (4)</li> </ul>
	<u>Revegetation</u> : The surface is generally revegetated. The amount of vegetation required for successful closure is based on regional climate factors.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994c), Guideline 6</li> <li>• WYDEQ-LQD (2006), Noncoal Mine, Environmental Protection Performance Standards</li> <li>• CMLRB (2010)</li> </ul>
Seismic Design	<u>Return Interval</u> : The seismic coefficient used will be determined based on the life of the mine. Mine buildings are designed based on 2% probability of exceedance in 50 years.	<ul style="list-style-type: none"> <li>• International Building Code (ICC, 2012)</li> </ul>
	<u>Site Acceleration</u> : Two-thirds of the peak acceleration is used in the pseudostatic analyses.	<ul style="list-style-type: none"> <li>• DOE (1989)</li> </ul>
Groundwater	<u>Monitoring Systems</u> : Point of compliance wells are monitored and additional wells may be installed based on operational excursions.	<ul style="list-style-type: none"> <li>• CMLRB (2010), Section 3.1.5(11), 3.1.7</li> </ul>
	<u>Modeling</u> : Existing groundwater flow and transport models are commonly updated and recalibrated prior to closure using historical monitoring data and additional subsurface data. Historical monitoring data and model predictions identify potential for long-term, off-site, contaminant migration.	<ul style="list-style-type: none"> <li>• NUREG-1620, Section 2.1.1</li> <li>• CMLRB (2010) Sec. 3.1.7(6)(b)(i)(B)</li> </ul>

**Table 10-5 Guidance for Mine Closure Design and Implementation BMPs (continued)**

Groundwater (continued)	<u>Pit Lake Conditions:</u> Geochemical and groundwater models are commonly used to predict the long-term pit lake water quality and potential for off-site migration that may impact the surrounding environment.	<ul style="list-style-type: none"> <li>• CMLRB (2010), Section 3.1.6</li> </ul>
	<u>Remediation:</u> If there is the potential for long-term, off-site, contaminant migration, remediation measures are identified and evaluated to ensure protection of human health and the environment. Remediation measures are implemented as necessary to meet closure criteria established by the regulatory agencies.	<ul style="list-style-type: none"> <li>• Washington RCW 78.44.091, RCW 78.44.141</li> <li>• CMLRB (2010), Section 3.1.7(3)</li> </ul>
Surface Water	<u>Diversions Upstream:</u> Riprap channels are constructed to divert water around the reclaimed mine structures (e.g., waste dumps, pits, embankments).	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• Washington RCW 78.44.141</li> </ul>
	<u>Channelized Flow:</u> On-site flow is collected in channels and diverted around waste rock, pits, adits, and other exposed areas containing wastes or areas of high mineralization.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• Washington RCW 78.44.141</li> </ul>
	<u>Sedimentation/Settlement Basins:</u> The channels used to collect and divert surface flow are constructed with basins of sufficient size to settle soil particles prior to discharge off site.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (2005), Guideline 8, Hydrology</li> <li>• WYDEQ-LQD (2011), Guideline 13</li> <li>• Washington RCW 78.44.141</li> </ul>
	<u>Riprap Design:</u> The channels are lined with riprap of sufficient size and thickness that they can withstand the effects of a PMP flow in the channel.	<ul style="list-style-type: none"> <li>• Washington RCW 78.44.141</li> </ul>
Waste Rock	<u>Geochemical Analyses:</u> Characterization of the waste rock piles is completed to determine the potential for ARD and other leachates to occur.	<ul style="list-style-type: none"> <li>• Washington RCW 78.56.100, 78.44.141</li> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> </ul>
	<u>Mine Drainage:</u> Sampling of water quality and modeling of long-term water quality is completed to determine water treatment options as needed.	<ul style="list-style-type: none"> <li>• Washington RCW 78.44.141</li> <li>• CMLRB (2010), Section 6.4.21</li> </ul>
	<u>Minimize Ponding:</u> The waste rock piles are graded at closure to facilitate drainage.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.56, RCW 78.44.141</li> </ul>
	<u>Minimize Run-On:</u> Diversion channels are constructed to reduce the surface flow onto waste rock piles.	<ul style="list-style-type: none"> <li>• WYDEQ-LQD (1994a), Guideline 1, Topsoil and Overburden</li> <li>• CMLRB (2010)</li> <li>• Washington RCW 78.56, RCW 78.44.141</li> </ul>

**Table 10-5 Guidance for Mine Closure Design and Implementation BMPs (continued)**

Waste Rock (continued)	<u>Regrade to Achieve Slope Stability:</u> Slope stability analyses are completed for waste rock piles. Water diversion channels are constructed on waste rock pile faces to control runoff.	<ul style="list-style-type: none"><li>• Washington RCW 76.56.090, Subsection (4), RCW 78.44.141</li></ul>
	<u>Surface Treatment:</u> Where it is needed, surface treatment of the waste rock piles to reduce the potential for ARD and other leachates is conducted. The surface treatment can involve lime treatment or other chemical treatment.	<ul style="list-style-type: none"><li>• Washington RCW 78.44.141</li><li>• CMLRB (2010), Section 6.4.21</li></ul>
	<u>Cover:</u> Soil covers or non-acid generating waste rock are used to reduce infiltration and oxygen flux through the pile.	<ul style="list-style-type: none"><li>• Washington RCW 78.56.100, RCW 78.44.141</li><li>• WYDEQ-LQD (1994a); Guideline 1, Topsoil and Overburden</li><li>• CMLRB (2010)</li></ul>
	<u>Erosion Stability:</u> The surface of the pile is regraded to reduce the potential for erosion. It may also be necessary to place riprap or rock mulch on the cover to reduce erosion.	<ul style="list-style-type: none"><li>• CMLRB (2010)</li><li>• Washington RCW 78.44.141</li></ul>

**Table 10-6 Guidance for Mill Closure Design and Implementation BMPs**

ITEM	BMP	GUIDANCE
Process Ponds, Tailings Impoundments and, Heap-Leach Liners	<u>Rinsing</u> : Heap-leach pads are commonly rinsed until the discharge reaches acceptable pH values and leachate concentrations.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5E(4)</li> </ul>
	<u>Interim Soil Cover</u> : A thin layer of soil may be placed on the surface of the heaps and tailings impoundments during drying of the heaps and consolidation of the tailings prior to the placement of the final cover.	<ul style="list-style-type: none"> <li>• EPA 40 CFR 61, Subpart B (NESHAP)</li> <li>• Colorado 6 CCR 1007-1 Criterion 8</li> </ul>
	<u>Drainage</u> : Modeling of the drain-out of the heap and tailings is completed to determine the amount of time before the final cover can be placed. Modeling is also completed to determine the anticipated long-term seepage rate from the tailings.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• NUREG-1620, Section 2.3</li> </ul>
	<u>Settlement/Cover Cracking</u> : Analyses of the potential cover cracking as a result of settlement is completed to ensure that the cover does not crack.	<ul style="list-style-type: none"> <li>• NUREG-1620, Section 2.3</li> <li>• NRC Regulatory Guide 3.11, Section B.2.2.3</li> <li>• Colorado 6 CCR 1007-1 Criterion 6</li> </ul>
	<u>Multi-Layer Cover System</u> : A final cover is completed that consists of the following components: an erosion protection layer/surface vegetated cover; frost protection layer; protection from root penetration; protection from burrowing animals; and radon barrier. The cover system is modeled using RADON to predict the potential radon emanation.	<ul style="list-style-type: none"> <li>• NUREG-1623, Section 2.2, Section 3.2, Section 3.3, Appendix A</li> <li>• NUREG-1620, Section 2.5</li> <li>• Colorado 6 CCR1007-1 Appendix A, Criterion 6</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Inspections and Maintenance</u> : The reclamation cover is inspected and maintained.	<ul style="list-style-type: none"> <li>• NUREG-1623, Section B.4, Section C.4</li> </ul>
Ore Stockpiles	<u>Ore Stockpiles</u> : Removed for processing off-site or placed in tailings impoundment.	<ul style="list-style-type: none"> <li>• NUREG-1623, Section 2.2, Section 3.2, Section 3.3, Appendix A</li> <li>• NUREG-1620, Section 2.5</li> <li>• Colorado 6 CCR1007-1 Appendix A, Criterion 6</li> </ul>
Embankments	<u>Slope Stability</u> : Slope stability analyses are completed for both static and pseudostatic conditions.	<ul style="list-style-type: none"> <li>• NUREG-1620, Section 2.2</li> <li>• NUREG-1623, Section 2.2.3 (5H:1V maximum slope)</li> <li>• NRC Regulatory Guide 3.11Section C.2.d</li> <li>• Colorado 6 CCR 1007-1 Criterion 4C</li> </ul>
	<u>Surface Reclamation/Revegetation</u> : The embankments are generally flattened to meet the long-term slope stability requirements and erosion requirements. The slopes may be revegetated. The requirements for successful revegetation are based on regional climate factors.	<ul style="list-style-type: none"> <li>• NUREG-1623, Section 2.2.4</li> <li>• Washington RCW 78.44.141</li> <li>• Colorado 6 CCR 1007-1 Criterion 6A</li> </ul>



**Table 10-6 Guidance for Mill Closure Design and Implementation BMPs (continued)**

Embankments (continued)	<u>Surface Erosion:</u> Analyses are completed to design a riprap and bedding layer. The riprap and bedding are installed to protect the surface of the covers from erosion.	<ul style="list-style-type: none"> <li>• NUREG-1623</li> <li>• Washington RCW 78.44.141</li> <li>• Colorado 6 CCR 1007-1 Criterion 4D</li> </ul>
	<u>Inspections and Maintenance:</u> Reclaimed facilities are inspected and maintained.	<ul style="list-style-type: none"> <li>• NUREG-1623, Section B.4, Section C.4</li> </ul>
Seismic Design	<u>Return Interval:</u> Seismic analyses are completed for a return interval of 10% probability of exceedance in 1000 years (10,000 year return period).	<ul style="list-style-type: none"> <li>• NUREG-1620, Section 1.4</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 6</li> </ul>
	<u>Site Acceleration:</u> Two-thirds of the peak acceleration is used in the pseudostatic analyses.	<ul style="list-style-type: none"> <li>• DOE (1989)</li> <li>• Washington WAC 246-252-030</li> </ul>
Groundwater	<u>Monitoring Systems:</u> Point of compliance wells are monitored and additional wells may be required based on monitoring history during operations.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5, Criterion 7</li> <li>• NUREG-1727, Section 11</li> <li>• NUREG-1569, Section 5.7.8</li> <li>• Washington WAC 246-252-030</li> <li>• Colorado 6 CCR 1007-1 Criterion 5</li> </ul>
	<u>Well Spacing:</u> The monitoring wells are located based on locations of contaminant sources, geology, groundwater flow, and predicted contaminant transport including dispersion.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 5</li> </ul>
	<u>Modeling:</u> Existing groundwater flow and transport models are commonly updated and recalibrated prior to closure using historical monitoring data and additional subsurface data. Historical monitoring data and model predictions identify potential for long-term, off-site, contaminant migration.	<ul style="list-style-type: none"> <li>• NRC (1992) Staff Technical Paper on Alternate Concentration Limits for Title II Uranium Mills</li> </ul>
	<u>Remediation:</u> If there is the potential for long-term, off-site, contaminant migration, remediation measures are identified and evaluated to ensure protection of human health and the environment. Remediation measures are implemented as necessary to meet closure criteria established by the regulatory agencies.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A</li> <li>• Washington RCW 78.44.141</li> <li>• Washington WAC 246-252-030</li> <li>• CMLRB (2010), Section 3.1.7(3)</li> <li>• Colorado 6 CCR 1007-1 Section 18.7.3, Criterion 7</li> </ul>
Surface Water	<u>Diversions Upstream:</u> Riprap channels are constructed to divert water around the reclaimed heap-leach pads and tailings impoundments.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 4(a)</li> <li>• Washington RCW 78.44.141</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Channelized Flow:</u> On-site flow is collected in channels and diverted around tailings impoundments and heap-leach pads.	<ul style="list-style-type: none"> <li>• NUREG-1623, Appendix A</li> <li>• Washington RCW 78.44.141</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Sedimentation/Settlement Basins:</u> The channels to collect and divert surface flow are constructed with basins of sufficient size to settle soil particles prior to discharge off site.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 8</li> <li>• EPA 40 CFR 440.34(b); EPA 40 CFR 440.131</li> <li>• Washington RCW 78.44.141</li> <li>• Washington WAC 246-252-030</li> </ul>

**Table 10-6 Guidance for Mill Closure Design and Implementation BMPs (continued)**

Surface Water (continued)	<u>Riprap Design:</u> The channels are lined with riprap of sufficient size and thickness that they can withstand the effects of a PMP flow in the channel.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 4</li> <li>• NUREG-1623, Section 2.2, Appendix A</li> <li>• Washington RCW 78.44.141</li> <li>• Washington WAC 246-252-030</li> </ul>
Air	<u>Dust:</u> Dust control is not required following mill decommissioning. However, air quality impact during closure and reclamation is from fugitive particulate matter (PM), most notably dust from heavy equipment movement, soil transportation, and wind erosion. Dust control measures include suppression using water, chemical dust suppression, covering stockpile soil, and ultimately revegetation of all disturbed areas.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 8</li> <li>• NRC Regulatory Guide 4.14</li> <li>• NRC Regulatory Guide 3.56</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Radioparticulates:</u> Air monitoring for radioparticulates is not required following site decommissioning.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 8</li> <li>• NRC Regulatory Guide 4.14</li> <li>• NRC Regulatory Guide 3.56</li> <li>• NRC Draft Regulatory Guide DG-4018</li> </ul>
	<u>Radon:</u> After completion of the tailings cover, radon measurements are collected to ensure compliance with permissible radon levels.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 6, Criterion 8</li> <li>• NRC Regulatory Guide 4.14</li> <li>• NRC, 1989; Regulatory Guide 3.64</li> <li>• Washington WAC 246-252-030, Subsection 6</li> <li>• Colorado, 6 CCR1007-1; Appendix A Criterion 6</li> </ul>
	<u>Criteria Air Pollutants CAP/HAP:</u> Air monitoring during reclamation/decommissioning as per air permit. No monitoring required following final reclamation.	<ul style="list-style-type: none"> <li>• EPA Clean Air Act</li> </ul>
Soils	<u>Soil:</u> Soil surveys are completed in the mill area to determine if soil contamination has occurred as a result of dust. Soil removal and placement in the closed impoundment may be required.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40 Appendix A, Criterion 6</li> <li>• Washington WAC 246-252-030</li> </ul>
Mill	<u>Remove Process Liners:</u> The process pond liners are removed and buried with other waste material.	
	<u>Mill Demolition:</u> All mill waste (including equipment) with contamination above release limits are disposed of in a licensed facility, typically the on-site tailings disposal cell.	<ul style="list-style-type: none"> <li>• NUREG-1727</li> <li>• NUREG-1757</li> <li>• NUREG-1620</li> </ul>
	<u>Soil:</u> Removal of contaminated soil and placement with the tailings may be required.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 40, Appendix A Criterion 6(6)</li> <li>• NRC, EPA, and DOE (2000), Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)</li> <li>• Washington WAC 246-252-030</li> </ul>
	<u>Other Facilities:</u> Decontaminate and release equipment and office trailers.	<ul style="list-style-type: none"> <li>• NRC 10 CFR 20</li> </ul>

**Table 10-7 Summary of Selected Case Histories and Technical Articles**

#	Resource	Source	Notes
1	Case history: Reclamation Plan, Atlas Corporation, Moab, Utah <i>Bruce W. Hassinger</i>	Tailings and Mine Waste '96 (p. 591-600)	...a reclamation plan was approved by the Nuclear Regulatory Commission (NRC) after completion of an Environmental Impact Statement (EIS) for the site (NRC, 1979). (p.591)
2	Durango disposal cell – UMTRA Case History <i>Marj Wesely, Mark Thomson, Hugh Hempill &amp; Chris Weston</i>	Tailings and Mine Waste '96 (p.601-608)	Construction at the Uranium Mill Tailings Remedial Action (UMTRA) site in Durango, Colorado was completed in 1991 with the capping of the 2.3 million cubic yard disposal cell... This paper presents a discussion of actual construction sequences, the modifications to the cell cover and eastern slope, the treatment of runoff water and the seepage water before and after closure, the proposed new method of water treatment and performance of the cell since closure. (p.601)
3	Risk assessment for CMR tailings dam complex <i>William Roberds, Gerald Strayton &amp; John Wates</i>	Tailings and Mine Waste '96 (p.609-620)	A risk assessment was conducted for the proposed reactivated CMR tailings complex for Crown Mines Ltd. Of South Africa. The focus in the risk assessment was developing an appropriate framework (or model) for conducting the risk assessment. (p.609)
4	Case study of Western Nuclear Split Rock Millsite reclamation <i>M.A. Pasha</i>	Tailings and Mine Waste '96 (p.621-630)	The reclamation design, which is in accordance with applicable NRC requirements, is presented. Status of reclamation activities, both work completed to date and those that remain to be conducted, is summarized. (p. 621)
5	Use of risk-based standards for restoration of ground water at in situ uranium mines <i>E. Caldwell &amp; J. Johnson</i>	Tailings and Mine Waste '97 (p.21-25)	A risk-based approach will identify the constituents in ground water most likely to contribute significantly to health impacts, so that restoration activities can be undertaken with risk reduction as the goal, keeping in mind the pre-existing risk level. (p.21)
6	Implementing the natural flushing strategy: An approach to meeting the EPA ground water standards at select uranium mill tailings sites <i>D. Metzler, R. Plienness, D. Peterson, H. Zhang, R. Knowlton, &amp; J. Knott</i>	Tailings and Mine Waste '97 (p.27-33)	Most of the Title I [Uranium Mill Tailings Remedial Action (UMTRA)] former processing sites [for natural flushing] retain residual ground water contamination in their uppermost aquifers as a result of former milling activities and past uncontrolled tailings seepage. (p.27)
7	Radionuclide transport from mined uranium ore at Pena Blanca, Mexico <i>William M. Murphy, English C. Percy &amp; David A. Pickett</i>	Tailings and Mine Waste '97 (p.401-404)	A study is proposed of radionuclide migration at the site of temporary unprotected storage of high grade U ore at Pena Blanca, Mexico. (p.401)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
8	Natural attenuation of hazardous constituents in groundwater at uranium mill tailing sites <i>Daniel W. Erskine, Clyde L. Yancey, and Errol P. Lawrence</i>	Tailings and Mine Waste '97 (p.489-498)	A uranium mill tailings site in Wyoming contributes seepage to groundwater in both the regionally reduced and oxidized portions of an aquifer associated with a uranium ore deposit. The geochemical speciation code PHREEQE (Parkhurst, 1980) was used to model geochemical processes along a flow path in each portion of the aquifer. (p.489)
9	Natural attenuation of ground water constituents at a uranium mill tailings site, Shirley Basin, Wyoming <i>J.A Schramke, S.F. Murphy, R.L. Lewis, R.L. Medlock, &amp; M.J.Franko</i>	Tailings and Mine Waste '97 (P.499-508)	Geochemical modeling was conducted with ground water samples from the Petrotomics uranium mill tailings site to determine the redox states and speciation of the constituents of concern. (p.499)
10	Evaluation of groundwater remediation at a uranium mill site in Uravan, Colorado <i>Errol P. Lawrence, Daniel W. Erskine &amp; Curtis O. Sealy</i>	Tailings and Mine Waste '97 (p.565-575)	A groundwater remediation program for a uranium mill site... The remediation program, is designed to abate a groundwater plume associated with leakage from a number of surface impoundments used for the management of process water and tailings at the mill site. (p.565)
11	A history of uranium tailings management in northern Saskatchewan <i>Maurice A. Balych &amp; Leonard S. Sinclair</i>	Tailings and Mine Waste '97 (p.763-772)	Uranium tailings management has progressed from simple topographical containment, through above ground storage facilities to the current direction of in-pit subaqueous deposition. (p.763)
12	Plans and guidelines for greater in-state involvement in mine waste problems <i>E.R. Hargett</i>	Tailings and Mine Waste '98 (p.3-6)	This paper furnishes conceptual plans and guidelines for increased state authority and responsibility for the commitment and overview of mine waste clean up problems. (p.3)
13	Environmental information systems for tailings management <i>D.V.B.McClarty, D.Berthelot, A.Coggan &amp; I.Ludgate</i>	Tailings and Mine Waste '98 (p.7-15)	Two mining companies and a university affiliate undertook the implementation of a Regional Environmental Information Management System to manage the environmental programs for the decommissioned Uranium mine sites and tailings management facilities near Elliot Lake, Canada. (p.7)
14	Historical mining, uranium tailings and waste disposal at one site: Can it be managed? A hydrogeological analysis <i>M.Junghans &amp; C.Helling</i>	Tailings and Mine Waste '98 (p.117-126)	Hydrogeological investigations of a uranium tailings impoundment in Johanngeorgenstadt, Saxony, Germany are being conducted... to distinguish between different groundwater types. (p.117)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
15	Characterizing dumps at an inactive uranium mine through aerial photographs and drill logs <i>D.C.Peters</i>	Tailings and Mine Waste '98 (p.339-347)	For mine properties which have incomplete or nonexistent records of mining and waste dump activity, there may be no direct means of assessing the overall properties of the dumps other than through drilling... Subsequent sampling and selective drilling then ultimately will be more applicable and useful to reclamation planning. (p.339)
16	Erosion protection for the Atlas Corporation uranium mill and tailings disposal area <i>J.W.Sjostrom, R.E.Blubaugh &amp; B.W.Hassinger</i>	Tailings and Mine Waste '98 (p.409-420)	Through the combination of several innovative erosion control measures, the tailings pile cover for the Atlas Corporation (Atlas) uranium mill and tailings disposal area was designed to address long-term climatic, geomorphological, hydrological, and geotechnical concerns. (p.409)
17	In situ removal of uranium from ground water <i>A.Abdelouas, H.E.Nuttall, W.Lutze &amp; Y.Lu</i>	Tailings and Mine Waste '98 (p.669-678)	A bioremediation concept has been developed to remove low concentrations of uranium from ground water. (p. 669)
18	Site selection approach for mine tailings <i>A.J. Krause &amp; D.L. Dwire</i>	Tailings and Mine Waste '99 (p.99-106)	This paper presents the input parameters and methodologies used to effectively complete site selection and provides working examples of several actual mining case studies. (p.99)
19	Integrating environmental requirements into project planning <i>R.W. Bleil</i>	Tailings and Mine Waste '99 (p.107-114)	The approach includes a system of identifying state, federal, and tribal regulatory requirements, negotiation issues and strategies, records requirements, training requirements, and budgeting techniques. (p.107)
20	Selection of treatment process for UMTRA groundwater <i>Randolph B. Richardson, Randall M. Juhlin &amp; Donald R. Metzler</i>	Tailings and Mine Waste '99 (p.735-742)	The groundwater at the uranium millsite at Tuba City, Arizona Tuba City site is contaminated with nitrate, sulfate and uranium... Available treatment technologies were reviewed for applicability. (p.735)
21	Upstream constructed tailings dams- A review of the basics <i>M.P. Davies &amp; T.E. Martin</i>	Tailings and Mine Waste '00 (p.3-15)	This paper presents the 'basics' of appropriate upstream tailings dam design, construction and stewardship. (p.3)
22	Instrumentation and monitoring behaviour or uranium tailings deposited in a deep pit <i>Y. Sheng, P. Peter &amp; A.R. Milnes</i>	Tailings and Mine Waste '00 (p.91-100)	...a program involving in situ instrumentation and monitoring was implemented to investigate the behaviour of tailings deposited in the pit. The present paper reports on the behaviour of tailings deposited in the pit based on the monitoring data at the early stage of the operation. (p.91)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
23	Prediction of long-term settlement for uranium tailings impoundments, Gas Hills, Wyoming <i>D.B Durkee, D.D. Overton, K.C. Chao &amp; T.E. Geick</i>	Tailings and Mine Waste '00 (p.111-120)	This paper presents the results of settlement analyses performed for Umetco Minerals Corporation (Umetco) on two separate uranium tailings impoundments at their Gas Hills Wyoming location. (p.111)
24	Speciation of <sup>226</sup> Ra, uranium and metals in uranium mill tailings <i>S.Somot, M.Pagel, J.Thiry &amp; F.Ruhlmann</i>	Tailings and Mine Waste '00 (p.343-352)	Mineralogical speciation of <sup>226</sup> Ra, uranium and metals in uranium mill tailings is of prime importance in order to choose best long-term tailing pond remediation options. (p.343)
25	Distribution of radionuclides in the tailings of Schneckenstein, Germany <i>T. Naamoun, D. Degering, D. Hebert &amp; B.Merkel</i>	Tailings and Mine Waste '00 (p.353-359)	Uranium ores were treated with different methods (flotation, acid and alkaline leaching). These techniques changed over time. Radionuclides from the Uranium decay series were analyzed in tailing material from four bore holes by different methods. (p.353)
26	Identification of long-term environmental monitoring needs at a former uranium mine <i>R.C. Lee, R.Robinson, M. Kennedy, S. Swanson &amp; M. Nahir</i>	Tailings and Mine Waste '00 (p.361-370)	A high-level analysis was conducted in conjunction with risk estimations to determine sensitivity of risks to uncertainties associated with radionuclide concentrations or radiation levels in exposure media including gamma radiation, radon, soil, water, and consumption of wild game/fish. (p.361)
27	Waste waters remediation from <sup>226</sup> Ra removal <i>E. Panturu, D.Filip, D.P.Georgescu, N.Udrea, F.Aurelian &amp; R. Radulescu</i>	Tailings and Mine Waste '00 (p.371-377)	It has been studied the <sup>226</sup> Ra removal from pond water at the uranium on processing plant using eight types of indigenous activated carbons. The paper presents tables and graphics with experimental results for each types of activated carbon and their removal from waste waters. (p.371)
28	Communication with the public about tailings projects <i>Jeremy Boswell, Nanette Hattingh &amp; David de Waal</i>	Tailings and Mine Waste '00 (p.381-391)	...the authors show the importance of the involvement of the recipient of the message in the design of the medium and the content of the message that is used in the communication about risk. Unless the receiver is involved in the process that is designed to communicate risk the message will fall on deaf ears. (p.381)
29	Acid In Situ Leach uranium mining – 1. USA and Australia <i>Gavin M. Mudd</i>	Tailings and Mine Waste '00 (p.517-526)	The [In Situ Leach (ISL) uranium mining] method is being proposed and tested on uranium deposits in Australia, with sulphuric acid chemistry and no restoration of groundwater following mining. The history and problems of acid ISL sites in the USA and Australia is presented. (p.517)



**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
30	Acid In Situ Leach uranium mining – 2. Soviet Block and Asia <i>Gavin M. Mudd</i>	Tailings and Mine Waste '00 (p.527-536)	The [In Situ Leach (ISL) uranium mining] method is being proposed and tested on uranium deposits in Australia, with sulphuric acid chemistry and no restoration of groundwater following mining. The history and problems of acid ISL sites in countries of the Former Soviet Union and across Asia is presented. (p.527)
31	Geotechnical characterization of in-pit tailings at Ranger Uranium Mine, Northern Australia <i>H. Li, G. Cramb &amp; A.R. Milnes</i>	Tailings and Mine Waste '01 (p.113-121)	A number of field investigations have been carried out to determine the geotechnical behaviour of in-pit tailings at Ranger uranium mine in Northern Australia. ... This information forms the basis for developing strategies and techniques to expedite consolidation and increase the density of the tailings in the pit for effective and timely rehabilitation of the pit after filling. (p.113)
32	Closure of the Atlas Uranium Tailings Impoundment <i>Michael E. Henderson</i>	Tailings and Mine Waste '01 (p.123-136)	This paper describes the recent work at the site, including a detailed characterization of the tailings, which was performed using a combination of piezocone and geotechnical drilling techniques. Data from this characterization were used to evaluate various methods of dewatering and speeding consolidation of the tailings. (p.123)
33	Groundwater characterization and alternative evaluation for the Split Rock uranium tailings project <i>L. (Toby) Wright</i>	Tailings and Mine Waste '01 (p.213-220)	This paper presents a case study of the groundwater characterization and development of ground water corrective action alternatives for the Western Nuclear, Inc. Split Rock Site in central Wyoming. A comprehensive multi-year site characterization was performed that included geologic, hydrologic and geochemical studies. (p.213)
34	Rabbit Lake groundwater monitoring optimization program <i>D. Pritchard, D. Rezanoff &amp; P. Landine</i>	Tailings and Mine Waste '01 (p.221-231)	The Rabbit Lake Uranium Mine, located in Northern Saskatchewan, Canada, has been operating since 1975, and has undergone major changes and expansions during the past 23 years... a review of the monitoring program has been completed, with the objective of optimizing the program to provide only that information required to meet the monitoring objectives. (p.221)
35	Evaluation of long-term seepage impacts from a uranium tailings facility <i>T.G Michel &amp; T.W. Hardgrove</i>	Tailings and Mine Waste '01 (p.295-312)	The development of a ground water Corrective Action Program (CAP) is examined and the performance of the CAP is evaluated. (p.295)



**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
36	Deep injection of warm tailings for thawing of frozen layers <i>P.G. Landine, N. Holl, D. Rezansoff, E. Yeates &amp; H.K. Mittal</i>	Tailings and Mine Waste '01 (p.383-391)	The Rabbit Lake In-pit tailings management facility (RLITMF) is located in northern Saskatchewan, Canada. Due to the cold climate at the mine site, tailings deposited during the winter months become frozen. Full consolidation of the tailings mass is required in order to minimize long term containment transport... The program has shown that deep tailings injection under gravity head is possible and that positive thawing benefits can be realized. (p.383)
37	Hydrochemical and geotechnical properties of cemented uranium paste tailings <i>D.R. Jones, H.-Y. Li, T.D. Waite &amp; B. Fenton</i>	Tailings and Mine Waste '01 (p.401-409)	The results of laboratory studies on the strength and hydraulic conductivity of cemented uranium tailings, and the ability of the tailings mass to retain...contaminants are reported (p.401)
38	The present condition of the Schneckenstein uranium tailings, Germany <i>T. Naamoun</i>	Tailings and Mine Waste '01 (p.441-451)	One of the aims of this work was to evaluate the different soil physical parameters of the tailing material and to determine their influence on the solubility and transport of contaminants in the tailing environment. (p.441)
39	The effectiveness of single and multiple open standpipe piezometers in monitoring of the pore pressure regime in tailings dams <i>G.J.R. le Roux</i>	Tailings and Mine Waste '02 (p.35-38)	This paper discusses the shortcomings of monitoring of the phreatic surface in tailings dams with single standpipe piezometers and concludes with a case study of incorrect 'phreatic levels' at platinum tailings dams in South Africa. (p.35)
40	Preliminary ecological risk assessment for the Elizabeth Mine site, South Strafford, Vermont <i>I. Linkov, S. Foster, E. Hathaway &amp; R. Sugatt</i>	Tailings and Mine Waste '02 (p.53-65)	The site has been listed on the National Priority List by the United States Environmental Protection Agency (USEPA) and investigations are underway at the site to determine the environmental impact of tailings and waste rock on the surrounding area and downstream receiving waters. This paper presents a preliminary-level ecological risk assessment approach in planning and evaluation to support an early cleanup action. (p.53)
41	Impact of acid rock drainage in a discrete catchment area of the former uranium mining site of Ronneburg (Germany) <i>J.W. Geletneky, G. Buchel &amp; M. Paul</i>	Tailings and Mine Waste '02 (p.67-73)	To reduce the concentration of radionuclides and heavy metals in ground and surface waters, the remediation activities include two main projects: (1) flooding of the underground mine; (2) backfilling and covering of the former open pit mine with material from the waste rock dumps. (p.67)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
42	Hydrochemical investigation at the uranium tailings Schneckenstein (Germany) <i>T. Naamoun</i>	Tailings and Mine Waste '02 (p.75-84)	A hydrochemical investigation was accomplished at the 'Schneckenstein' site. (p.75)
43	Estimation of the mobility of heavy metals in tailing sediments <i>T. Naamoun</i>	Tailings and Mine Waste '02 (p.217-229)	Realistic evaluation of the environmental contamination risks from uranium tailings requires an understanding of ways of binding or of the specific chemical forms of trace metals in the tailing materials and consequently their mobility and participation in the water cycle. (p.217)
44	Uranium tailings of Schneckenstein (Germany) reservoir of contaminants <i>T. Naamoun</i>	Tailings and Mine Waste '02 (p.231-241)	For this task, the concentration of a wide range of main and trace elements were determined by means of the X-ray fluorescence analysis. (p.231)
45	In situ bioremediation of uranium and other metals in groundwater <i>W. Lutze, W. Gong &amp; H.E. Nuttall</i>	Tailings and Mine Waste '02 (p.249-261)	Aquifers near uranium mines may be contaminated with uranium and other metals. Under certain conditions, indigenous microbes can be used to clean up the groundwater. (p.249)
46	Mobility tracing of radionuclides in the uranium tailings Schneckenstein (Germany) <i>T. Naamoun, D. Degering &amp; D. Hebert</i>	Tailings and Mine Waste '02 (p.303-311)	The gamma together with the alpha spectrometric measurements are the best tools for the resolving environmental problems having relation with radioactive contamination. In the current work, the equilibrium and disequilibrium between most of elements of the uranium chain were studied. (p.303)
47	Radioactive tailings issues in Kyrgyzstan and Kazakhstan <i>R.B. Knapp, J.H. Richardson, N. Rosenberg, D.K. Smith, A.F.B. Tompson, A. Sarnogoev, B. Duisebayev &amp; D. Janecky</i>	Tailings and Mine Waste '02 (p.313-321)	Soviet era uranium mining and ore processing practices in Central Asia have left a nuclear legacy that threatens human health, promises severe and long-term environmental degradation, and retards economic development... Operations have created a large quantity of waste, including actinides and beryllium, that is stored in retention basins. (p.313)
48	Stabilization of uranium in pitwaters using phosphate and coal tailings <i>S.C. Muller, T. Delaney, R. Ryan, J. Weber, S. Swapp, C. Eggleston &amp; D. Nash</i>	Tailings and Mine Waste '02 (p.339-348)	Uranium and radium daughter products present potential exposure risks in abandoned or inoperative open pit waters and water filled tailings ponds. This investigation will involve a statewide characterization of the uranium problem in pitwaters, column and settling testing results, and plans for pilot testing at impacted, open pits. (p.339)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
49	Researches concerning the Purolite assimilation for use within the uranium separation-concentration Resin In Pulp process <i>E. Panturu, Gh. Filip, St. Petrescu, D. Georgescu, F. Aurelian &amp; R. Radulescu</i>	Tailings and Mine Waste '02 (p.361-363)	Mechanical resistance determination was performed for SGA-600 and AM resins, showing superior characteristics for these resins and enabling their use in 'Resin In Pulp' process. (p.361)
50	Performance of vertical wick drains at the Atlas Moab Uranium Mill tailings facility after 1 year <i>Michael E. Henderson, Jared Purdy &amp; Tracey Delaney</i>	Tailings and Mine Waste '02 (p.387-391)	Perforated vertical wick drains were installed in 2000 to accelerate tailings consolidation and provide hydraulic relief prior to placing a final cover. This paper summarizes the performance of the wick drains, after nearly one year of operation. (p.387)
51	Community consultation in the rehabilitation of the South Alligator Valley Uranium Mines <i>P.W. Waggitt</i>	Tailings and Mine Waste '02 (p.403-410)	The paper follows the development of an intensive and comprehensive consultation process involving all stakeholders... The paper ends with a discussion of lessons learned and a summary of the outcomes achieved and details of the program for the future. (p.403)
52	Hydrogeochemical investigations on the site of Schneckenstein, Germany <i>T. Naamoun, S. Kutschke &amp; S. Gottschalk</i>	Tailings and Mine Waste '03 (p.7-14)	Between 1996 and 1997, a hydrological investigation was accomplished in the 'Schneckenstein' study site. (p.7)
53	Solution collection design issues on large heap facilities <i>J.F. Lupo, J.S. Harmon &amp; K.F. Morrison</i>	Tailings and Mine Waste '03 (p.57-71)	Topics covered in this paper include foundation settlement, solution collection pipe stability under high heap loads, and ore hydraulic properties within high heaps. (p.57)
54	Prediction of the behaviour of pollutants by means of hydrochemical model <i>T. Naamoun</i>	Tailings and Mine Waste '03 (p.287-290)	Hydrochemical study was conducted at the uranium tailings of 'Schneckenstein' to define the different hydrochemical parameters of pore water in the tailing system. (p.287)
55	Flushing of water from mill tailings at the Homestake Grants reclamation project <i>G.L. Hoffman &amp; A.D. Cox</i>	Tailings and Mine Waste '03 (p.365-374)	Dewatering of uranium tailings at Homestake Mining Company's Grants uranium mill site has proven to be more difficult than initially predicted....Testing to date has indicated that the injection/flushing program is successful... (p.365)
56	Tailing dam failures – the human factor <i>Allen H. Gipson</i>	Tailings and Mine Waste '03 (p.451-456)	In many of these cases professionals are letting cost govern the decision making process in lieu of prudent and responsible practice. (p.451)
57	Influences of construction subtleties on the hydraulic performance of water-balance covers <i>G.M. Smith &amp; W.J. Waugh</i>	Tailings and Mine Waste '04 (p.143-151)	An alternative cover was completed in 2000 to contain uranium mill tailings... The cover was designed to mimic the water balance of the native soil and plant community. (p.143)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
58	Modeling of density-dependent groundwater flow and transport at the uranium mill tailings site near Moab, Utah <i>D.M. Peterson, M. Kautsky, K.E. Karp, T. Wright &amp; D.R. Metzler</i>	Tailings and Mine Waste '04 (p.185-194)	A vertical section model of density-dependent groundwater flow was developed for a former uranium ore-processing site near Moab, Utah (p.185)
59	Uranium tailings facility design and permitting in the modern regulatory environment <i>K. Morrison, J. Elliott, J. Johnson &amp; B. Monok</i>	Tailings and Mine Waste '08 (p.305-313)	...the Piñon Ridge Project is the first new uranium mill being proposed for construction in the USA in over 25 years... The project includes design and permitting of three 30.5-acre tailings cells, as well as the process facilities, evaporation ponds, and ore pads. This paper will focus on the regulatory requirements pertaining to the tailings cell design. (p.305)
60	Reclamation of the Panna Maria uranium mill site and tailings impoundment: A 2008 update <i>C.L. Strachan &amp; K.L. Raabe</i>	Tailings and Mine Waste '08 (p.381-391)	This paper will describe the work since 1998. The reclaimed mill site and tailings impoundment are scheduled for final review and acceptance... (p.381)
61	Design & Construction of an evaporation pond at a historic uranium mining facility <i>T.A. Chapel, C. Woodward &amp; R. Jolley</i>	Tailings and Mine Waste '08 (p.401-408)	Construction of the evaporation pond involved some interesting challenges, including processing and compacting the clay soils... Work is currently underway to investigate if similar techniques can be used to develop a larger evaporation facility for phase 2 of the mining operation at Tony M. (p. 401)
62	Uranium mill tailings impoundment closure: A retrospective <i>Clint Strachan, Greg Smith &amp; Jack Caldwell</i>	Tailings and Mine Waste '09 (p.15-20)	We review advances in the science and technology of tailings pile reclamation since the time when the majority of uranium mill tailings piles were reclaimed and discuss how, if at all, these advances have affected our design decisions at that time. (p.15)
63	Best available technology design for a uranium tailings storage facility <i>Melanie Davis, Clint Strachan, Mark Abshire, Daniel Overton &amp; Toby Wright</i>	Tailings and Mine Waste '09 (p.21-31)	This paper presents a best available technology (BAT) design and regulatory requirements for a proposed tailings storage facility to manage tailings for a uranium mill in an arid region of the western United States. (p.21)
64	Laboratory versus field SWCC data for mine tailings and mine waste covers <i>D.J. Williams</i>	Tailings and Mine Waste '09 (p.159-169)	The paper presents laboratory and field SWCC data for hypersaline mine tailings and for mine waste covers, which highlight the strong influence that stress history, structure, cementation, disturbance and saturation can have on the data. (p.159)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
65	Tailings impoundment failures, black swans, incident avoidance, and checklists <i>J. Caldwell and L. Charlebois</i>	Tailings and Mine Waste '10 (p.33-39)	The thesis of this paper is that tailings impoundments fail as a result of a string of incidents, each of which is trivial and within the bounds of normal events, but which, taken together, constitute an event so unusual that it lies outside the bound of normal occurrence and experience... In this paper we examine current theories and hence methods for avoiding failure of tailings impoundments. (p.33)
66	New directions in tailings management <i>C. Strachan and J. Caldwell</i>	Tailings and Mine Waste '10 (p.41-48)	This paper summarizes the body of knowledge, new technologies, and practical experience, along with case histories that substantiate the fact that tailings disposal can be managed in compliance with international guidelines and standards; local regulations and requirements; in an environmentally responsible manner; and in a manner that provides employment. (p.41)
67	Unique geosynthetic liner system for uranium mill tailings disposal <i>G.T Corcoran &amp; H.R. Roberts</i>	Tailings and Mine Waste '10 (p.65-70)	This paper provides a description of the waste materials, design of the liner and slimes drain systems, and construction of the Cell containment system elements. (p.65)
68	Groundwater modeling at the Panna Maria uranium facility in support of an ACL application <i>M. Gard, J. Warner, L. Cope &amp; K. Raabe</i>	Tailings and Mine Waste '10 (p.143-155)	The objective of the model was to simulate and predict seepage from the Panna Maria Tailings Impoundment and the long term net effect this seepage has on the groundwater in the various aquifers in the vicinity of the site and ultimately on the San Antonio River. (p.143)
69	Chemical compound forms of cadmium in uranium tailings of Schneckenstein <i>T. Naamoun &amp; B. Merkel</i>	Tailings and Mine Waste '10 (p.451-455)	The present study sought to evaluate the release and mobility of cadmium from abandoned uranium residues. (p.451)
70	Uranium residue impacts on ground and surface water resources at the Schneckenstein site in East Germany <i>T. Naamoun &amp; B. Merkel</i>	Tailings and Mine Waste '10 (p.457-455)	This paper summarizes groundwater and superficial water analyses as well as geochemical modelling of uranium and other pollutants which were undertaken in order to evaluate the contamination risk of groundwater in the vicinity of the Schneckentein site (p.457)
71	Geotechnical Risks Related to Tailings Dam Operations <i>J.F. Vanden Berghe, J-C. Ballard, J-F. Wintgens, B. List</i>	Tailings and Mine Waste '11 (p.151-161)	The factors that influence the risk of tailings dam failure are discussed in this paper. (p. 151)

**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
72	Design, Construction and Operation of a Large Centerline Tailing Storage Facility with High Rate of Rise <i>James Obermeyer &amp; Tatyana Alexieva</i>	Tailings and Mine Waste '11 (p.237-250)	This paper presents the design basis and criteria that were adopted for the Quebrada Enlozada [Tailing Storage Facility] TSF, provides a summary of the main design components, and discusses operation of the facility during the first 5 years of its projected 22 year life. (p.237)
73	Uranium Diffusion in Soils and Rocks <i>Stephanie M. Moore &amp; Charles D. Shackelford</i>	Tailings and Mine Waste '11 (p.549-561)	The results of a study undertaken to review the process of diffusion of uranium in soils and rocks are presented and discussed. (p.549)
74	Final Covering and Diversion of Runoff from Wismut's Uranium Tailings Ponds at Seelingstädt (Germany) – Status Achieved from Concepts to Realization <i>Ulf Barnekow, Marcel Roscher &amp; Gunter Merkel</i>	Tailings and Mine Waste '11 (p.803-814)	The paper presents the actual remediation status achieved for final covering, vegetation and runoff diversion from concepts to realization and provides an outlook to future permitting procedures and remediation at the sites foreseen to be completed by 2022. (p.803)
75	Management of Waste from Uranium Mining and Milling in Australia <i>John Harris, Des Levins, Bob Ring, Wally Zuk</i>	Nuclear Engineering and Design 176 (1997) 15-21	Discusses waste management practices at several mines in Australia, which are in accordance with best practicable technology for the uranium mining industry.
76	Lost Creek In-Situ Uranium Recovery Project, Sweetwater County, Wyoming. <i>Lost Creek ISR, LLC; Department of the Interior, Bureau of Land Management</i>	EPA number: 120117, 901 pages, April 27, 2012	This paper discusses the construction, operation, and decommissioning of a proposed in-situ leach uranium recovery facility. Uranium recovery would consist of dissolving underground uranium-bearing minerals into solution and bringing the solution to the surface.
77	Uranium Mining, Processing, and Enrichment <i>Ian Hore-Lacy</i>	Encyclopedia of Energy Vol. 6 (2004) (p. 317-328)	This article outlines uranium mining, milling, and processing practices. The author discusses cases from around the world. Mining and milling waste is also discussed.
78	Tailings dam Seepage at the Rehabilitated Mary Kathleen Uranium Mine, Australia <i>B.G. Lottermoser and P.M. Ashley</i>	Journal of Geochemical Exploration 85 (2005) (p. 119-173)	Seepage from the tailings dam are producing TDS, U, and SO <sub>4</sub> concentrations which exceed Australian water quality guidelines for livestock drinking water.
79	Geochemical Evaluation of Different Groundwater – Host Rock Systems for Radioactive Waste Disposal <i>V. Metz, B. Kienzler, W. Schubler</i>	Journal of Contaminant Hydrology 61, (2003) (p.265-279)	Examines the geochemical suitability of a bedrock repository for radioactive waste disposal. Different models are discussed.



**Table 10-7 Summary of Selected Case Histories and Technical Articles (continued)**

#	Resource	Source	Notes
80	In-Situ Stabilization of a Low-Level Radioactive Site – A Case History <i>Amir A. Metry and Donald R. Phoenix</i>	Conference Proceedings – Treatment and Handling of Radioactive Wastes. American Nuclear Society Topical Meeting. Richland, WA. (1983)	Feasibility study for in-situ stabilization as the remedial action plan for an inactive uranium-processing mill in Canonsburg, Pennsylvania.
81	Design of Drainage Facilities for the UMTRA Project <i>Karen Agogino, Berg Keshian, and Raoul Portillo</i>	CA - Geotechnical and Geohydrological Aspects of Waste Management, Proceedings of the 8 <sup>th</sup> Annual Symposium (1986)	The remedial action plan design approach is to protect tailings embankments and radon barrier from runoff from PMP. Case studies are presented for Durango, CO and Lakeview, OR.
82	Analysis of Complex Seepage Problems with Disposal of Uranium Tailings – Selected Case Studies <i>Devraj Sharma, Margaret Asgian, William Highland, and Joanna Moreno</i>	Mineral and Energy Resources, Vol. 26, Issue 1. Jan. 1983. (p. 13-23)	Discusses saturated and unsaturated flow and the associated geochemical interactions. Also, discusses the influence of liners, native soil, bedrock and groundwater. Case studies are presented.
83	Controlling Open-Pit Slope Failures at Shirley Basin <i>John Atkins and Mohammad Pasha</i>	Mining Engineering, Vol. 25, Issue 6, June 1973	Slope stability analyses aided designs which allowed for ore recovery from the bottom of the pit, minimizing toe failures. Dewatering has slowed single bench failures from proceeding into multiple bench failures.