EXHIBIT L

VDH URANIUM STUDY:

INTERIM REPORT #2

Uranium Study:
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Commonwealth of Virginia
Department of Health

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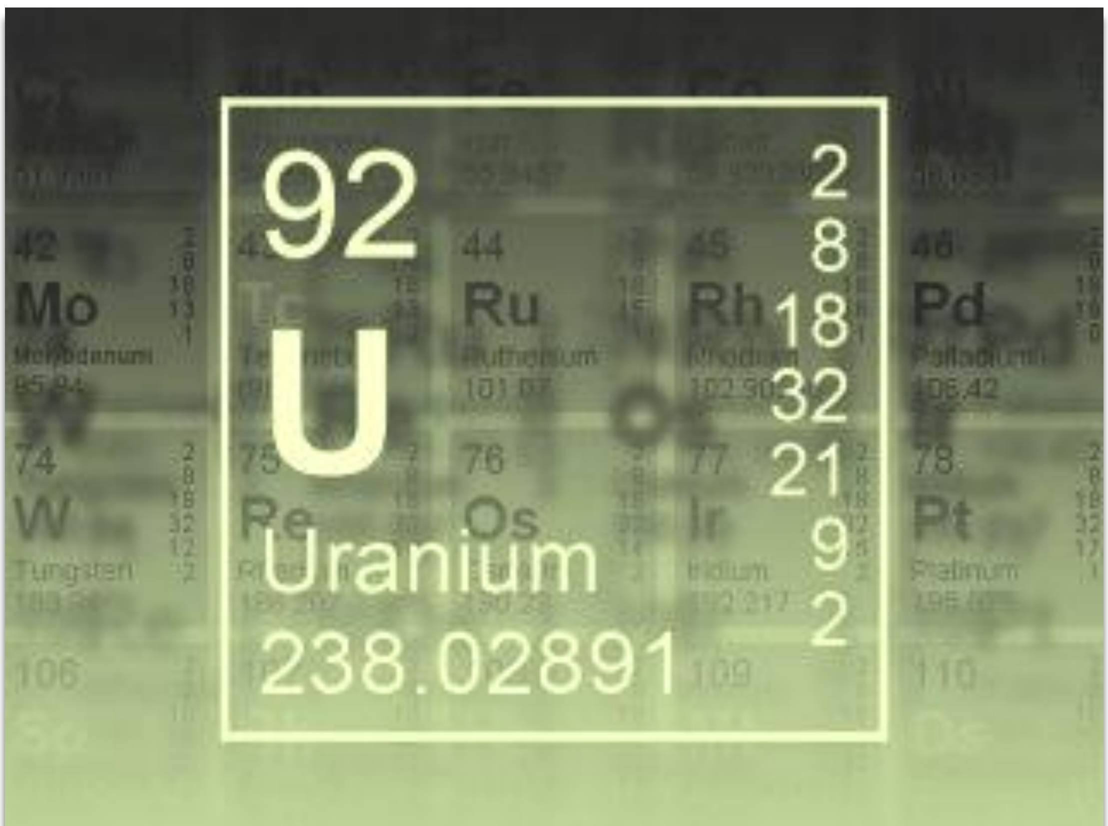

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ABBREVIATIONS

$\mu g/m^3$	micrograms per cubic meter
ABA	Acid-Based Accounting
ACGIH	American Conference of Governmental Industrial Hygienists
AHR	Airway Hyper Responsiveness
ALAP	As low As Practicable
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
ARARs	Applicable or Relevant and Appropriate Requirements
ARD	Acid Rock Drainage
ASTM	American Society for Testing and Materials
BADCT	Best Available Demonstrated Control Technology
BEIR	Biological Effects of Ionizing Radiation
BLM	U.S. Bureau of Land Management
BMP	Best Management Practices
BP	Blood Pressure
CAPs	Concentrated Ambient Particles
CCR	Code of Colorado Regulations
CDC	Centers for Disease Control and Prevention
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, & Liability Act
CFR	Code of Federal Regulations
CHF	Congestive Heart Failure
CNSC	Canadian Nuclear Safety Commission
CO	carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
DE	Diesel Exhaust
DEQ	Department of Environmental Quality
DMME	Department of Mines, Minerals and Energy
DOE	Department of Energy
ED	Emergency Department
EGUs	Electricity Generating Units
EPA	Environmental Protection Agency
FSME	Federal and State Materials and Environmental
FUSRAP	Formerly Utilized Sties Remedial Action Program
GPS	Global Positioning System
HCT	Humidity Cell Testing
HMWMD	Hazardous Materials and Waste Management Division

HRV	Heart Rate variability
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
IHD	Ischemic Heart Disease
ISL	In Situ Leach
ISR	In Situ Recovery
IT	Intra Tracheal
LLD	Lower limits of detection
L-N-T	linear-non-threshold
MCL	Maximum Contaminant Levels
MCLG	Maximum Contaminant Level Goal
mrem	millirem
MSHA	Mine Safety and Health Administration
MWMP	Meteoric Water Mobility Procedure
NCRP	National Council on Radiation Protection
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute of Occupational Safety and Health
NMEID	New Mexico Environmental Improvement Division
NMSS	Nuclear Material Safety and Safeguards
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NUREG	Document prepared by U.S. Nuclear Regulatory Commission
O_3	Ozone
OSHA	Occupational Safety and Health Administration
OSL	Optically Stimulated Luminescent
PAG	Potentially Acid Generating
PM/PM_{10}	Particulate Matter/coarse particle(s) (diameter <10 microgram)
PM/$PM_{2.5}$	Particulate Matter/coarse particle(s) (diameter <2.5 microgram)
QA	quality assurance
RAI	Request for Additional Information
RCW	Revised Code of Washington
REL	Recommended Exposure Level
RfD	Reference dose
RWC	Revised Washington Code
SMCL	Secondary Maximum Contaminant Level
SWPPP	Storm-water Pollution Prevention Plan
TEDE	Total Effective Dose Equivalent
TLVs	Threshold Limit Values
UFP	ultrafine particles

UMTRAP	Uranium Mill Tailings Remedial Action Project
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	United States Geological Survey
VAC	Virginia Administrative Code
VDH	Virginia Department of Health
WAC	Washington Administrative Code
WES	Wright Environmental Services, Inc.
WE	Wright Environmental
WISE	World Information Service on Energy Uranium Project
WLM	Working Level Months
wlm/y	working level months per year
WNA	World Nuclear Association
WYLQD	Wyoming Land Quality Division
WYLQD-NC	Wyoming Land Quality Division-Noncoal Program
yr	Year

1.0 INTRODUCTION

This report includes development of a set of recommendations to the Virginia Department of Health (VDH) concerning statutes, regulations and requirements that are necessary and relevant for effective life-cycle regulation of uranium mining and milling in Virginia. The report also provides our recommendations for optimizing overall state regulatory policy associated with potential uranium mining and milling in the Commonwealth, including development of self-consistent, uniform policies that encourage best management practices.

2.0 WATER QUALITY AND HUMAN HEALTH IMPACTS

The potential for water to act as a pathway for contaminants, both chemical and radiological, that could negatively impact human health, is a prime consideration when evaluating the detriment a uranium mine/mill may have. Both surface waters and groundwaters afford transport media and pathways for the spread of contaminants. Each of these pathways will be discussed separately. This section will evaluate potential pathways under both normal operating conditions of a mine and mill and under accident conditions.

2.1 Surface Waters

2.1.1 Normal Operating Conditions

Under normal operating conditions during the construction and operation of a uranium mine and/or mill, state and federal regulations require up-stream runoff to be diverted around the mine and mill site. Site runoff, mine waters, and process liquids are required to be contained on site and treated to remove hazardous chemicals and radionuclides prior to release offsite. The releases of these waters are regulated by radioactive concentrations limits set in Nuclear Regulatory Commission (NRC), or in VDH regulations if Virginia were to become an Agreement State for uranium. These restrictions are amplified by conditions of a radioactive materials license to be developed for a mill. In addition, waters from mine dewatering, site runoff, and mill process wastewaters are subject to the release quantity and quality standards of one or more National Pollutant Discharge Elimination System (NPDES) permits, to be approved and issued by Virginia Department of Environmental Quality (DEQ) as the authorized agency administering the NPDES program in Virginia. Discharge limits are normally set to require the quality of the discharge be at least at the level of the receiving stream or water body if not higher. Prior to any release to surface waters, the waters to be discharged must be tested to verify that no limit of the radioactive materials license or the NPDES permits is exceeded. These regulatory procedures, processes, and permitting are “best management practices” to ensure that there is no degradation of stream quality from controlled releases.

Under normal operating conditions, liquid releases to surface waters from a uranium mine and/or mill should cause no detriment to water quality of the receiving surface water and therefore should have no detrimental effect on human health or the environment, because of the protections provided above.

2.1.2 Accidents, Including Catastrophic Events

Accidents involving relatively small spills, such as the rupture of a tank containing chemicals used in processing the uranium ore, or the produced yellow cake, should result in little or no off-site releases to surface waters. The process to license a mill includes a spill prevention program with engineered and operational (administrative) controls, required by the regulatory agency

(NRC or VDH). The license application process includes a review and evaluation of impacts prior to the construction and operation of the mill.

However, low-probability/high-consequence events, such as a catastrophic failure of a tailings containment system, should be considered in the evaluation of potential impact(s) such occurrences could have on human health. The most obvious, and immediate, impact on human health would be the injury and death of persons caused by the mechanical impact of the "flood" of tailings solids and liquids that could accompany a catastrophic failure of a tailings confinement structure or tailings dam.

A regulatory requirement to site a tailings containment system, requiring its location "down-stream" from areas potentially influenced by such an event, would greatly decrease the potential for such human health impacts to occur (NRC 2012c). Included in the uranium mill license application and environmental impact statement processes are reviews of alternate sites for the location of the mill and tailings containment structures.

Regardless of accident potential, given current tailings system designs our review of the literature of uranium tailings dam failures in the U.S. has identified no deaths attributable to such events.

In addition to the immediate potential impacts on human health, near-term and long-term effects due to the hazardous chemicals and radiologic constituents of the tailings must be considered. Tailings consist of the solids and liquids produced in the processing of uranium ore. Appendix I shows the typical chemical and radiological properties of the tailings from a 1,800 metric ton (ore input) per day acid leach mill, processing 0.1% ore (NRC, 2003a). Although the chemical make-up of tailings from an alkaline leach mill would not be the same, the composition would be very similar except that acidic species would be replaced with basic (or alkaline) species. The uranium content of the tailings is reduced by processing: 0.007% by weight as compared to 0.1% by weight in the ore (NRC, 2003a). The primary radionuclides present in the tailings are the radioisotopes of radium, thorium, lead, polonium, and bismuth that were present in the ore. However, the hazardous chemicals present in the tailings in fact present the greatest concern for receiving surface waters and impact on human health (NRC, 1980d).

2.1.3 Church Rock Tailings Dam Failure

Twelve uranium tailings dam failures (of these one was intentionally breached to release effluents) have been documented to have occurred in the United States since 1958 (World Information Service on Energy Uranium Project [WISE], 2012; NRC, 1980c; Azam, Shahid and Uiren Li, 2010). All of these occurred at uranium tailings containment structures built before the passage of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) and the adoption of current regulatory criteria for uranium mills.

The most recent and the largest of these uranium mill tailings dam failures occurred in the early morning on July 16, 1979, at the United Nuclear Church Rock Uranium Mill in western New Mexico. This dam failure will be used as a "worst case scenario" to evaluate the potential of surface water related health impacts of a catastrophic release at a uranium mill. The evaluation is conservative in that the failure of the tailings dam occurred at a tailings confinement system that was not constructed in accordance with current federal criteria for such facilities including the prime option for such tailings confinement systems to be constructed below grade.

As a result, of this tailings dam failure approximately 100 million gallons of acidified tailings solution and approximately 1,100 tons of tailings solids (sand) spilled out of the tailings impoundment. This failure was widely reported in the news media and documented in governmental reports and notices (NRC, 1980d; Wasserman, H. and Norman Solomon, 1982; Finch, James 2007; Ruttenber, A. James and Kathleen 1984).

The tailings containment structure that failed at the Church Rock Uranium Mill was an unlined pond with a 25-foot tall 30-foot wide earthen dam located adjacent to and above Pipeline Arroyo, a tributary of the Puerco River. It was one of three tailings impoundments at the mill and the most recently constructed.

The Puerco River under natural conditions was an ephemeral stream whose flow came from spring snowmelt and brief, intense summer thunderstorms. Beginning in the 1950s the character of flow in some reaches of the river changed from ephemeral to perennial as the result of releases of effluents from the Gallup, New Mexico, sewage-treatment plant and mine water from uranium mines in the area.

The Pipeline Arroyo was a normally dry arroyo, but beginning in 1960 uranium mining began near the arroyo. Until 1975, untreated effluents from mine dewatering operations at the mines located along the arroyo were released directly into the Pipeline Arroyo creating a continuously flowing stream. In 1975, treatment of these effluents to remove radium was initiated. These releases continued until February 1986 when mine dewatering ceased following the cessation of mining in the area in 1985. During this time period the discharge of mine dewatering effluents have been estimated to have released 560 metric tons of uranium and 260 curies of gross alpha activity to the river.

Reviews of the causes of the Church Rock tailings dam failure and subsequent environmental impacts are tabulated in Table 2-1. Strict adherence to current federal regulatory criteria for uranium mills would have prevented this tailings dam failure.

The uranium tailings dam failure led to a flood through the Pipeline Arroyo and the Puerco River which reached at least as far downstream as Gallup, New Mexico (20 miles downstream) where there were reports of backed up sewers and lifted manhole covers. Trace amounts of contaminants in the released tailings have been reported as far as 80 miles downstream from the site.

No deaths occurred as the result of the flooding; and no structures were reported as being damaged or destroyed.

The near-term health impact came from the acidic nature of the tailings solution, which can cause chemical burns if ingested or come into contact with the skin. "*The potential for acute chemical effects persisted for approximately 2 days until water from upstream mining operations and the natural alkalinity of the stream bed neutralized the tailings solution*" (NRC, 1980d).

Although there is no scientific or scholarly reference with documentation of actual injuries occurring, a newspaper article published in 2009 relates anecdotally:

"*Church Rock residents waded through the flood with bare feet…'People started complaining about their feet getting hot'…Some residents went to the hospital but were released with a diagnosis of simple heat stroke.*" (Farmington Daily Times, 2009)

Following the accident the U.S. Geological Survey (USGS), the Centers for Disease Control and Prevention (CDC), the Environmental Protection Agency (EPA), and the New Mexico Environmental Improvement Division (NMEID) conducted studies on the impact of the flooding on groundwater quality and the environment and potential future impacts on health from the contaminants deposited in and along the affected streams. These efforts to assign values to those effects caused by the tailings dam failure are complicated by the natural background levels of radioactive materials in the soils and waters and the contributions from prior releases of untreated and treated water from uranium mine dewatering processes. The estimated releases of uranium and gross alpha from the dewatering operations and the tailings dam failure are tabulated in Table 2-2.

During 1988 through 1991, the USGS in cooperation with the Office of Navajo and Hopi Indian Relocation, the Bureau of Indian Affairs, the Arizona Department of Environmental Quality, the Arizona Department of Water Resources the Navajo Nation, and the New Mexico Environmental Department conducted a study of the effects of uranium-mining releases on groundwater quality in the Puerco River Basin (USGS, 1997). This study covered the area from the mouth of Pipeline Arroyo to 6 miles downstream from Chambers, Arizona. The course of the Puerco River for much of this stretch flowed through a portion of Navajo lands called the New Lands.

The stated purpose of this study was to describe:

- the water quality of the Puerco River alluvial aquifer,
- the movement of water between the Puerco River and underlying alluvial aquifer, and

- changes in water quality of the alluvial and bedrock aquifers related to releases of contaminant by uranium-mining activities.

An earlier reconnaissance-level study (USGS, 1987) of the groundwater quality in the Puerco Basin conducted in 1985 had shown that radionuclide concentrations in water from five of the fourteen wells sampled were at or above the Maximum Contaminant Levels (MCLs) for the State of Arizona and EPA.

The 1988 through 1991 study found dissolved gross alpha, gross beta, uranium, and radium activities and dissolved molybdenum and selenium concentrations to be elevated in streamflow as far as 87 miles downstream from the mines (USGS, 1997).

Measurements of groundwater from 69 groundwater sampling points in the Puerco River Basin led to the following conclusions.

- Because water levels in the alluvial aquifer are typically shallow – within about 0.6 meter (approximately 2 feet) of the elevation of the lowest part of the streambed – near-stream groundwater potentially can be affected by contaminants in streamflow.
- Except for several samples collected within several meters of the streambed, groundwater samples downstream from Gallup, New Mexico, meet the MCLs of the EPA for gross alpha, radium-226, and radium-228, and the proposed MCL for uranium. Alluvial groundwater, however, commonly exceeded the Secondary Maximum Contaminant Levels (SMCLs) of the EPA for dissolved, iron, and manganese, which are constituents that are unrelated to uranium mining/milling releases.
- Concentrations of dissolved uranium and U-234/U-238 activity ratios in shallow alluvial wells as far downstream as Chambers, Arizona, indicate some residual contaminated water was still present in October 1990. Data indicate that it is unlikely that radionuclides releases to the Puerco River by uranium mining/milling activities could infiltrate to bedrock aquifers.
- Extent and concentration of uranium is related to (1) concentration of uranium in the Puerco River during mining, (2) variation in mixing between native groundwater and recharge from streamflow, and (3) removal of uranium in solution by sorption on sediments.
- Estimated total volume of uranium released by mining activities (including the tailings dam failure) was not found at predicted levels in 1989-91. As indicated by the results of sample analyses from the alluvial aquifer, sorption on sediment was the probable fate of the missing uranium.

- Radionuclide concentrations and uranium-series isotope ratios on sediments suggest that concentrations of radionuclides on sediment near the channel are larger than on sediment away from the channel.

Following the tailings dam failure investigators from the CDC, the EPA, and the NMEID conducted an assessment of human exposure resulting from the uranium tailings dam failure and the release of mine dewatering effluents. The results of these assessments were presented in a peer-reviewed publication coauthored by two scientists from CDC, one from EPA, and two from the New Mexico Health and Environment Department (Ruttenber and Kreiss, 1984). The study focused on the area around the Pipeline Arroyo and the stretch of the Puerco River from the mouth of Pipeline Arroyo through the town of Gallup, New Mexico. This was the area most impacted by the release from the tailings dam failure.

The initial review of environmental monitoring data following the release concluded that the two most likely routes of human exposure were from the inhalation of re-suspended dry tailings and ingestion of domestic animals that watered from the Puerco River. Other potential exposure pathways were considered but ruled out because no residents of the area along the arroyo and river from the mill site to Gallup, New Mexico, used water from the Puerco River for personal consumption and only a few small gardens were adjacent to the river. Contamination of regional groundwater was evaluated as a source of exposure but eliminated when no elevated radionuclides in the groundwater test wells were observed in the ten months following the spill.

Air sampling was conducted downwind from where a cleanup crew was working and constituted the worst-case conditions for exposure to airborne particulates. The results of this sampling were used in the determination of the most likely pathways for significant human exposure and the selection and method of evaluation of people to undergo follow-up *in vivo* evaluations.

In vivo monitoring was used to screen for evaluating direct radiological exposure from the tailings spill. Using aerial photographs and representatives of the Church Rock community only six people (5 children and 1 adult) were identified who admitted to being near the banks of the Church Rock portion of the Puerco River and consented to *in vivo* monitoring. Each of the six people was evaluated for the presence of radionuclides in the body using whole body counting and urinalysis.

The human consumption of local livestock that watered in the Pipeline Arroyo and Puerco River were considered as a pathway for internal radiation exposure. Sheep, cattle, and goats were identified as the domestic animals in the area. Two cows, four sheep, and two goats from the area were purchased and autopsied.

Data from the air sampling was modeled for radiation dose to people exposed following the tailings dam failure using conservative (i.e., factors producing highest doses) assumptions and atmospheric transport models. The total 50-year radiation dose commitment from all the radionuclides measured in the air samples are shown in Table 2-3. For comparison, the annual effective dose per individual in the U.S. is 620 millirems (mrems) (National Council on Radiation Protection [NCRP], 2009).

Whole body counting of six people believed to be the most highly exposed were all found to have normal amounts of radioactivity, primarily K-40. Specific analyses for uranium, thorium, and their deacay products found no detectable activity of these radionuclides in any of the six. In order to calculate the maximum possible radiation dose that any individual could have received, dose calculations were made using the activities for each of these radionuclides at the minimum level of detection for the whole body counting system. Thorium 230 was the radionuclide that was determined to be the radionuclide that would have delivered the highest possible dose. That dose was calculated to be a 50 year life-time dose of 7.9 rems to the lungs of a ten-year-old child. That would equate to a whole body dose equivalent of 948 mrems or an average annual whole body radiation dose equivalent of approximate 19 mrems in each of the 50 years.

Urinalyses of the six people found no sample in which the gross alpha, gross beta or gross gamma activities were above the limit of detection. Similarly, concentrations of total uranium and thorium were below the limits of detection.

Human dose contributions from eating domestic animals that drank contaminated waters were calculated based on the radionuclide concentrations in the various organs of the eleven autopsied animals. Calculations were made using conservative factors and consumption patterns. The total 50-year radiation dose commitment from all the radionuclides measured are tabulated in Table 2-4.

Clearly, of the two pathways for potential human health impacts, the consumption of animals is the dominate factor. The animals (Table 2-4) consumed waters contaminated with routine releases of untreated and treated waters from mine dewatering processes and the releases as the result of the uranium tailings dam failure.

The Church Rock uranium tailings dam failure and the assessments of environmental effects and chemical and radiological (as measured by radiation dose) impacts on human health are illustrative of a “worst-case” occurrence. The potential human health impacts and the real extent for accidents at a specific uranium mine and mill can only be assessed once the actual location and design of a mine/mill complex has been determined.

At least one study has been conducted for a hypothetical uranium mine and mill to be located at a potential site in the Coles Hill area (Baker, 2011). A technical critique of the study has been published that disagrees with several of the assumptions and methods used in the study (Kleinfelder, 2011). The differences in the professional opinions expressed in these two reports demonstrate the necessity for professional review of all technical reports, their methods of analysis, and the conclusions reached. These differing opinions also show the necessity for seeking input from various individuals and organizations when making decisions in the application and environmental assessment processes.

To put the Church Rock failure into some perspective for the Navajo region of the country, see Appendix III entitled The Navajo Experience.

2.2 Groundwater

Historically most of the uranium mining and milling operations in the United States have resulted in contamination of local aquifers and portions of regional aquifers that degraded groundwater quality and thereby increased the potential for negative human health impacts.

Open pit and shaft mining of uranium have led to negative impacts on the quantity of groundwater available to other users, particularly private water well owners, due to the draw-down of the aquifer that resulted from the mine dewatering processes. While the decrease in the water level in a well may not have had a direct impact on its water quality, indirect effects of such draw-down may influence the inflow of waters of lesser quality.

2.2.1 Effects of Uranium Mining

Routinely open pit and underground uranium mining operations go through or into aquifers, particularly shallow local aquifers commonly used for private water wells. As a result of penetrating an aquifer, groundwater flows into the mine. In order to prevent flooding and to be able to continue mining operations, this water is removed from the mine and released onto the surface or otherwise managed. During much of the history of uranium mining in the United States the dewatering of uranium mines was done by pumping the water out of the mine and releasing these untreated mine-waters to surface streams, ponds, or dry gullies or arroyos. After the mid-1970s these releases were required to be treated before release.

Normally the greatest impact on the aquifers (and therefore, groundwater) by the practice of mine dewatering is on the quantity of water available especially to small private wells near a mine. The mine acts as a large well drawing down the aquifer and forming a cone of depression in the water level in the aquifer centered around the mine. As a result, the water table level may be lowered in wells surrounding the mine and thereby reducing the quantity of water available in the wells. Generally, this draw-down does not negatively impact the quality of the groundwater present in the aquifer because the flow of groundwater is into the mine and not out of the mine.

However, when mine dewatering is stopped, the quality of the water in the aquifer may be negatively impacted. Water may flow out of the mine into the surrounding aquifer carrying contaminants with it. These contaminants are able to dissolve in the water due to changes in the chemical nature of the surrounding rock when it was exposed to air during the mining operations.

Whether these negative impacts occur is highly site specific and cannot be adequately assessed until the site is chosen and the hydrologic conditions and ore characteristics are known. Only with data regarding a specific site can an assessment be made of the potential impacts on human health that the operation of a uranium mine would have.

In Interim Report No. 1 (Wright Environmental Services, Inc. [WES], 2012a), criteria were presented for the environmental monitoring of private water wells and public water supply wells around a proposed site during the collection of background data for the applicant's environmental report and to continue such monitoring throughout the life of the mine/mill. Data regarding water quality and other items such as the depth to water were included in the environmental monitoring and data reporting recommendations.

2.2.2 Effects of Uranium Milling Operations

The greatest potential for detrimental impacts on groundwater and thereby impacts to human health and the public outside the licensed mine/mill area is the failure to properly manage the uranium mill tailings. Uranium mill tailings contain highly acidic (or alkaline) solutions containing dissolved metals, radiological components, and other organic and inorganic compounds that are known to be hazardous to human health.

At most of the legacy uranium mills, tailings were placed into unlined tailings impoundments or in some cases directly into similarly unlined, mined-out mines that penetrated the aquifer(s). As a result, there is widespread contamination of groundwater in local aquifers and portions of regional aquifers at these sites. Current federal regulations do not permit uranium mill tailings to be managed in this manner and require that all tailings ponds be lined and use below grade placement as the prime option for tailings disposal. Therefore, it is not valid to compare the impacts on human health from these sites with a uranium mill that is designed, constructed, and operated in accordance with current federal criteria for licensing procedures and regulatory oversight of the management of uranium mill tailings.

Current federal criteria require that each uranium mill tailings impoundment structure be constructed on an engineered foundation, and that the impoundment itself be doubly lined with a leak detection system installed between the two liners to detect any leakage through the liner directly underneath the tailings (NRC, 2012c). In addition, monitor wells surrounding the uranium mill tailings structure are required to be placed into the aquifers below the structure to monitor for radionuclides and chemicals present in the tailings.

If leakage is detected the owner/operator of the uranium mill will be required to immediately take action to determine the cause of the leak and take corrective actions to repair the leak and regain control of any materials that may have leaked from the structure. The regulatory agency

(NRC or VDH[1]) may require that the owner/operator immediately stop operations that produce additional tailings, reduce the hydrostatic head (which provides the driving force for leakage) within the structure, construct slurry walls, place grout, begin pump-back activities, and /or take other measures to prevent the spread of contaminates beyond the licensed area of the mine/mill to off-site properties including the aquifer.

Under current regulations and regulatory inspection/enforcement practices, it is highly unlikely that the management of a uranium mill tailings structure will result in the contamination of off-site groundwater. Without degradation of off-site groundwater, there would be no negative impact on human health of the public or the environment via the groundwater pathway as a result of uranium mill tailings. Contamination of off-site groundwater would be a low potential risk, and if it did occur, would have an extremely low risk for human health or environmental effects (because of measures available to stop and mitigate a release).

[1]If Virginia becomes an Agreement State for uranium milling.

3.0 EXISTING STANDARDS FOR MINE WASTE DISPOSAL RELATED TO HUMAN HEALTH

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

Although uranium itself is not highly radioactive, the mined ore should be regarded as potentially hazardous due to uranium's decay products. Exposure can occur directly, via gamma radiation, or internally, via ingestion or inhalation of alpha and beta particle emitters. Gamma radiation comes principally from isotopes of bismuth and lead in the uranium decay series. Alpha and beta radiation are produced during radioactive decay of several of the uranium deacay products. Radon gas is produced via decay of radium-226. The radiation hazards involved are actually similar to those in many mining and ore treatment operations.

Radon gas emanates from the rock (or tailings) as radium decays. It then decays to (particulate) radon daughters, some of which are alpha-emitters. Radon occurs in most rocks, and it is generally present in the air we all breathe, sometimes at high concentrations. At high concentrations it is a health hazard, since its short half-life means that disintegrations giving off alpha particles occur more frequently. Alpha particles damaging cells in the lung can initiate lung cancer. Because radon naturally tends to concentrate in most mines, it is strictly monitored by MSHA.

Radiation exposure of workers in a uranium mine, ore processing plant, and/or tailings area are limited by regulation. Radiation exposures to the public from ore and tailings are usually quite low. For example, the maximum estimated dose to a member of the public from releases at the Cotter Corp. uranium mill was 7 mrem, vs. the limit of 100 mrem (Cotter, 2006).

Radon daughter exposure of miners is small in an open pit mine because there is generally sufficient natural ventilation to remove the radon gas. Dust controls can be effective in minimizing the exposure of workers to heavy metals and particulate uranium chain nuclides.

3.1 MSHA Mining Regulations

Mine health and safety in the United States are regulated by the MSHA; the regulations are found in 30 CFR – Parts 1 to 199.

MSHA mine worker safety regulations are found in 30 CFR Part 57.5037. This regulation pertains to radon daughter exposure monitoring for workers located at facilities where uranium is mined, and for those where other materials are mined.

Sampling equipment, procedures and frequency as well as record keeping requirements are spelled out in regulations. The regulations state that sampling shall be done using equipment and procedures described in section 14.3 of the American National Standards Institute (ANSI) N13.8-1973, entitled *"American National Standard Radiation Protection in Uranium Mines,"*[2] which is incorporated by reference and made a part of the standard (or equivalent procedures and equipment) acceptable to the Administrator, Metal and Nonmetal Mine Safety and Health, MSHA.[3]

3.1.1 Current Virginia Mining Regulations (VAC 5-481-620)

The VAC 5-481-600 regulation is not specifically a uranium mining regulation, but rather a part of the Radiation Protection Regulation. It regulates human exposure to radiation sources including diagnostic x-ray machines and other radiographic and tomographic systems, brachytherapy, and covers persons licensed or registered by the Department to receive, possess, use, transfer, or dispose of sources of radiation. The following regulations, radiation protection programs (10 CFR 20.1101) and definitions (10 CFR 20.1003) are applicable in the Commonwealth of Virginia (12 VAC 5-481-630). The regulations describe licensing requirements, the limits of human exposure to radiation, handling of equipment, and reporting requirements for licensed sources of radiation.

3.1.2 Mining Regulations Related to Uranium Mining

Onsite worker health and safety regulations pertaining specifically to radon daughter exposure monitoring are in 30 CFR Part 57.5037 of the MSHA mine worker safety regulations. Federal MSHA regulations are applicable to all mining activities in the United States. Virginia regulation 12 VAC 5-481-630, addresses radiation protection programs and occupational dose limits. Virginia defers to 10 CFR Part 20 – Standards for Protection Against Radiation. NRC

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[2] Approved July 18, 1973, pages 13-15, by the American National Standards Institute, Inc.

[3] This publication may be examined at any MSHA Metal and Nonmetal Mine Safety and Health district office, or may be obtained from the American National Standards Institute, Inc., 25 W. 43rd Street, 4th Floor, New York, NY 10036; www.ansi.org.

Agreement States (Virginia, Colorado, and Washington) have adopted NRC 10 CFR Part 20 as its radiation protection regulation.

3.1.3 U.S. Nuclear Regulatory Commission/Federal Regulations (10 CFR Part 20)

As an Agreement State, Virginia has an established program to assume NRC regulatory authority under the Atomic Energy Act of 1954, as amended. Currently Virginia has authority from the NRC to regulate radioactive materials, but not uranium milling or byproducts. If uranium milling regulation were to be assumed by Virginia, the NRC would relinquish to Virginia portions of its regulatory authority to license and regulate byproduct materials, source materials and special nuclear material. Information concerning the NRC Agreement State Program is available at http://www.nrc.gov/about-nrc/state-tribal/agreement-states.html .

The NRC's 10 CFR Part 20 regulations, already applicable within Virginia, specifically address the following: radiation protection programs, occupational dose limits, radiation dose limits for individual members of the public, radiological criteria for license termination, surveys and monitoring, control of exposure from external sources in restricted areas, respiratory protection and controls to restrict internal exposure in restricted areas, storage and control of licensed material, precautionary procedures, waste disposal, records, reports, exemptions and additional requirements, and enforcement. Occupational dose limits for adults are discussed in 10 CFR Part 20.1201. NRC licensed facilities are required to adhere to these dose limits except for planned special exposures, discussed under Part 20.1206.

3.2 Radiological and Toxicological Characteristics of Mine and Milling Wastes from Conventional Facilities

Mine and mill waste materials are associated with geologically anomalous concentrations of chemical elements (ore deposits). Thus, they commonly have an elevated risk of leaching chemical constituents that may compromise water resources. This potential is exacerbated by disaggregation of rock into smaller pieces during mining, as well as by potentially exposing material to geochemically oxidizing conditions.

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

Several regulating agencies offer either guidelines or regulations concerning the characterization of mine and mill waste for environmental problems resulting from acid mine drainage or other leachates. In this review (presented within this chapter), regulations and guidelines from several regulating agencies are considered and include the states of Arizona, Colorado, Washington, and

Wyoming as well as the U.S. Bureau of Land Management (BLM), which oversees much of the minable public lands in the western United States. BLM oversaw the permitting of a uranium mine in Utah in 2009, the first permitted after a 30 year hiatus

3.2.1 Summary of Acid Rock Drainage and Other Mine Rock Leachates

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

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

3.2.2 Material to Which Acid Rock Drainage and Leachate Concerns Apply

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

From the perspective of regulating agencies, concerns regarding ARD are primarily directed at waste rock. Washington State identifies only waste rock as a material of concern(Washington State, 1994c; - Subsection 1(b)). Similarly, the Wyoming Department of Environmental Quality, Land Quality Division (WYLQD) (1994a) guidelines indicate a focus on topsoil and overburden materials. However, Colorado (2010) Rule 6.4.21 Subsection 14 indicates a need to *"include appropriate geochemical evaluations of any material that will be exposed by mining, placed in on-site solution containment systems or facilities, stockpiled, or disposed of on the affected land, and that involves uranium mining or has the potential to cause acid mine drainage or to release designated chemicals, or toxic or acid-forming materials."* Nevada provides rock characterization guidelines (not regulations) that specifically cite the need to consider ore, waste material, process components and long-term management. Pits, mine workings and tailings are not directly specified, although the Colorado regulations and Nevada State Office BLM guidance directly imply their significance in their identification of all material exposed.

3.2.3 Sampling

As noted in Arizona regulations, (Arizona, 2004) "The primary objective of a sampling program is to obtain representative samples from a range of geochemical groups within each lithologic unit in order to characterize materials that may generate an acid rock drainage and have a reasonable probability of causing pollutant to reach an aquifer."

Virtually all rock associated with a mining project should be evaluated for its potential to form ARD (Colorado, 2010). Many mine materials and individual rock types can be quickly excluded from ARD concerns due to the lack of sulfides. However, all materials and individual rock types must be evaluated for potential leaching of chemical constituents of concern. Whether for ARD potential and/or metal leaching potential, proper sampling is a concern.

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

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

The frequency of sampling described by EPA (1994a) and WYLQD (1994b) seek to address the issue of representativeness for waste rock, but do not speak to tailings. Metallurgical testing during mine feasibility evaluations produces tailings samples, and these are commonly associated with specific periods (years of development) for a proposed mine project. Tailings samples are routinely sampled for all anticipated periods of future development, to ascertain what changes in tailings may occur as a result of ore composition variations over time. Arizona (Arizona, 2004) in Appendix B notes that different rock types may have varying ranges of chemical characteristics. Acid-base accounting (ABA), and iterative sampling and characterization, may be required to demonstrate that material characterization is representative.

Arizona (2004) calls for consideration of several characteristics of mine rock that should be taken into account to create a representative sampling program, including:

- lithological and mineralogical variation;
- degree and extent of primary and secondary sulfide, and oxide mineralization;
- form in which mineralization occurs (e.g., disseminated or in veins);
- mass and volume of different lithologies;
- degree and extent of fracturing; and
- degree of oxidation.

3.2.4 Laboratory Testing

Representative samples of mine rock and tailings should be tested to assess ARD formation potential and leaching of chemical constituents. The potential test procedures range from assessing the balance of acid-producing and acid-consuming potential, to short- and long-term leach testing which can vary in scale.

3.2.5 Acid-Base Accounting

Acid-based accounting is a fundamental testing technique to gauge the potential of mine material to form ARD. Such testing is always conducted, although it is not specified in any state regulations, and it should be considered a Best Management Practice (BMP). Colorado (2010) and Washington State (Washington, 1994) do not specify the use of ABA, but state that *"appropriate geochemical evaluations"* (Colorado, 2010) or *"accurate identification of the acid generating properties"* (Washington, 1994c) should be performed. Wyoming, Nevada and Arizona indicate specifically that ABA tests need to be completed. Of these, only Arizona (2004) sets a regulated policy that is part of the state's Aquifer Protection Permit application process. Other entities offer the ABA specification in non-regulatory guideline documents.

3.2.6 Humidity Cell Testing

For material considered uncertain with respect to ARD formation by ABA, long-term leach testing is routinely expected although it should be considered a BMP, not a regulatory requirement. This testing is also referred to as kinetic, or humidity cell testing (HCT) (American Society for Testing and Materials [ASTM], 2007 - D5744-07e1). Samples are exposed to alternate humid air/dry air cycles with weekly leaching by distilled water. Chemical parameters are tracked weekly to assess if a material will produce ARD and/or to gauge the chemical composition of contact water. This test is specified in Nevada's guidance, and is suggested for use by Arizona (2004) in cases where ARD formation cannot be ruled out by static (ABA) methods. Other states do not specifically describe or call for HCT work in any guidance documents or state regulations. As with ABA, HCT work should be considered a BMP, and its use falls under the call for appropriate geochemical evaluations (Colorado, 2010) and is ordinarily expected from permitting agencies.

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

3.2.7 Leach Testing

The HCT is a long-term leach test applicable to material that may produce ARD. Leaching of metals and other chemical constituents of concern are typically determined using short-term leach tests. Arizona (2004), although not specifically requiring the use of HCT, does require leach testing of materials and accepts the use of the EPA method 1312 (Synthetic Precipitation Leaching Procedure) (EPA, 1994b) for all sampled materials, as well as the Meteoric Water Mobility Procedure (MWMP) (ASTM, 2002 D2242-02) and other less rigorous tests. Nevada calls for use of the MWMP. WYLQD offers guidelines to determine a variety of chemical properties related to suitability of the material as an agricultural medium for purposes of reclamation of waste materials (WYLQD, 1994b), but does not specify leach testing with respect to chemical constituents that may leach from mine rock.

3.3 Segregation and Safe Disposal of Sub-Ore Grade Waste Rock

Whether as representative of an ARD risk or non-acid leaching of chemical constituents, appropriate waste rock handling (including sub-grade ore) and reclamation plans are integral to mining permits.

All agencies considered in the present review, except Arizona (Arizona, 2004), call for waste rock handling plans that include segregation. Specifically:

- Washington Subsection (1)(b)(ii) calls for "*a strategy for encapsulating potentially toxic material from the environment, when appropriate, in order to prevent the release of heavy metals acidic drainage*" (Washington, 1994c);
- WYLQD Subsections (II)(A)(5) and (6) offer guidelines that "*the results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that all toxic or acid- forming material is stockpiled and backfilled in a manner that will prevent environmental degradation*" and "*A reclamation plan should be developed, using the overburden and interburden analyses, demonstrating that toxic or acid-forming overburden material will be*

placed so as not to preclude surface reclamation and revegetation or the re-establishment of acceptable surface water and groundwater quality and quantity" (WYLQD, 1994c);

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

3.4 Reducing Human Health Risks from the Release of Radionuclides and Contaminants from Mining and Milling

3.4.1 Introduction

The reduction of human risks is accomplished through characterization of potential contaminant sources, and the ability of engineering designs to contain potential sources that might result in physical and/or environmental damage. The process of characterization of the waste source and engineering design is driven by regulations and BMPs that are common in the uranium mining industry.

Mining of uranium is generally regulated by state agencies. The milling of uranium has historically been regulated by either the NRC, or state agencies under an Agreement with the NRC. We have reviewed selected NRC and state standards related to minimizing the ecological risks from radionuclides and contaminates associated with the mining and milling of uranium. A summary of our findings and some BMPs are provided below. For this section we have focused our efforts on regulatory guidance from Colorado, Wyoming, Washington State, and the NRC. Some guidance from other agencies has also been reviewed and cited.

3.4.2 Uranium Tailings and Methods of Placement

Conventional mining and milling of uranium results in the development of waste rock and tailings. Waste rock is generally composed of subgrade ore and overburden. This material has historically been stored on the surface or placed back in the underground workings or open pit. The tailings are the result of processing the ore by either milling or heap-leaching. Milling is accomplished by grinding the ore and extracting the uranium. The process of milling previously resulted in a tailings material generally slurried into lined impoundments. In current systems, a partially dried paste might be transferred via belt to a below-grade repository.

A heap-leaching facility extracts uranium by stacking run-of-mill ore on a lined pad and applying a leaching solution (acid or base) to the surface of the ore to extract uranium. The ore can be stacked either by a conveyor system, or via trucks and loaders. The uranium rich solution is collected and the uranium may be extracted in an ion-exchange system. The leached ore is classified as mill tailings.

3.4.3 Mining Best Management Practices

3.4.3.1 Characterization of Materials (ore/wastes/topsoil)

The current practice prior to commencement of mining operations is to characterize the ore, waste rock, and topsoil, using the results of the characterization to develop the ore, waste rock, and topsoil handling plans. Characterization of the material includes determining the potential for ARD, the mineral content, and the potential for leaching. Characterization of materials is discussed in more detail in Sections 2.0 and 3.0.

Revised Code of Washington (RCW) 78.56.100, Subsection (1)(b)(i), indicates that characterization of the waste rock shall consist of *"an accurate identification of the acid generating properties of the waste rock."* (Wahington, 1994c). The Wyoming Title 35-11-406, Section ix, indicates that "*a plan for insuring that all acid forming, or toxic materials"* are contained. The BMPs for characterizing the material are provided in Section 2.0.

3.4.3.2 Ore and Waste Rock Handling Plans

Segregation of waste rock and ore during operations is an integral part of a mine operation, and is common practice for conventional uranium mining facilities. The following is a summary of the regulations reviewed that relate to characterization of materials.

- Washington RCW 78.56.100, Subsection (1)(b)(i-iii) indicates that "*the applicant must develop a waste rock management plan approved by the department of ecology and the department of natural resources which emphasizes pollution prevention*". (Washington, 1994c). This plan normally includes an assessment of the ARD potential (see Section 2), encapsulation of the waste rock, and reclaiming the water to reduce infiltration.
- WYLQD Subsections (II)(A)(5) and(6) offer guidelines that "*The results of the overburden evaluation should be integrated into the mine plan so that the applicant can demonstrate their ability to ensure that all toxic or acid-forming material is stockpiled and backfilled in a manner that will prevent environmental degradation*" and "*A reclamation plan should be developed, using the overburden and interburden analyses, demonstrating that toxic or acid-forming overburden material will be placed so as not to preclude surface reclamation and revegetation or the re-*

establishment of acceptable surface water and groundwater quality and quantity" (WYLQD, 1994a).

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

3.4.3.3 Encapsulation and Isolation

The current method for mitigating the effects of uranium mine waste is to isolate the waste from external receptors. Washington Subsection (1)(b)(ii) calls for applicants to provide *"a strategy for encapsulating potentially toxic material from the environment, when appropriate, in order to prevent the release of heavy metals acidic drainage"* (Washington, 1994b).

3.4.3.4 Ore Pad Liners

Ore has the potential for leaching into the underlying soils, however, it has been our experience that lined ore pads are not used 100% of the time. The use of liners under ore pads would reduce the potential for leaching contaminate from the ore into the soil and groundwater. The Colorado Department of Public Health and Environment states that *"steps must be taken during stockpiling of ore to minimize penetration of radionuclides into underlying soils; suitable methods include lining and/or compaction of ore storage areas"* (Colorado Department of Public Health and Environment [CDPHE], 2011, Appendix A, Criterion 5H).

3.4.3.5 Back Stowage of Waste

Underground mining operations may involve pre-sorting of the ore underground. The material that is below the cut-off grade (i.e., waste rock or protore) is placed in workings without bringing it to the surface.

The State of Washington notes in the Washington Administrative Code (WAC) 246-252-030 Subsection 3, that "*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)*".

Internal backfilling in pits as soon as feasible after mining has been used to reduce the amount of waste stored in above ground impoundments, and reduce the formation of pit lakes.

3.4.3.6 Liners for Waste Storage Areas

The use of liners under waste rock storage areas is not a common practice, and is not required by the regulations reviewed for this section. However, there is the potential for ARD and leaching of metals from the waste rock. It would be reasonable to review the need for liners under waste rock pads while developing future regulations, especially in areas of high precipitation. While the State of Colorado does not require liners under the waste storage areas, they do require that *"all refuse and acid forming or toxic producing materials that have been mined shall be handled and disposed of in a manner that will control unsightliness and protect the drainage system from pollution"*(Colorado, 2010).

3.4.3.7 Storm-Water Pollution Prevention Plans

It is common practice for the states to require storm-water pollution prevention plans (SWPPP) as part of the mining application process. The EPA provides guidance on their website **(**http://cfpub.epa.gov/npdes/stormwater/swppp.cfm**)** for the development of SWPPPs. In mining applications, the primary concern is sediment containment.

3.4.3.8 Dust Minimization and Control

During operations, the owner is required to control the amount of dust released to the open environment. This is commonly done by placing sprayer bars on conveyors, and by maintaining a wet tailings and heap-leach pad surface.

3.4.3.9 Mine Effluent Control

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

3.4.3.10 Acid Rock Drainage Control

The development of ARD is a concern for regulators and operators and has resulted in many long-term treatment and cleanup operations around the world. The quantification of the potential for ARD is discussed in detail in Sections 2.0 and 3.0. Materials and individual rock types must be evaluated for potential leaching of chemical constituents of concern. Whether for ARD potential and/or metal leaching potential, proper sampling is a concern. After the geochemical properties have been identified then appropriate segregation, handling and encapsulation plans should be developed to reduce the potential for ARD drainage to occur.

3.4.3.11 Closure

The applicant should submit a closure plan as part of the application process. However, unlike milling and tailings facilities, the long-term care of mine waste does not generally transfer to the Department of Energy (DOE) and remains the responsibility of state regulators. At a minimum, the reclamation plan should include plans for: regrading of the waste rock to increase the stability; development of waste rock cover design; evaluation of personal potential of the waste rock cover; and revegetation of surface disturbance with native plants. If the mining operation is an open pit facility analyses of the long-term water level and water quality should be completed. The State of Colorado requires that *"all grading shall be done in a manner to control erosion and siltation of the affected lands, to protect areas outside the affected land from slides and other damage. If not eliminated, all highwalls shall be stabilized* (Colorado, 2010)."

3.4.4 Milling Best Management Practices

3.4.4.1 Effluent Control and Monitoring

Colorado, Wyoming, Washington, and the NRC do not allow for the discharge of mill process water. The State of Washington requires that "*…as part of the milling process the operator needs to provide a plan for the control of effluent and monitoring. The licensee shall establish a detection monitoring program needed to establish the groundwater protection standards in subsection"* (WAC 246-252-030 Subsection8). It is standard practice for excess process water to be disposed via evaporation ponds, or through active evaporation such as the use of sprayers.

3.4.4.2 Ore and Tailings Characterization

The ore and tailings need to be characterized for both geochemical and geotechnical properties. The host formation and ore commonly have elevated risks of leaching chemical constituents, and may result in ARD. The quantification of these properties is addressed in Section 2. The geotechnical nature of the ore and tailings should be addressed for construction of tailings impoundments and heap-leach pads. The strength and permeability of these materials is considered during the design process. See discussion in Section 3.7.

3.4.4.3 Dust Control

During operations it is required that the operator reduce the amount of dust by instituting appropriate controls. Colorado requires that the tailings should be placed so that *"topographic features... provide good wind protection"* in Appendix A, Criterion 4B (CDPHE, 2011). Active dust control is commonly accomplished by placing sprayer bars on conveyors and maintaining a wet tailings and heap-leach pad surface. During placement of tailings, a beach normally forms. At times during operations, the beach area dries and results in the potential for windblown tailings. To counteract the potential for windblown tailings from the beach, operators frequently place sprayers on the tailings beach to keep the surface moist.

3.4.5 Tailings Control

Tailings are generally contained in an impoundment or heap-leach pad, both of which should be designed using engineering principals and expert judgment. As part of the design process, geotechnical data needs to be collected. The State of Washington states that *"the technical site investigations phase shall consist of, but not be limited to, the following: (a) Soil characteristics; (b) Hydrologic characteristics; (c) A local and structural geology evaluation, including seismic conditions and related geotechnical investigations; (d) A surface water control analysis; and (e) A slope stability analysis"* (Washington 1994b in; RCW 78.56.090, Subsection (4)). It is generally left to the reviewing agency to determine if the geotechnical investigation is adequate.

Laboratory testing of the soil and rock samples collected during the geotechnical investigation generally includes strength testing of the material to be used to construct the impoundments; consolidation/swell testing of the underlying soils, and permeability testing of the underlying soils and the material to be placed in the tailings impoundment or on the heap-leach pad. Wright Environmental Services did not find any specific regulations dictating how much soil and rock testing need be completed or what samples need to be tested. The amount and type of testing is generally left to the design engineer and reviewing agency. However, the reviewing agency ensures that a satisfactory amount of samples have been tested to allow for adequate design.

3.4.6 Tailings Cell Design for Operations

Prior to about 1970, many tailings impoundments were constructed without liners. This method of construction of tailings impoundments resulted in long-term environmental impacts. Currently the design and installation of liners and leak detection systems is standard practice for tailings impoundments and heap leach pads. The state regulations reviewed (Colorado, Washington, and Wyoming) and the NRC requires that the applicant design a lined impoundment or heap-leach pad with a leak detection system. Washington State requires that tailings facilities be constructed with liners and leak detection systems. The design of these systems is to be provided in an engineering design report (Washington 1994b in RCW 78.56.100, Subsection (1)(a)(ii)); (CDPHE, 2010 in, Appendix A, Criterion 5A);(NRC 10 CFR, in Part 40 Appendix A).

The location of the tailing impoundment is also important. The State of Washington states that*"...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 groundwater;

(c) topographic setting;

(d) identifiable adverse geologic conditions, such as landslides and active faults; and

(e) visibility impacts of the public generally and residents more particularly." (Washington 1994, RCW 58.56.090)

As part of the design process, it is also common practice to complete slope stability analyses of the impoundments and heap-leach pads. Washington State requires that slope stability analyses be completed (Washington, 1994b) in RCW 58.56.090. Slope stability analyses should be completed using the seismic standards outlined in our Engineering Design BMPs.

As part of the design of tailings impoundments, seepage analyses need to be completed to insure the stability of the embankment. We did not identify any standards from the states of Colorado, Washington, Wyoming, or the NRC that provide guidance related to the completion of seepage analyses.

During operation and construction of a tailings impoundment or heap-leach pad it is important to complete inspections. The construction quality control is important for the long-term function of the tailings impoundment or heap-leach pad. The NRC requires that the applicant submit a construction quality assurance (QA) plan.

To reduce the potential for failure of the tailings impoundment, the CDPHE requires that *"The mill operator shall conduct at least daily inspection of any tailings or waste retention systems"* (CDPHE, 2011). Records of the inspections are to be maintained for review by the CDPHE.

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

3.4.7 Closure/Waste Disposal

As part of the application process, it is required by the NRC and the states of Washington, Wyoming, and Colorado, that a reclamation plan be submitted to ensure that a site can be reclaimed. Washington State requires that *"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"* ([Washington,1994b] in RCW 78.56.100, Subsection (1)(b)(iii)). Agencies also require that, *"The permit holder shall reclaim each segment of the mine within two years of completion of* *surface mining on that segment except as provided in a segmental reclamation agreement approved in writing by the department*" ([Washington, 1994b] in RCW 78.44.111).

The CDPHE states that "*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)*" (CDPHE, 2011) in Appendix A, Criterion 3. While disposal of tailings below grade is the "prime option" for the regulatory agencies referenced in this section, this is not always possible.

Closure of the tailings impoundment involves dewatering and cover design. The dewatering of the tailings should be completed prior to the installation of the cover system. Seepage analyses of the tailings should be completed to estimate the length of time that it will take to develop a stable tailings surface, such that a final cover with radon barrier can be constructed. Historically, tailings have taken as long as decades to consolidate, due to large amounts of clay-sized material and residual water in the associated materials.

The CDPHE states that the final tailings cover should be of 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" (CDPHE, 2011) in Appendix A, Criterion 6. This is in agreement with NRC Regulatory Guide 1623. The final cover design normally involves radon attenuation analyses, erosional stability evaluations, infiltration and stability analyses, and review of the potential intrusion of plants through the cover.

The radon attenuation analyses are commonly completed using the NRC radon program. Washington State requires that "licensees shall place an earthen cover (or approved alternative) over tailings or wastes at the end of milling operations and shall close the waste disposal area in accordance with a design which provides reasonable assurance of control of radiological hazards to: limit releases of Radon-222 from uranium by-product materials, and Radon-220 from thorium by-product materials, to the atmosphere so as not to exceed an average release rate of 20 picocuries per square meter per second (pCi/m^2s)"(per WAC 246-252-030 Subsection 6). The State of Washington requirements are in keeping with the NRC radon guidance in Regulatory Guide 3.6 (NRC, 1989).

Erosion control of the tailings cover is maintained by "*a full, self-sustaining vegetative cover [that] must be established or rock cover employed to reduce wind and water erosion to negligible levels*" ([CDPHE, 2011] in Appendix A, Criterion 4D). However, it is difficult to ensure that a vegetative cover will remain during the life of the impoundment. Thus, erosion analyses is commonly completed using the NRC guidance for determining final rock size and filter criteria for the cover system to reduce the potential for erosion as specified in NRC Regulatory Guides (NUREG) 1623. However, even when the NRC criteria are used, erosion of the soil covers has occurred. To reduce the potential for erosion it is important to require that a filter layer be installed under the rip-rap.

Washington and Colorado also recommend that: "*Upstream rainfall catchment areas must be minimized to decrease erosion potential and the size of the probable maximum flood which could erode or wash out sections of the tailings disposal area*," specified in WAC 246-252-030 Subsection, (3)(a), and (CDPHE, 2011) in Appendix A, Criterion 4A.

To reduce long term leaching from tailings, a zero infiltration cover system is generally required. Washington State requires that *"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"* (Washington, 1994b) in RCW 78.56.100, Subsection (1)(b)(iii). The amount of infiltration through the cover can be analyzed by completing unsaturated flow analyses using local climate data.

Final stability analyses of the tailings impoundment and cover system are completed using the NRC-specified seismic evaluation period of 10,000 years.

Intrusion of plants and animals through the cover has been an issue at many closed tailing facilities. The burrowing of animals has been addressed by the placement of suitable rock on the surface of the cover. A capillary break is normally installed in the cover system to reduce the potential for water to penetrate the radon barrier. Frost also has the potential for weakening the radon barrier; the barrier needs to be placed below frost depth. The Army Corps of Engineers has developed software to determine frost depth (Aitken and Berg, 1968).

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

Long-term care of waste from a closed and reclaimed mill historically has been turned over to the DOE:

"*The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation. As a minimum, annual site inspections must be conducted by the government agency retaining ultimate custody of the site where tailings or wastes are stored, to confirm the integrity of the stabilized tailings or waste systems, and to determine the need, if any, for maintenance and/or monitoring. Results of the inspection must be reported to the United States Nuclear Regulatory Commission within sixty days following each inspection. The United States Nuclear Regulatory Commission may require more frequent site inspections if, on the basis of a site-specific evaluation, such a need appears necessary, due to* *the features of a particular tailings or waste disposal system*" (Specified in WAC 246-252-030 Subsection, (12)).

3.5 Mitigation of Mine and Mill Contaminants from Existing Sources to Both Groundwater and Surface Water

3.5.1 Introduction

Sections 2.0 through 4.0 describe methods: to identify rock which may generate ARD or metals-bearing leachates when mined and exposed to oxygen and moisture at the surface; selective handling plans for segregating reactive rock from less reactive and non-reactive rock; and BMPs to inhibit the mobilization and offsite transport of radionuclides and other contaminants from storage facilities at mining and milling operations. One of the objectives of mine/mill development plans, plans of operations, and closure plans should be to utilize the information generated from these types of studies to minimize the generation of radionuclide and metal-bearing leachates within mine and mill facilities storing ore, processed ore or mine rock storage facilities.

The objective of this section is to consider mitigation of contaminants from various facilities storing ore, processed ore or mine rock storage facilities at mines and mills. The term *"mitigation"*, as defined in the Revised Washington Code (RWC), Title 78, Chapter 56 (Metals, Mining and Milling Operations) means: *"(a) To avoid the adverse impact altogether by not taking a certain action or parts of an action; (b) to minimize adverse impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology or by taking affirmative steps to avoid or reduce impacts; (c) to rectify adverse impacts by repairing, rehabilitating, or restoring the affected environment; (d) to reduce or eliminate adverse impacts over time by preservation and maintenance operations during the life of the action; (e) to compensate for the impact by replacing, enhancing, or providing substitute resources or environments; or (f) to monitor the adverse impact and take appropriate corrective measures."*

In the context of this discussion, it is assumed that the proposed mine/mill has been approved and that definition (a) is not applicable.

3.5.2 Overview of Existing Regulations

The NRC information relevant to "mitigation" with respect to tailings impoundments is provided in NRC 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. Specifically, Technical Criterion 5D in Appendix A indicates that applicants should consider, among other things:

- solution recycling to reduce net input of liquid to the tailings impoundment;
- dewatering of tailings to reduce the head within the impoundment; and
- neutralization to promote immobilization of hazardous constituents.

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

Wyoming regulations that set forth environmental protection performance standards applicable to noncoal mines are provided by the Wyoming Department of Environmental Quality, Land Quality Division – Noncoal Program (WYLQD-NC, 1994). The WYLQD-NC Chapter 3, Section 2 states:

"(h)Tailings impoundments, tailings disposal areas, heap leach facilities, and spent ore disposal areas, excluding uranium mill tailings facilities regulated by the United States Nuclear Regulatory Commission.

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

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

Colorado's mitigation regulations parallel those provided by the NRC. Specifically, Colorado's 6 Code of Colorado Regulations [CCR] 1007-1, Part 18: Licensing Requirements for Uranium and Thorium Processing contains Appendix A *Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes from These Operations*. Appendix A of the

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

RWC, Title 78, Chapter 56 (Metals, Mining and Milling Operations), Part 100(1)(a)(ii) states: "*The toxicity of mine or mill tailings and the potential for long-term release of regulated substances from mine or mill tailings shall be reduced to the greatest extent practicable through stabilization, removal, or reuse of the substances*."

Some conceptual BMPs are provided below. These BMPs are presented for various phases in the mine/mill life cycle: Site Preparation/Construction; Operations; and Closure. The BMPs were based on information from the NRC and the States of Wyoming, Colorado and Washington. Additional international sources are also cited.

3.5.3 Site Preparation/Construction Phase

The potential for leachates to be generated during the development phase of a mine are low and, for a mill site, likely minimal. The exceptions are if pre-stripping of overburden is performed for an open pit mine and exposes mineralized material, or if driving of tunnels, shafts, etc. for an underground mine exposes mineralized material. Additionally, development of borrow sources for construction purposes (e.g., roads, foundations) could expose mineralized material, or the construction material itself could be mineralized.

Because the potential to create mine/mill contaminants during the mine development phase are low, opportunities to physically mitigate contaminants are minimal. Therefore, the focus at this stage should be on the collection and incorporation of additional site-specific data into the design and construction of engineered structures, revision of site models, and continued enhancement of BMPs. Specific areas of focus should include:

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

- As the mine/mill design continues to be optimized, the site water balance should be updated.
- With respect to pre-stripping or tunneling operations performed in *preparation* for mining, BMPs for the following could be considered to mitigate mine contaminants:
  - General construction BMPs to inhibit the generation of potentially contaminant-bearing sediments, dust; and
  - Surface water control to limit the volume of "run-on" water from adjacent up gradient areas. The run-on control features should be sized to control water generated by a precipitation/flood event that is linked to the duration of the preparation/construction phase.

Groundwater control may be required depending on the extent of the stripping or tunneling. From an environmental standpoint, the goal of the groundwater control should be to minimize the contact of groundwater with mineralized surfaces exposed by the stripping/tunneling. If the groundwater controls involves pumping, then a monitoring program to document the quality of the produced water will be required.

A management plan for contact water generated from incident precipitation and seepage, including quality monitoring, may be required.

Waste rock generated by the stripping or tunneling will be disposed at appropriate locations or, where the chemical, radiological and physical characteristics of the material are appropriate, used for construction purposes at the site.

With respect to the *development* of onsite resources (mining) for construction purposes (borrow materials), BMPs for the following could be considered to mitigate potential contaminants at mine or mill sites if the borrow mining exposes mineralized rock:

- general construction BMPs to inhibit the generation of potentially contaminant bearing sediment, dust, etc; and
- surface water control to limit the volume of "run-on" water from adjacent up gradient areas. The run-on control features should be sized to control water generated by a precipitation/flood event that is tied to the duration of the (borrow) mining.

Groundwater control may be required depending on the extent of borrow mining. If the groundwater control system involves pumping, then a monitoring program to document the quality of the produced water will be required.

A management plan for contact water generated from incident precipitation and seepage, including quality monitoring, may be required.

Waste rock generated by the mining will be disposed at appropriate locations.

The chemical and radiological characteristics of borrow material should be factored into its construction application.

3.5.4 Operations Phase

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

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

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

Measures can also be included in the operations plan to limit water infiltration into facilities storing ore, processed ore or mine rock storage facilities at mines and mills. The use of interim covers and other engineering controls should be encouraged to reduce the volume of leachate generated. The use of interim covers may have ancillary benefits by controlling dust and decreasing radon flux.

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

3.5.5 Closure Phase

During the *closure phase*, the goal of the permit should be on quickly transitioning the facility from active management to passive management. The objectives of the closure plans with respect to mitigation of contaminants from waste rock piles, tailings impoundments, etc. should include:

- dewatering tailings, if appropriate, to minimize long-term water treatment obligations and to enhance tailings consolidation (which expedites capping);
- reducing the volume of leachate generated by decreasing both the short and long-term infiltration into waste rock piles, tailings impoundments, etc;
- to the extent practicable, decreasing the concentration of metals, radionuclide activity, acidity, etc. of the leachate by manipulating the geochemical conditions within the waste rock piles, tailings impoundments, etc;
- transitioning treatment of leachate (if necessary) from active to passive;
- as the mine/mill progresses through the closure process, the site water balance should be updated; and
- ongoing monitoring and refinement of the closure plan (adaptive management).

Depending upon the type of tailings, active dewatering during the closure phase may expedite both the transition from active to passive water treatment (if required) and the capping of the pile. As previously discussed, the permitting process must recognize that each milling process is unique and should provide the operator the flexibility to propose to manage tailings (and water) in a variety of ways that all arrive at the same goal – protection of human health and the environment.

Preparation of the waste rock piles, tailings impoundments, etc. for covering should begin as soon as practicable. This may include grading and dewatering/consolidation, as previously discussed. The sooner the cover is constructed, the lower the volume of water entering the pile and the lower the volume of leachate generated.

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

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

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

4.0 EVALUATE METHODS TO INCORPORATE "AS LOW AS REASONABLY ACHIEVABLE" STANDARDS INTO COMMONWEALTH REGULATIONS

4.1 Overview of the As Low As Reasonably Achievable Principle

The As Low As Reasonably Achievable (ALARA) Principle is based on the assumption that any increment in radiation dose carries with it a commensurate increase in risk of detrimental effects, including cancer and genetic abnormalities, i.e., linear-non-threshold assumption (L-N-T). There is no precisely equivalent concept for exposures to chemicals, particularly those for which there is a threshold for adverse health effects. However, the American Conference of Governmental Industrial Hygienists (ACGIH) adopted the principle that occupational exposures to hazardous airborne materials should be kept As Low As Practicable (ALAP). The British government incorporated the principle that exposure to workplace hazards must be kept As Low As is Reasonably Practicable (ALARP) into workplace safety requirements. The term "Chemical ALARA" has been adopted by some to describe the policy and methods for keeping exposures to hazardous materials as low as reasonably achievable. While the ALARA principle and regulation is applicable specifically to radiation exposure, the principles and methodology can be used as a model for protection of workers and members of the public with regard to other hazardous exposures. Implementation of specific regulations requiring programs for keeping non-radiation hazards to workers and members of the public ALARA may be problematic since there are no federal regulatory precedents; however, incorporation of such requirements into licenses and permits is certainly feasible. It is important to note that the development and enforcement of license conditions would be within the purview of either the NRC or Virginia, depending on its Agreement State status. The metrics for determining compliance with ALARA requirements would need to be established, e.g., fraction of the exposure or concentration limit that would constitute a constraint for a specific situation or practice.

4.1.1 Development of the As Low As Reasonably Achievable Principle

The International Commission on Radiological Protection (ICRP) in recognition of the fact that there may not be a threshold for stochastic effects of radiation (e.g., cancer) advised that "every effort be made to reduce exposures to all types of ionizing radiation to the lowest possible level" (ICRP, 1955). The recommendation was modified over subsequent years and ICRP publications. The concept of keeping radiation doses ALARA with economic and social factors being taken into account was introduced by the ICRP in 1977 (ICRP, 1977) in its radiation protection recommendations as one of the three principles of radiation protection and dose limitation.

- Justification: No practice shall be adopted unless its introduction produces a positive net benefit.

- Optimization: All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.
- Limitation: The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

The system of optimization and dose limitation was further defined in subsequent ICRP publications (ICRP, 1989; ICRP, 1990; ICRP, 1997; ICRP, 2004; ICRP, 2006a; ICRP, 2006b) culminating in the 2007 Recommendations of the ICRP (ICRP, 2007a; ICRP, 2008). The concept of dose constraints for occupational exposures was introduced in the 1990 recommendations of the ICRP (ICRP, 1990) without specifying numerical values and with no discussion of constraints for public exposures.

The basis for the ALARA principle is the assumption that the risk from radiation is a function of the dose with no threshold. Optimization is defined as the "*source-related process to keep the likelihood of incurring exposures … the number of people exposed, and the magnitude of individual doses as low as reasonably achievable, taking economic and societal factors into account.*" (ICRP, 2007a). The process, as defined by the ICRP (ICRP, 2007a), involves evaluating the exposure situation, selecting an appropriate constraint or reference level, identifying possible protection options, and selecting and implementing the best option.

4.1.2 International Commission on Radiological Protection 103 Recommendations for Implementing As Low As Reasonably Achievable

The ICRP in Publication 103 (ICRP, 2007a) re-enforces the principle of optimization with restrictions on individual doses through dose and risk constraints in planned exposure situations and reference levels for emergency and existing exposure situations. Planned exposure situations include those associated with current mining and milling activities. The recommendations for existing exposure situations would include those associated with previous uranium operations and natural background. The dose constraint is intended to be determined during the planning process. It is a source-related, prospective restriction on individual doses below the dose limit. As Low As Reasonably Achievable or optimization would apply at levels below the dose constraint.

4.1.3 U.S. Nuclear Regulatory Commission Considerations in Implementing As Low As Reasonably Achievable

The NRC regulations require that licensees use, "to the extent practical, procedures and engineering controls" to achieve worker and public doses ALARA (10 CFR 20.1101 (b)). Regulatory Guide 8.31 provides guidance for uranium recovery facilities in how to implement programs to keep doses ALARA (NRC, 2002a).

The NRC (NRC, 2012b) has reviewed and provided comments on ICRP Publication 103 (ICRP, 2007a). The NRC staff recommended that the system of constraints, as described in Publication 103, not be adopted into regulations. Stakeholders expressed concern that constraints could become de facto limits noting "ALARA cannot be a one-size-fits-all requirement." The NRC staff concluded that adopting the ICRP recommendations for ALARA planning would result in a prescriptive set of requirements that would be difficult to implement and would not guarantee that doses would be reduced, and that it would be difficult to establish a system across the NRC and Agreement States in a "consistent and transparent manner." The staff concluded that the NRC could develop additional guidance for implementing ALARA based on industry experience.

4.2 Potential Role of Constraints for Uranium Industry to Implement As Low As Reasonably Achievable

Discussions of dose constraints should be centered around the system of radiation protection for planned exposure situations as contrasted with existing exposure situations. Previous ICRP recommendations referred to these situations as "practices" and "intervention." In existing exposure situations, optimization needs to ensure that the intervention does more good than harm. While the NRC, at least for the present, has declined to adopt constraints into regulations, Agreement States, presumably would be free to add constraints to their regulatory schemes since they would be more stringent than NRC regulations. Alternatively, such provisions may be incorporated into license and permit conditions for uranium recovery facilities.

Regulatory dose limits for the general public for uranium mills (25 mrem per year [mrem/yr] to any organ (excluding radon) (40 CFR 190)) are lower than the dose limit for the general public in 10 CFR 20.1401, i.e., 100 mrem/yr including radon. The applicability of the 100 mrem/yr dose limit for members of the public has been re-affirmed by the ICRP as providing "an appropriate level of protection" (ICRP, 2007a,b).

4.3 Agreement State Incorporation of As Low As Reasonably Achievable Into Regulations

Agreement States have incorporated ALARA into regulations consistent with NRC regulations. No other specific state regulatory guidance for implementing ALARA has been identified. However, states, such as Colorado, have incorporated specific ALARA requirements into license conditions. For example, the Colorado Radioactive Materials License for Cotter Corporation required that new administrative offices be constructed outside of the restricted area such that potential doses to persons working in the office and members of the public would be ALARA.

Agreement States and the NRC require uranium mill licensees to submit an annual ALARA Audit Report through their license conditions. The non-specific 10 CFR 20.1101 (c) regulation requiring an annual review of the radiation protection program is applicable to all licensees. The content of the ALARA Audit for uranium recovery facilities is defined in Regulatory Guide 8.31 (NRC, 2002a) and is generally specified as a license condition.

4.4 As Low As Reasonably Achievable for Hazards Other Than Radionuclides

The ALARA Principle is applied specifically to radionuclides and its rationale is based on the L-N-T assumption with regard to radiation protection. It has no exact corollary in industrial hygiene or general industrial safety. However, there are guiding and, in some cases, legally binding provisions in other fields that are similar such as the ACGIH Threshold Limit Values (TLVs) whereby exposure should be kept ALAP (ACGIH, 2012) and the British requirement that all hazards be maintained ALARP (HSE, 2012; NSW TRC, 2011).

While ALARP appears to apply only to physical safety, the principle may serve as a model for similar requirements applicable to uranium recovery facilities. ALARP has two key elements (NSW, 2011):

(1) "*All efforts should be made to reduce risks to the lowest level possible until the point is reached where the cost of introducing further safety measures is grossly disproportionate to the safety benefit that would be achieved*."; and (2) "*A risk should be tolerated only if it can be demonstrated that there is a clear benefit in doing so*."

The ALAP and ALARP principles apply to workers and do not appear to be applicable to the general public. In fact, the ACGIH makes a clear point that the TLVs should not be interpreted to be a "safe" level and are not to be applied to members of the public.

The Occupational Safety and Health Act includes a general duty clause that requires industry to mitigate recognized hazards to workers. The General Duty Clause (Section 5(a)) requires that employers "*furnish employment and places of employment which are free from recognized hazards to the health and safety of their employees.*" The clause encompasses exposures that are not covered by a specific regulatory standard.

For members of the public, the specific radioactive materials license or mine permit is the most reasonable vehicle for a clause similar to ALARA for non-radiological potential hazards to human health or the environment. Regulations often include provisions that "best practices" must be used to control releases of hazardous materials.

4.5 Recommendations

4.5.1 Dose Constraints

Dose constraints may incorporate enforceable limits for workers in site-specific licenses, but not in general radiation protection regulations applicable to all licensees. Typical radiation doses in the uranium recovery industry are in the range of 200 to 500 mrem/yr. License conditions could set constraints in that range. For some uranium facilities, the doses can exceed those levels, particularly where high-grade ore is processed. Such situations can be addressed if the emphasis is on constraints in licenses or permits. Exceeding the constraint would require a formal plan on the part of the licensee to reduce doses and prevent future occurrences.

4.5.2 Radon Decay Product Exposure Limit

The principle source of radiation dose to underground miners is inhalation of radon decay products. A reasonable constraint on the radon decay product exposures to miners in mining regulations would be the National Institutes of Occupational Safety and Health (NIOSH) Recommended Exposure Level (REL) of 1 working level month per year (WLM/y) (NIOSH, 1987). The NIOSH Report indicates that an exposure limit of 1 WLM/y is feasible under modern mining conditions.

4.5.3 Existing Radiation Dose Limits for Members of the Public

The existing regulatory radiation dose limits and constraints for members of the public are adequately protective and reasonable. The constraint for dose to an identifiable member of the public from airborne particulate radionuclides is 10 mrem/yr (10 CFR 20.1101(d)). By comparison, the ICRP recommended constraint for public for prolonged exposure to long-lived radionuclides is 30 mrem/yr (ICRP, 2004).

The EPA radiation dose limits for members of the public from underground uranium mines and uranium mills are already more restrictive than the NRC dose limit of 100 mrem/yr (10 CFR 20.1301) for members of the public from other types of facilities such as hospitals, universities, and research facilities. Specifically underground mines are covered by National Emission Standards for Hazardous Air Pollutants (NESHAPS) (40 CFR 61.22) with a limit of 10 mrem/yr from radon decay products; and uranium mills under (40 CFR 190.10), 25 mrem/yr to the whole body or any organ (excluding dose from radon). These dose limits would be applicable even if Virginia becomes an Agreement State. Therefore, there is no need for a separate constraint limit on radiation doses to members of the public from uranium milling facilities.

4.5.4 As Low As Reasonably Achievable for Chemical Exposures

It is not practical to specify ALARA constraints for chemical exposures. Such constraints must be set based on the specific chemicals used and types of exposures for a particular facility. However, the requirement in 10 CFR 20 that the licensee develop and implement an ALARA program for radiation exposures should be expanded in the mill license or mine permit to include chemical exposures. In practice, “action levels” are generally set for airborne concentrations of hazardous materials at levels below the TLVs incorporated by reference into MSHA and OSHA regulations. Licensees often establish ALARA Review Panels consisting of representatives from the full range of site workers. The function of the panel is to routinely inspect plant operations, review compliance with the license conditions and suggest ways to reduce radiation doses. The function of the ALARA Review Panel could be expanded to include chemical hazards or a similar panel for risks other than radiation could be established.

Virginia regulations and license or permit conditions should emphasize the applicability of the ALARA requirement to environmental releases of hazardous materials not just radiation doses and human health risks.

5.0 DEVELOPING RECOMMENDATIONS FOR ENVIRONMENTAL MONITORING

Environmental monitoring, performed well, is arguably one of the most important elements in a public radiation protection program. A well-designed and properly implemented program provides assurance that unexpected or accident-related changes in environmental concentrations of toxicants associated with a facility's operations will be detected early. This allows for quick response by the facility operator, the regulatory agency and a local citizens committee charged with assisting in regulatory oversight of facility construction, operation, shutdown and ongoing monitoring.

A uranium extraction facility potentially includes a large open pit and/or underground mining operation, and a milling facility (processing ore in liquids to extract uranium). A modern facility will include a large impoundment of paste (partially de-watered) mill tailings (very finely divided processed ore with uranium largely extracted but all other uranium-decay-chain radionuclides present, with other toxicants including solvents potentially present). All materials that may be identified as precursors to some health effect must be monitored in the offsite environment. This monitoring includes pre-operational, operational, post-operation shutdown, and long-term (decades to centuries) surveillance. Such monitoring includes all potential sources of these materials, including the mines, ore piles, waste rock areas, and the mill and tailings facilities. Facility monitoring is performed at the source (the mines, mill and tailings area); environmental monitoring at the site boundary (defined in the radioactive materials license) and at sensitive locations outside the boundary (such as a home or homes in the dominant wind direction). This Section evaluates the requirements for a suitable environmental monitoring program.

An environmental monitoring regulatory guidance document involves definition of both general and site-specific conditions, and is designed to cover both routine and accidental releases. The existing NRC and State regulatory system provides a structure for the identification of toxicants, minimum detectable concentration targets for specific media, and recommendations concerning types and placement patterns for the monitoring system. This report, other reports being developed under the contract supporting this work for the VDH, documents developed under contract with the DEQ, and regulations or guidance including the Clean Air Act, 40 CFR Part 61 (NESHAPS radon) and others, provide material supporting the development of a monitoring program. The NRC's Regulatory Guide 4.14 (NRC, 1980) is specific to uranium milling (and considers uranium mining to a very limited extent), and is the primary focus of this Section.

Helpful to this discussion are recent implementations of the Regulatory Guide 4.14, as found in license applications that have resulted in radioactive materials licenses for potential facility operators. These applications and the resulting licenses display current NRC and State regulatory thought concerning adequate environmental monitoring. These applications and licenses are based on Regulatory Guide 4.14 and other regulations and guidance, but are also based on careful reviews by new applicants of successful applications, licenses and actual monitoring programs. Such programs include those in place, for example, at existing facilities such as Crow Butte, Nebraska; Highlands, Wyoming; Cotter Corporation, Colorado; White Mesa, Utah; and Palangana, Texas. They provide solid "guidance by example" as to what Federal and State regulators currently think comprises an adequate environmental monitoring program. Material covering these and other existing, new or planned environmental monitoring programs has been reviewed for the preparation of this report, and has resulted in the development of many of the recommendations presented here.

Virginia, if uranium extraction is eventually authorized, may become involved in the development of the first license application including monitoring programs specific to eastern U.S.: climate, geography, surface/subsurface characteristics, crop, population and other important variables. We briefly outline in this Section the existing environmental monitoring guidance as specified in Regulatory Guide 4.14 and elsewhere, noting recommendations to bring the guidance up to date and more specific to the eastern U.S. environment.

The goal of this Section is to help develop a monitoring program adequate for the Virginia environment. To provide context for recommendations provided here, we include examples of NRC Regulatory Guide 4.14 guidance, condensed and highlighted via text boxes.

Site-specific considerations in Virginia would drastically affect the details of any environmental monitoring program. Meteorological and other data are used during licensing to convert general environmental monitoring recommendations into specific monitoring plans for a proposed facility. Examples of such data include wind patterns, storm potential and influence of terrain, ground and surface water resources and flow patterns. Crops grown within the region of potential crop contamination by facility releases, and the locations of communities and specific residences near a facility, including their food and water supplies, are used during licensing to convert general environmental monitoring recommendations into specific monitoring plans for a proposed facility.

Regulatory Guide 4.14 was originally issued for public comment in 1977, when conventional uranium mills dominated the industry. The Guide notes that environmental monitoring data are needed for the following purposes:

- to estimate maximum potential annual radiation doses to the public from effluent releases;
- to determine whether the regulatory requirements, including the 10CFR20 dose limits, release limits and ALARA requirements, and the requirements of 40CFR190 (Environmental Radiation Protection Standards for Nuclear Power Operations) have been met;

- to evaluate the performance of effluent controls, including tailings pile controls;
- to evaluate the impact of milling during operations and after decommissioning; and
- to establish baseline data to evaluate decommissioning, or the impact of unusual events.

A characteristic of the NRC Guidance Documents is demonstrated in the Regulatory Guide 4.14 "*Individual applicants or licensees may propose alternatives for new or existing monitoring programs that need not necessarily be consistent with this guide.*" In other words, site-specific or unusual conditions may cause an applicant to propose different approaches to meeting the data needs.

The 23-page Regulatory Guide 4.14 is concise enough to be read quickly as its own "summary". We focus here on specific content and concepts which are either sufficient as written to monitor for routine and accidental releases, or which should be modified.

The key aspects of a uranium extraction facility environmental monitoring plan involve the monitoring of:

- air;
- ground and surface water;
- vegetation and domestic food animals;
- soil and sediment;
- direct radiation; and
- meteorological data collection.

The Commission is revising NRC Regulatory Guide 4.14 as this report is being written. The Guide currently focuses on conventional uranium mills; our discussions with NRC staff indicate that the revision is likely to divide the guidance into three sections:

- conventional uranium mills;
- heap-leach uranium mills; and
- In Situ Recovery (ISR) facilities.

The sampling program outlined in the current version of the guide is separated into two parts: preoperational or baseline monitoring and operational monitoring. Baseline data are submitted to the NRC as part of the license application process; much of the operational monitoring program will then build on that database, including continuation of monitoring at many of the same locations. This poses problems for applicants and issues for the Regulator. The selection of preoperational monitoring locations is usually based on poor meteorological (met) information, for example, and it is often the case that installation of a good onsite met station eventually leads to data indicating that the original monitoring locations were not correctly chosen. A great deal of unnecessary effort by both the applicant and the regulator can be avoided by early and careful selection and placement of met monitoring gear.

Because members of the WES team have observed both poor instrument selection and poor met station location during uranium facility licensing work in recent years, WES begins this discussion with a few recommendations emphasizing the importance of early and competent selection of the meteorological monitoring station location(s). Recommendations are provided later in this Section concerning met station instrumentation, but selection of a station location is best done at the site, by an expert. Selection should be facilitated by review of data from nearby met stations, detailed topographic maps, and airflow modeling if the site is complex topographically.

Recommendation: Installation of a well-designed met station(s), carefully sited, should be encouraged via regulatory guidance to be a top priority in the license application data collection process.

Recommendation: An early site visit by the regulatory authority should be suggested in Virginia guidance documents to facilitate joint discussion of applicant-proposed met monitoring instrumentation and siting.

Recommendation: A monitoring program acceptable under Regulatory Guide 4.14 collects at least 12 consecutive months of preoperational data. Given uncertainty in the representativeness of a single year's worth of data, met data collection should proceed for two years prior to licensing. Other data sources, for example nearby first order weather station data sets, should be compared statistically to the meteorological information being developed onsite, to look for indications of similarity or divergence. Favorable comparisons can be a powerful indication that chosen air particulate monitoring or food source locations, for example, are valid.

6.0 MEDIA SPECIFIC ENVIRONMENTAL MONITORING RECOMMENDATIONS

6.1 Air Particulate and Radon Monitoring

Regulatory Guide 4.14 guidance is essentially identical for preoperational and operational air sampling. The purpose of sampling, at a co-located set of facilities, is to estimate releases of particulate radionuclides from all potential mine, mill, and tailings impoundment sources. These include mill stacks, ore piles (suspension by wind), crushing and grinding operations, and transfer systems including truck, loader and belt. They also include dust suspended by truck transport from an open pit mine, daily use of explosives to blast ore from the deposit into the mine pit, suspension by traffic or wind from roadways, and particulates released from underground mining activities.

Regulatory Guide 4.14 notes that air samples should be collected continuously, at:

- a minimum of three locations near the site boundary;
- a remote, background location;
- near a structure with the highest predicted airborne radionuclide concentrations due to milling operations; and
- near at least one structure in any area where predicted doses exceed 5 percent of the 40CFR190 standards.

Guidance is provided concerning selection of the air monitoring locations. The sampling should be adequate for the determination of Regulatory Guide-specified concentrations of natural uranium, Th-230, Ra-226 and Pb-210, and the Guide specifies Lower Limits of Detection for nuclides to be monitored.

Careful selection of the background monitoring location is particularly important. Influence from nearby roads or other sources can cause dust loading or high radionuclide readings compared to actual local background. A later determination that the wind patterns used to identify an upwind location were incorrect will cause relocation of the background station.

The need to monitor radon gas (Rn-222) at the above locations is also noted in the Regulatory Guide. At the time the Guide was written, monitoring for radon was a difficult and expensive process, requiring 110 volt line power and frequent visits to collect data printouts. A number of systems have since been developed to deal with this issue; Landauer provides a good current solution: The RadTrak® track-etch based integrating radon monitor. The unit is small and adequately sensitive, providing useful data to about 0.1 pCi/l when exposed for a three-month period.

Recommendation: Adequate radon concentration sensitivity is achieved using Landauer's most sensitive detector option, and maximum sensitivity is best supported using same-detector-batch background controls, available via discussion with Landauer technical staff when a RadTrak quarterly shipment schedule is first set up. Most environmental monitoring programs to date have not taken advantage of this option.

The NRC and various state agencies have accepted the results of the RadTrak unit for purposes of licensing; the instrument's sensitivity is adequate to understand the risks associated with long-term exposure to radon. The detector is not suitable for shorter-term measurements, unless at very high radon concentrations that should never be encountered in the public environment.

Radon detectors are placed at the same locations as the air particulate monitors.

Recommendation: Environmental air particulate sampling should take advantage of recent, energy-efficient computer-controlled air pumps and solar power systems. An example of such a system is shown below. Such devices can run continuously and reliably with no external power source, allowing placement in locations that were previously very difficult to monitor continuously.

Recommendation: The number and locations of continuous air and radon sampling stations should be determined based on factors in addition to those noted in Regulatory Guide 4.14, including nearby topography. Topography may channel effluents, causing unexpected concentrations in locations not predictable using simple modeling systems.

Recommendation: Air filters should be exchanged on a monthly rather than the weekly basis currently noted in the Regulatory Guide 4.14, after site-specific demonstration of system reliability. Reducing the effort associated with weekly filter exchanges encourages the placement of additional monitoring stations. This will reduce the possibility that "hot spots" in the environment may be missed by air particulate monitoring, only to be discovered later during soil, food crop or water source monitoring.

Recommendation: Sampling for Particulate Matter (PM_{10} and $PM_{2.5}$) (air particulate dust particle sampling) should be performed during licensing to establish background levels, and during operations and facility closure. Dust from mining, transport, milling and wind-driven suspension may create an offsite hazard.

Note: Please see Section 6 for a discussion of air particulate (dust) and other health hazards.

Note: $PM_{10/2.5}$ sampling must be performed using a second air sampling system; the radionuclide air particulate sampler will likely use a glass fiber filter from which all collected particulate material will be dissolved and analyzed. Sufficient excess power can be provided by solar-powered air samplers to allow parallel operation of other systems such as laser-outfitted particle capture and size analysis systems.

It is instructive, given the above observations, to observe current NRC positions related to air particulate and radon monitoring, in the case noted below for a western in situ leach (ISL) uranium mine/mill facility. The following material is taken from the NRC website. Note that the issues noted have been resolved and a NRC facility license has been issued.

The NRC Moore Ranch license application review comments related to air particulate sampling (quoted from the Moore Ranch License Application Safety Evaluation Report on the NRC web site):

"*Table 2 of Regulatory Guide 4.14 suggests that air particulate samplers should be installed at the following locations:*

- *near the site boundaries;*
- *in different sectors that have the highest predicted concentrations of airborne particulates;*
- *at the nearest residence or structure(s) that can be occupied; and*
- *in one control location, which should be in the least prevalent wind direction from the site.*

Air particulate sampling should be continuous with weekly filter changes and quarterly composite by location for natural uranium, radium-226, thorium-230, and lead-210 analysis. The applicant identified four air particulate sampling locations in … the technical report. The applicant shows the air particulate sampling locations … ; however, these locations are not identified by sector or distance. Descriptions of these locations are as follows:

- *MRA-1 - approximately 1.5 km (0.93 mi) from the CPP in the east-southeast sector*
- *MRA-2 - approximately 1.3 km (0.81 mi) from the CPP, bordering the northeast and east-northeast sector*
- *MRA-3 - approximately 2.4 km (1.49 mi) from the CPP in the south-southwest sector*
- *MRA-4 - approximately 2.5 km (1.55 mi) from the CPP in the west-southwest sector (control location)*

Based on the information provided, the staff does not concur with the sampling locations. According to the applicant, the predominant wind direction is from the southwest to west sectors, and the predominant wind directions from these sectors represents 40 percent of the total wind direction distribution annually. Considering this wind data, the staff does not concur with the *applicant's conclusion that location MRA-1 is well positioned to monitor potential airborne emissions from the site carried by winds from the west. MRA-1 is monitoring winds from the west-northwest sector not the west sector, which is not one of the three predominant wind directions.*

In addition, the staff does not concur with the applicant's conclusion that MRA-3 is well positioned to monitor potential airborne emissions from the north and north-northeast sectors. The staff determined that MRA-3 is monitoring winds from the north-northeast sector, which is not one of three. The staff cannot determine if MRA-3 represents the highest predicted concentration. The staff has determined that the wind from the north-northeast sector is also not one of the three predominant wind directions.

Typically, the highest predicted concentration would be that receptor point at the boundary between the controlled area and the unrestricted area. Furthermore, the three sectors with the highest calculated concentration would represent the highest predicted concentration and, thus, the proper location of air particulate sampling and co-location of other sampling medium. The applicant has not clearly defined the controlled areas and the unrestricted area, and, therefore, the staff has concluded that the applicant has not demonstrated that these air particulate sampling stations are in sectors representing the highest predicted concentrations. This failure to identify the locations of the three air particulate sampling stations in different sectors that have the highest predicted concentrations of airborne particulate warrants a license condition."

"*The applicant has also not identified an air particulate sampling location at the nearest residence or inhabitable structure. Failure to identify an air particulate sampling location at the nearest residence or inhabitable structure warrants a license condition…*"

"*The applicant will collect weekly air particulate samples and composite quarterly for analysis at a contract laboratory for natural uranium, radium-226, thorium-230 and lead-210. This frequency of collection and analytical parameters are consistent with Table 2 of Regulatory Guide 4.14, therefore, the staff finds this acceptable*."

The NRC Moore Ranch license application radon monitoring review comments (quoted from the Safety Evaluation Report):

"*Table 2 of Regulatory Guide 4.14 suggests that radon-222 sampling be conducted at five or more locations using the same locations used for air particulate sampling, except the analytical frequency should be monthly. The applicant identified 10 radon sampling locations in … the technical report; however, the applicant does not appear to have placed radon sampling stations at the same locations used for air particulate sampling. The staff has identified this issue as a license condition, and the license condition is discussed in … this SER.*

The applicant identified MR-1 as the control location; however, this location is not the same as MRA-4, which is a control location for air particulate sampling. Regulatory Guide 4.14 suggests colocating radon stations with air particulate stations. Colocating radon and air particulate sampling stations, as well as direct radiation and soil sampling, allows staff to evaluate all dose pathways for each sampling media at one location and determine the TEDE at that receptor point. TEDE determination, as defined by 10 CFR 20.1003, means the summation of all possible external doses and all possible internal doses. Sampling locations that are not colocated may result in different concentrations contributed from different sources (i.e., the well field versus the CPP) resulting in a partial TEDE. The staff has determined that the applicant needs to colocate all sampling media, as described in Regulatory Guide 4.14. The staff has identified this issue as a license condition, and the license condition is discussed in … this SER.

The applicant shows the air radon sampling locations in Figure 5.7-2; however, similar to the air particulate sampling stations, these locations are not identified by sector and distance. The staff cannot conclude that the applicant has placed the three site boundary radon gas samplers in locations that have the highest predicted concentrations of radon that is consistent with Regulatory Guide 4.14. Therefore, the staff cannot determine if the placement of the three site boundary radon gas samplers is acceptable. The staff has identified this issue as a license condition, and the license condition is discussed in… this SER."

In both the above cases, the NRC has identified issues related to the selection of air sampling locations. Early, site-specific met data would have made the selection of appropriate air particulate monitoring sites simpler and justifiable, saving Regulatory review time and effort.

6.1.1 Stack Sampling During Operations

Regulatory Guide 4.14 specifies that stack sampling should be isokinetic (sampled at the same flow velocity as the stack flow velocity), representative (care should be taken to sample all particle sizes, and sampling should cover the periods during which uranium air concentrations differ), and adequate for the release rates and concentrations of uranium, Th-230, Ra-226, and Pb-210 (if the latter three cannot be determined from other data). Other stacks should be representatively sampled at least semiannually, using methods adequate for the determination of release rates and concentrations of these four nuclides. All stack flow rates should be measured at the time of sampling, per the Regulatory Guide 4.14 which notes that effluents from the yellowcake dryer and packaging stack should be sampled at least quarterly during normal operations:

Recommendation: Stack monitoring should instead be continuous at key locations during the entire period of facility operations. Key locations are defined as those stacks, vents or other potential emission points from which particulates may be released during accidental events.

Given the likely use of vacuum-dryer options at future uranium mills, routine particulate emissions from dryer operations are now expected to be essentially zero. Releases during accidents, however, can be significant if, for example, a packaging system opens to the air, or a closed barrel pressurizes chemically and fails. Continuous monitoring will ensure that a valid estimate of the release quantity and particle size makeup will be available to quickly estimate environmental concentrations. This information, combined with an adequate, well-positioned air particulate monitoring program at the site boundary and key offsite residences, will be essential to the Regulator's determination of appropriate responses. Such responses may include immediate monitoring of offsite surfaces, vegetation, water supplies and air sampler filters for contamination, leading to recommendations including possible local food or water source interdiction.

6.1.2 Radon Flux

The Regulatory Guide 4.14 notes that radon flux measurements (measurement of the rate of radon gas emanating through soil surfaces) should be made in three separate months during normal weather conditions in the spring through the fall when the ground is thawed. Measurements should be made at the center of the milling area and at locations 750 and 1500 meters from the center in each of the four compass directions. The purpose of flux measurements is to establish the naturally occurring rate of radon release from undisturbed soils in the immediate vicinity of the planned tailings disposal area. These data are needed for later comparison to radon flux measurements from a closed and capped tailings cell.

Note: Various methods have been used over the decades to monitor radon flux. A current, adequate system involves placement of a ~12" diameter flat canister, containing prepared activated charcoal, for 24 hours on the soil surface. The monitors are then evaluated by a qualified laboratory within a short period (generally less than 24 hours), via gamma-radiation analysis.

6.1.3 Post-operation

Regulatory Guide 4.14 does not provide a discussion of post-operational monitoring, either during facility closure, which can require years of work, or post-closure, during the decades when continuing monitoring of closure effectiveness should be required. It is likely that this missing guidance will be covered in the revised version.

Recommendation: A complete Virginia program must include during-closure and long-term environmental monitoring for air particulates, radon, gamma radiation, soil and water systems, preferably continuing for many decades after closure. Monitoring should be performed in accordance with the Regulatory Guide specifications, enhanced per recommendations noted here, modified to reflect new data acquired during the facility lifetime and the mine, mill and tailings impoundment final sizes and conditions.

Recommendation: An adequately funded and properly staffed citizens committee could extend its monitoring expertise into the period following facility shutdown and final closure, given sufficient experience during facility construction and operation. With adequate supervision by the regulatory authority, such a committee could carry out many of the environmental monitoring functions for the post-closure period, greatly reducing Virginia staff travel requirements.

General note: The NRC's Regulatory Guide 4.14 applies to uranium mills and to most aspects of an ISR uranium mine. It does mention the need to coordinate some sampling with pre-mining activities, and our recommendations here emphasize the need for a complete mining environmental sampling program.

Recommendation: The same level of environmental monitoring effort, focused on the same radionuclides, should be expended in the monitoring of releases from nearby uranium mine facilities. There is no technical reason to consider, for example, radon released from a mine to be different in terms of risk than radon from a mill or tailings impoundment. Environmental monitoring specifications for a uranium mill should be applied to a nearby mine, underground or open pit. Samplers specific to the mine should be placed and operated using the same guidance as those used to monitor the mill.

6.2 Ground and Surface Water

Regulatory Guide 4.14 specifies that pre-operational (pre-op) groundwater sampling should occur quarterly from at least three wells down-gradient from the proposed tailings area, and one well up-gradient. Operational samples should be taken from these wells monthly through the first year of operation, quarterly thereafter. Pre-operationally, at least three locations near other sides of the tailings area should be sampled. The basis (data and modeling) for selection of the well locations should be presented when data are reported. Location of the wells should be determined by hydrological analysis of the potential movement of seepage from the tailings area. New wells, specific to this determination, are preferred over existing wells.

Per the Regulatory Guide, groundwater samples should be collected pre-op and during operations at least quarterly from all wells within two kilometers of the proposed tailings area, if the well is or *could be used* for drinking water, livestock or irrigation. Surface water samples should be collected quarterly from each onsite water impoundment such as a pond or lake, and any offsite impoundment that might receive seepage/drainage from tailings, potentially contaminated areas, or from impoundment failure.

Samples should be collected at least monthly pre-op and during operations from streams, rivers, any other surface waters or drainage systems crossing the site boundary, and any offsite surface waters subject to drainage as noted in the previous paragraph. Intermittent streams should be sampled when flowing. Samples should be collected at the site boundary or immediately downstream of the area of potential influence. During operations, any unusual releases (such as surface seepage) that are not part of normal operations should be sampled.

The suite of sampling recommended in the Regulatory Guide is historically based on uranium milling in the central-western states. Most locations exhibit much lower average precipitation rates and population densities than are seen in Virginia, with resulting lower likelihood of water contamination associated with uranium milling. Nonetheless, the Regulatory Guide 4.14's recommended sampling methodology, including quarterly analyses of all wells that are or could be used for drinking water, does provide for greatly increased sampling in areas with a large number of wells with potable water.

Recommendation: Given the potential for extreme precipitation events in Virginia, the distance at which influence of mine/mill/tailings releases on water supplies is likely greater than in the central-western U.S. Consideration should be given to routine monitoring of all water supplies (both public and private) out to a greater distance from a co-located uranium extraction facility. This expanded region of background monitoring would allow for quick analysis of drinking water supplies within the area of potential influence, allowing rapid response by regulatory authorities if interdiction, including replacement of water sources, were to be required after an accidental release. The following Recommendation suggests a possible method for developing groundwater sampling distances appropriate to a specific uranium mine/mill facility.

Recommendation: A number of discussions in this and associated WES reports note the need for either increased sampling densities or increased sampling radii or distances, compared to existing NRC or other guidance/regulation. Ideally, and in response to reviewer comments during preparation of this report, this report should provide specific recommendations as to the appropriate number of samples and the distance beyond which certain types of sampling are not required. However, such recommendations are highly sensitive to the exact location of a proposed uranium mine/mill facility. A facility near Richmond might suggest a requirement for the sampling of many thousands of garden plots and other media, while a facility in a lower-population region might suggest sampling only a relatively small number of food sources but a larger number of wells.

Wright Environmental Services, Inc. can, however, recommend the following in this context: pre-licensing air, surface water and groundwater modeling, using up-to-date transport models and site-specific data sets, can provide the regulator with the basis for an understanding of such variables. For example, detailed modeling of an area's groundwater systems will identify the potential for fracture flows, and detailed atmospheric transport modeling will provide reasonable estimates as to the directions, distances and concentrations of radionuclides potentially released during specified accidents. After regulatory review and modification of the pre-license submittals, employing the services of regulatory staff or outside experts, this information will become the basis for more exact determinations of, for example, the direction/distance beyond which air, surface water or groundwater sampling is unlikely to provide information of value following routine or accidental releases of toxicants.

To resolve this issue within Virginia regulatory guidance potentially developed specific to uranium mining/milling, one approach might be to note that distance limits or specific numbers of samples are simply recommended minimums. To determine the values appropriate for a specific area, the potential licensee should be required to develop detailed, model-based evaluations, resulting in recommendations as to specific distances, directions and sample numbers/sampling locations. The regulator could then respond, during the Request for Additional Information (RAI) application review process, either by 1) accepting the potential licensee's results and recommendations, or,2) requesting that they be re-done given new input from the Regulator, or,3) by performing additional modeling in-house to develop specific distance and sample number license conditions to be imposed. This approach allows for flexibility to deal with the Virginia environment, including specific plans to deal with variables such as the presence of disadvantaged, elderly, children, racial/ethnic minorities, low income and disabled groups potentially influenced by development of uranium mining/milling at a specific site. The result would be a detailed and specific set of license conditions noting facility-specific methods to deal with such situations.

Recommendation: Monthly or weekly sampling of the wells most likely to have been influenced by an accidental release to the environment should be substituted for quarterly sampling, until data and modeling indicate that the potential for delayed increases in radionuclide concentrations has passed. Delayed increases could, for example, be associated with the movement of a contamination plume through a groundwater system over time, with the potential for a significant delay in a toxicant concentration increase at a distant location. While detailed modeling of the anticipated movement of ground- or surface-water near a specific site is necessary to specify the exact period during which increased sampling frequency would be required, a minimum of three such increased-frequency samples is recommended, to ensure that a simple sampling anomaly doesn't obscure data interpretation.

Recommendation: A co-located uranium extraction facility also presents new potential hazards in terms of hazardous chemicals used in significant quantities during production. While required safety features including bermed storage and proximity limits for incompatible chemicals decrease the likelihood of releases under normal conditions, 1,000-year or hurricane events add a level of unpredictability to the issue of safe storage of chemicals. The Virginia pre-licensing regulatory structure should include identification of all hazardous materials to be used at the site, and development of an ongoing inventory and safe-storage audit system regularly reviewed by regulatory staff. Please see Appendix II for a discussion of potential hazards associated with disease precursor toxicants.

Recommendation: The pre-operational and operational quarterly water sampling program specified in Regulatory Guide 4.14 should include analysis for diesel fuel and combustion products, and other hazardous materials to be used in large quantity at the facility. "Background" concentrations of some materials in common use may be significant in air or water, associated with pre-existing sources, and responses to uranium facility releases should be based on increases in concentrations of potential toxicants, rather than absolute results. Please see Appendix II for a discussion of hazards.

6.3 Vegetation, Food and Fish Samples

Regulatory Guide 4.14 specifies that pre-operational and operational sampling schedules should be the same, except that operational sampling need occur only "*Where a significant pathway to man is identified in individual licensing cases…*" What constitutes "significant" is not defined: however, the Air Monitoring section of Regulatory Guide 4.14, summarized previously, suggests air sampling at locations where predicted radiation dose exceeds 5% of the 40CFR190 standards.

Forage vegetation should be sampled at least three times during the grazing season, in the three different compass sectors having the highest predicted airborne radionuclide concentrations due to milling operations. At least three food samples should be collected at the time of harvest or slaughter or removal of animals from grazing, for each type of crop including vegetable gardens or livestock raised within three kilometers of the mill site. Fish samples should be collected semiannually from any bodies of water that may be subject to seepage or surface drainage from potentially contaminated areas, or that could be affected by an impoundment failure.

Note: Pre-operational sampling is recommended for all of the above, operational sampling only where a significant pathway to man has been identified.

Recommendation: Differing from the water sampling guidance, the Regulatory Guide does not "scale" sample collection recommendations for foods based on the number of growing locations within a certain distance (3 kilometers in this case) from the facility. Given the factors of greatly increased likely population, food crop and irrigation system density in the Virginia environment vs. the central-western states, consideration should be given to increasing the number of food samples taken pre-operationally and operationally. An accident resulting in release of radioactive or non-radioactive toxicants could be both short-lived and significant, with real-time monitoring and meteorological data allowing identification of the most likely food crop receptor regions to be sampled, given specific wind and precipitation data. (Note that discussions of actual uranium production facility accidents and consequences is provided in some detail elsewhere in this report). In general, because the Curie (total radioactivity) quantities of radionuclides available for release from a uranium production facility are very small, compared to the quantities available for release during a power reactor accident, and also because the energies available to disperse such materials are much lower for a uranium facility vs. a power reactor, the anticipated human health consequences of a uranium facility accident are far lower than those possible for a power reactor accident.

A pre-existing set of toxicant background measurements for food crop areas could be essential in determining whether increases have occurred linked to a uranium facility accident. The current Regulatory Guide sampling recommendations may not provide the specific data needed at the location of potential impact. Given detailed knowledge of pre- and post-accident food radionuclide concentrations, the regulatory authority could more easily make decisions regarding appropriate responses including potential food interdictions. To determine the appropriate numbers and locations of forage vegetation, food crop and animal samples to be taken prior to and during operations, the potential licensee should be required to perform area-specific modeling similar to that described in Section 6.2 of this report. Such modeling should allow the regulatory agency to confirm the directions and distances for which the potential exists for significant pathways to humans, from both routine and potential accidental release scenarios. This approach allows area-specific forage and food sampling requirements to be developed, with recommendations initiated by the potential licensee and approved by the regulatory authority.

Recommendation: In addition, several “indicator species” prevalent in the Virginia region and routinely hunted for food, should be routinely sampled during the pre-operational and operational periods, to establish baseline concentrations of uranium-chain nuclides (as specified in Regulatory Guide 4.14 for food animal muscle tissue analysis). These indicator species should include the white-tail deer and the wild turkey.

Note: Fish sampling as specified in the regulatory guide is “scaled”, in that an increased number of water bodies within 3 km leads to increased numbers of background samples being routinely taken.

6.4 Soil and Sediment Sampling

Regulatory Guide 4.14 specifies that, prior to initiation of mill construction, and if possible prior to mining, one set of soil samples should be collected following the specifications below.

- Samples to a depth of five centimeters, at 300-meter intervals in each of the 8 compass directions out to 1500 m from the center of the milling area (defined as the point midway between the proposed mill and tailings area). Five-centimeters samples should also be collected at each of the air particulate sampling locations.
- Samples to a depth of 1 meter should be collected at the center of the milling area and a distance of 750 meters in each of the 4 compass directions. Samples should be divided into three equal sections by depth for analysis.
- Soil sampling should be repeated for each location later disturbed by site excavation, leveling or contouring.

- One set of sediment samples should be collected from the locations defined earlier for surface water sampling. For surface water passing through the site, sediment should be sampled upstream and downstream of the site. Samples should be collected following spring runoff and in late summer preferably following an extended period of low flow. In each location, several sediment samples should be taken in a traverse across the body of water and composited for analysis.

During operations:

- surface soil samples should be collected annually at each air particulate sampling location; and
- sediment samples should be taken at the same locations used for operational water sampling.

Notes: The Uranium Mill Tailings Remedial Action Project (UMTRAP), begun in 1983 after publication of Regulatory Guide 4.14, essentially set the cleanup standard for remedial action of soils contaminated with uranium decay-chain radionuclides. An area is determined to be suitable for free release if soil concentrations, to a depth of 15 centimeters, do not exceed 5 pCi/g (plus local background) Ra226. Most uranium-related remedial action projects have used the UMTRAP standard to determine completion of cleanup. A significant difference between Regulatory Guide 4.14 sampling and the UMTRAP standard is the soil sampling depth: 5 centimeters vs. 15 centimeters, respectively. Use of the Regulatory Guide's 5-centimeters sampling depth produces data that are incompatible with the sampling likely to be required post-operation at a uranium facility undergoing remedial action.

Recommendation: Guidance for pre-operational soil sampling should specify a sampling depth of 15 centimeters.

Review of NRC comments associated with the Moore Ranch license application is instructive in this context. The following are extracted from the NRC website's Safety Evaluation Report for the Moore Ranch application. Note that these issues have been resolved and a license has been issued.

"*Table 2 of Regulatory Guide 4.14 suggests that soil sampling be conducted in five or more locations that are the same as for air particulate sampling. It suggests collecting annual grab samples and analyzing them for natural uranium, radium-226, and lead-210. The applicant stated that the surface soil sampling will be conducted on an annual basis at the locations of the four air particulate sampling locations. These samples will be grab samples at a depth up to 5 cm and will be analyzed for natural uranium, radium-226, and lead-210.*

Because the staff cannot conclude that the applicant has placed the three site boundary air particulate samplers in locations consistent with Regulatory Guide 4.14, the staff cannot determine if the proposed soil sampling locations are consistent with Regulatory Guide 4.14. Therefore, the staff cannot determine if the placement of the three site boundary soil samples are acceptable. The staff has identified this issue as a license condition, and the license condition is discussed in… this SER."

Again, early placement of a station to collect meteorological data would provide the justification needed to support air particulate monitor site locations, co-located with soil sampling sites.

6.5 Direct Radiation

Regulatory Guide 4.14 specifies that, prior to mill construction (and if possible prior to mining, gamma exposure rate measurements should be made at 150 m intervals in each of the eight compass directions out to a distance of 1500 m from the center of the milling area, and at the air particulate monitoring locations. Measurements should later be repeated for each location disturbed by site excavation, leveling or contouring. The measurements may be made using passive integrating devices, pressurized ion chambers, or properly calibrated portable survey instruments.

During operations, gamma exposure rates should be measured quarterly at the air particulate monitoring sites. Note: current facilities and those undergoing licensing utilize high-sensitivity Optically Stimulated Luminescent (OSL) integrating environmental dosimeters to measure total exposure at the air particulate monitoring sites for each quarter. These measurements are begun during the pre-operational period, allowing comparison to operational values.

Recommendation:

- The potential for channeling of contaminants released to air or surface water is increased in a topographically complex environment that may be found in the Virginia region.
- Technology enhancements now allow for much more complete documentation of existing surface contamination conditions than was possible when the Regulatory Guide 4.14 was written.
- A region with uranium (or thorium) ore present at or near the ground surface may appear to be contaminated after an accidental release, unless definitive data to the contrary were collected earlier.

Therefore, a much more thorough evaluation of surface soil radionuclide concentrations should be performed during pre-operational evaluations than that specified by the Regulatory Guide.

Recommendation: Methods are now available to characterize the gamma radiation exposure rate over the entire area of a proposed facility, rather than at a few points as specified in current guidance. Most recent license applications for uranium extraction facilities have included the results of such GPS-based gamma radiation surveys, even though such surveys are not yet required. These applications include site maps showing the radiation exposure rates over the entire area to be licensed, and soil sample/exposure rate correlation data that allow estimation of surface Ra-226 concentrations over the entire area (Figure 6-2). An example of such an exposure rate map is presented below. The original data, roughly one million global positioning system (GPS)-located one-second gamma exposure rate readings, were Kriged (algorithm-manipulated to develop an area depiction) to produce this plot of the entire site.

6.5.1 Analysis of Environmental Samples

Regulatory Guide 4.14 also presents several tables summarizing sampling specifications, clarifying schedules, methods, procedures and lower limits of detection (LLD), and noting acceptable reporting formats. The LLDs are provided for: U-nat, Th-230 and Ra-226 in air, water, soil, sediment and vegetation/food/fish, Po-210 in water and vegetation/food/fish, and Rn-222 in air.

6.6 Meteorological Data Collection

Specifications for a uranium extraction facility meteorological station:

Note: Much of this information is also included in one of the reports prepared by the Wright Environmental (WE) Team for DEQ and others under a separate contract. It is repeated here to ensure that it is immediately available to VDH reviewers.

A good understanding of wind speed, direction, rainfall, evaporation parameters and other variables influencing atmospheric dispersion and deposition is necessary for the development and operation of a uranium extraction facility's environmental monitoring and reporting system. NRC Regulatory Guide 4.14 references a number of authorities, noted in this report's bibliography, regarding the specification of an adequate meteorological station.

In the years since the Regulatory Guide was published, developments in the fields of meteorological monitoring and the modeling of hazardous materials atmospheric transport, dispersion, deposition, uptake by and to humans, and the calculation of associated risk, has changed significantly. For example, current environmental transport codes have capabilities that greatly exceed those of the MILDOS code now in use in the uranium regulatory context. Models now may employ met data from several sources, plus terrain (topographic) data, to provide better pre-licensing estimates of environmental air particulate concentrations associated with releases from a proposed uranium extraction facility.

For example, AERMOD (EPA, 2004), a computer code developed by the American Meteorological Society and the EPA, handles flat or complex, rural or urban terrain and includes algorithms for building effects and plume penetration of inversions. It uses Gaussian dispersion for low-turbulence atmospheric conditions, and non-Gaussian dispersion for high turbulence conditions. It employs a met data preprocessor that accepts surface meteorological data, upper air soundings and data from on-site instruments. It uses a terrain preprocessor to enhance calculation of the behavior of near-surface plumes. An eventual conversion of regulatory requirements from the currently-accepted MILDOS atmospheric transport model to a more current model is recommended, and should lead to better prediction of a facility's impacts, especially in complex terrain. Selection of an alternative model is probably best handled at the NRC level, since it would involve changes affecting licensing over the entire U.S. It is likely that the NRC is considering such a change currently, while it revises Regulatory Guide 4.14.

Even given the modeling systems currently in use for estimation of air concentrations associated with releases from a uranium extraction facility, the capabilities and thus specifications associated with current meteorological stations have changed drastically. Solar-powered systems are now the norm, as are instruments capable of providing far better low-wind-speed and dispersion data. Rather than revisit discussions of the earlier systems, we provide here a recommended set of met station specifications. These specifications parallel those of recently-installed systems at several new or pre-license, proposed facilities in the western U.S.

6.6.1 Information Sources for Meteorological Station Specification and Siting

The best reference in this regard is the EPA's Meteorological Monitoring Guidance for Regulatory Modeling Applications. The document provides guidance for the collection and processing of meteorological data for general use in air quality modeling applications.

Information is provided concerning the *in situ* monitoring of primary meteorological variables (wind direction, wind horizontal and vertical speed, temperature, humidity, pressure, and radiation), for remote sensing of winds, temperature, and humidity, and for processing of derived meteorological variables such as stability, mixing height, and turbulence. The material supports most categories of air quality modeling including: steady-state, non-steady-state, Gaussian, and non- Gaussian models. The document notes that one of the most important aspects covered is the selection of the monitoring location: "Is the site representative?" Some information is also provided on the use of airport data, but the report notes that airport data, in general, are insufficient for a variety of reasons. This has proved to be the case, in the view of the NRC, as reflected in its recent reviews of at least one ISR license application: The Commission required installation of an on-site met station as a license condition.

Additional reading is recommended, by the EPA, to provide a more detailed background on the topic: "Guideline on Air Quality Models" Appendix W to 40 CFR Part 5; "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurements";

"On-site Meteorological Instrumentation Requirements to Characterize Diffusion from Point Sources"; and, "Standard for Determining Meteorological Information at Nuclear Power Sites".

Specific recommendations: The basis for these specifications remains the 1988 NRC Regulatory Guide 3.63, "Onsite Meteorological Measurement Program for Uranium Recovery Facilities – Data Acquisition and Reporting," but instrument specifications below are updated to current equivalent standards."

6.6.2 Siting

NRC Regulatory Guide 3.63 states:

"*The location of the meteorological instruments should represent as closely as possible the long-term meteorological characteristics of the area for which the measurements are being made. Whenever possible, the base of the instrument tower or mast should be sited at approximately the same elevation as the facility operation. Ideally, the instruments should be located in an area where localized singular natural or man-made obstructions (e.g., trees, buildings) will have little or no influence on meteorological measurements. Measurements of wind speed, wind direction, and sigma theta if measured should be made at least 10 obstruction heights away from the nearest obstruction*."

"*To the extent practicable, these instruments should not be located in the prevailing downwind direction of an obstruction. At most facilities, the instruments could all be sited at one location. At some sites, instruments may need to be sited at more than one location if the meteorological conditions are not similar throughout the site vicinity*."

A station location should be selected considering:

- site operations;
- local topography;
- prevailing wind direction;
- proposed building(s);
- naturally occurring obstructions (trees, embankments); and
- any additional factors including safe access.

The station location needs to be representative of the locations of proposed operations, and should meet the objectives listed below.

- Base of station should be at same elevation as the facility operation (whenever possible).

- Station should be located in open area free from obstructions, upwind of nearby obstructions.
- Wind parameter measurements should be made at a distance at least 10 times the height differential of any obstructions (e.g., the station needs to be at least 300 feet away from a 30 foot building). Rough measurements should be made to verify that the tower will be a sufficient distance from obstructions and can be safely accessed for installation and servicing.
- If meteorological conditions vary over the site, more than one station may be required.
- Wind parameters should be measured at 10 m height with the sensor oriented into prevailing wind. Additionally, the sensor needs to be two times the tower width away from tower.

6.6.3 Other Recommendations

NRC Guide 3.63 specifies the following maintenance, servicing, and data requirements.

- Station should be able to withstand severe weather including blowing sand, lightning, and icing.
- Station should be inspected a minimum of once every 15 days.
- Station should be serviced at a frequency that ensures 90% annual data recovery and 75% annual joint data recovery of wind speed, wind direction, and atmospheric stability.
- The system should be calibrated at least once every 6 months (dusty environment requires calibration more frequently, e.g. quarterly).
- Extensive recordkeeping maintained for the duration of the uranium recovery operation.

Recordkeeping should include the following information.

- Operating logs and results of reviews, inspections, maintenance, calibrations, audits.
- A description of the types of observations taken, with the results and their acceptability.
- Actions taken regarding deficiencies noted.
- Recordkeeping should identify who is responsible for data acquisition and data archiving.

Recommendation: All radiation protection (worker and environmental) data should be plotted routinely (weekly in most cases), and should also display as plotted lines the related quality assurance information (examples: LLDs, 3 sigma uncertainty bounds) with the plotted monitoring data. Most plots should display such information for the previous 12 months (new data entry causing deletion of data more than 12 months old). This approach allows easy identification of trends (example: an increasing dose rate in a worker area) and outliers (examples: spikes in radon daughter concentrations, or lab analysis errors displaying as gross outliers). The plots are also extremely useful during Radiation Safety Officer and Facility Safety Committee reviews, and during announced or unannounced Regulatory inspections.

Recommendation: The above data/QA plots should, as quickly as is feasible (example: upon receipt of data from a lab, immediately after a quick check including lab-reported QA parameters), be made available to Regulatory staff and members of the general public, through a website that is accessible without password or other access requirements (in other words, an open website).

6.6.4 Use of The Data In MILDOS Calculations

The MILDOS code, used to provide estimates of radionuclide air concentrations, requires an estimate of stability class, combined with wind direction and wind speed, organized into a stability class array. A variety of methods of stability class measurement may be used to run the MILDOS code. Based on EPA Meteorological Onsite Guidance (EPA-454/R-99-005) WE believes that the Turner Method is the best approach to determining stability class. However, this method requires cloud cover and ceiling height data which can be difficult to interpret and process. The problem with obtaining cloud cover data has led to the development of other methods to estimate stability class. The solar radiation delta-T method, discussed in documents such as the EPA report noted above, retains the basic structure of the Turner Method but does not require cloud cover and ceiling height data. Wright Environmental Services, Inc. therefore recommends use of the solar radiation delta-T method, which includes the use of a solar radiation device and temperature probes at two different heights to calculate stability. The system below reflects this recommendation.

6.6.5 Equipment Specifications

Table 6-1 provides recommendations for a uranium extraction facility meteorological station capable of meeting the intent of Regulatory Guide 3.63 in the context of current instrument capabilities.

This system can be powered by A/C or a solar power system. If solar power is chosen, additional solar panels and deep-cycle batteries will be required to power the 2-m and 10-m temperature aspirator fans. WES also recommends use of a monitoring communication system such as: wired telephone; cellular wireless, satellite, or short range wireless (e.g.: 2.4 GHz). This added capability will ensure that data loss situations are recognized and resolved quickly.

6.7 Summary: Goals for an Environmental Monitoring Plan

Environmental monitoring plans should contain the elements listed below.

- Representative measurements of concentrations of constituents in environmental media such as air, water, vegetation, domestic food products, soil, radiation and meteorology.
- Adequate coverage of the areas of interest, such as watersheds, counties, property, green spaces including recreational parks.
- Adequate continuing measurement of background concentrations of constituents identified in baseline studies.
- Representative measurements of direct gamma radiation.
- Acquisition of adequate data on which to base exposure and dose estimates for members of the public, including minority and disadvantaged populations.

Again, site-specific considerations in Virginia would drastically affect the details of a facility's environmental monitoring plan. Specific monitoring plans usually accompany a license application or a proposed state or federal action.

7.0 MANAGEMENT, GIVEN STATE-SPECIFIC CLIMATE AND HYDROLOGIC CONSIDERATIONS

This section provides Virginia-specific comments that are pertinent to the NRC Regulations in 10 CFR Part 40, Appendix A. Please also refer to Sections 2.0 (Water Quality and Human Health Impacts), 5.0 (Developing Recommendations for Environmental Monitoring) and 6.0 (Environmental Monitoring) of this report for additional detail related to known conditions.

7.1 Technical Criteria

The NRC source material regulations in 10 CFR Part 40, Appendix A include "*Criteria Relating to Operation of Uranium Mills and Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for their Source Material Content.*" The introduction to this regulation states that every license applicant is required to include specifications relating to milling operations and the disposition of tailings or wastes resulting from such milling activities in their proposal. 10 CFR Part 40, Appendix A establishes the "technical, financial, ownership, and long-term site surveillance criteria relating to the siting, operation, decontamination, decommissioning, and reclamation of mills and tailings or waste systems and sites at which such mills and systems are located."

The criteria are paraphrased below, pertinent to control of releases from a site, such that might have a potential impact on human health. Specific comments on potential differences provide a general evaluation and interpretation of how a regulation might be applied to a Virginia mine or mill site, or sites in other states. It is important to note that the regulations were not promulgated with any particular climate in mind. Design criteria of milling facilities are adjusted for site-specific conditions.

As stated in the introduction to the Appendix, licensees or applicants may propose alternatives to the specific requirements in the 10 CFR 40, Appendix A, taking into account local or regional conditions, including geology, topography, hydrology and meteorology. Alternatives may be approved if they are demonstrated to be equivalent to or more stringent than the requirements of the Appendix A and standards promulgated by EPA in 40 CFR 192, Subparts D and E. Appendix A criteria are discussed in detail in the following sections.

7.1.1 Criterion 1 - Siting and Design Objective of Permanent Isolation of Tailings and Associated Contaminants

Major considerations of this criterion include remoteness from populated areas, the potential of minimizing disturbance and dispersion by natural forces, and no ongoing maintenance. Both siting and design would need to consider hydrologic and other natural conditions that might contribute to long-term immobilization and isolation of contaminants from groundwater sources. The criterion emphasizes that while isolation of the tailings is a function of both engineering design and siting, "overriding consideration must be given to siting features given the long-term nature of the tailings hazards."

Virginia-specific comment: Inadequate consideration of potential extreme rainfall events, hydrologic regime, or population centers would be grounds for denial of a license for a proposed facility. Site-specific considerations within Virginia would be addressed at the point that a license application was submitted.

7.1.2 Criterion 2 - Proliferation of Small Waste Disposal Sites

This criterion largely applies to *in situ* extraction operations and wastes from small remote above ground extraction operations. There are currently no such operations foreseen in Virginia.

7.1.3 Criterion 3 – Prime Option for Disposal of Tailings

The criterion states that below grade disposal of tailings is the "prime option." This can occur either in excavated pits or in a mine. The license applicant must seriously consider this disposal option. In situations where below grade disposal is not be the most environmentally sound approach, such as a high water table, other options may be explored.

Virginia-specific comment: A mine/mill complex, especially one with an underground mine might eliminate the need for a specially excavated disposal pit and provide superior tailings isolation over long time periods. Full below-grade disposal (with no options for partially below-grade disposal cells) could be a consideration in establishing regulations.

7.1.4 Criterion 4 – Required Site and Design Criteria

Whether tailings are disposed above or below grade, certain site and design criteria are required, including:

- upstream rainfall catchment areas should be minimized to decrease erosion potential and size of possible floods that could damage sections of the tailings disposal area;
- topographic features should provide good wind protection;
- embankment and cover slopes should be relatively flat and final site stabilization. If slopes steeper than 5h:1v are proposed, reasons should be given in the application;
- a self-sustaining vegetative cover must be established or rock cover employed to reduce erosion. If a vegetative cover is unlikely to be self-sustaining, changes in slope design may be considered. Slopes, types of rock and conditions for rock cover of slopes are detailed;
- the impoundment may not be located near a fault that could cause an earthquake larger than the impoundment was designed to withstand; and

- to enhance the thickness of the cover over time, where feasible, the impoundment should be designed to incorporate features that will promote deposition of sediment.

Virginia-specific comment: Given the climate in Virginia, a self-sustaining vegetative cover to the impoundment would likely be applicable.

7.1.5 Criterion 5 – Criteria 5A-5D and Criteria 13 incorporate basic groundwater protection standards imposed by EPA in 40 CFR192, Subparts D and E, which apply during operations and prior to the end of closure

Criterion 5A(1) – The primary groundwater protection standard is a design standard for surface impoundments used to manage uranium and thorium byproduct material. Unless specifically exempted by criterion 5A(3), surface impoundments must have a liner to prevent migration of wastes from the impoundment into adjacent soil.

Criterion 5A(2) – Describes the liner construction and foundation of impoundment.

Criterion 5A(3) – The applicant will be exempted from requirements in criterion 5A(1) depending on the nature and quality of the wastes, the proposed alternate design and operation, a favorable hydrogeologic setting and other factors which would influence the quality and mobility of the leachate produced and its potential to migrate to groundwater.

Virginia-specific comment: Given the climatic conditions in Virginia, it is unlikely that an exemption would be granted.

Criterion 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.

Virginia-specific comment: With regard to 5A(4), the potential for extreme events would require more storage than would be likely at a western site such as Colorado or Utah.

Criterion 5A(5) – Dikes, if used to form the surface impoundment, must be designed, constructed and maintained with sufficient structural integrity to prevent massive failures of the dikes. It must not be assumed that the liner system will function without leakage during the active life of the impoundment.

Criteria 5B(1) – 5B(6) – Uranium and thorium byproduct materials must be managed to conform to the following secondary groundwater protection standard.

Criterion 5B(1) – Hazardous constituents entering groundwater from a licensed site must not exceed specified concentration limits in the uppermost aquifer beyond the point of compliance during the compliance period. Specified concentration limits are listed in criterion 5B(5). The Commission will also establish the point of compliance and the compliance period on a site-specific basis. The compliance point is selected to provide the earliest practicable warning that the impoundment is releasing hazardous constituents to the groundwater. The groundwater point of compliance must be selected to provide prompt indication of contamination on the hydraulically down gradient edge of the disposal area.

Virginia-specific comment: As noted in the criteria, NRC or Virginia, as an Agreement State, has latitude to establish the compliance location at which groundwater is sampled.

Criterion 5B(2) – A constituent becomes a hazardous constituent when the constituent is (a) reasonably expected to be in or derived from the byproduct material in the disposal area; (b) has been detected in the groundwater of the uppermost aquifer; and (c) is listed in Criterion 13 below.

Criterion 5B(3) – Even when constituents meet all three tests in 5B(2), the Commission may exclude a detected constituent on a site-specific basis if it finds that the constituent is not capable of posing a substantial present or future hazard to human health or the environment. In making that determination, the Commission will consider (a) potential adverse effects on groundwater quality based on 9 listed considerations and (b) potential adverse effects on hydraulically-connected surface water quality based on 10 listed considerations.

Virginia-specific comment: As noted in the criteria, if Virginia was an Agreement State of the NRC, it would be able to exclude certain constituents based the considerations listed.

Criterion 5B(4) – In making determinations under Criteria 5B(3) and 5B(6), about use of groundwater in the area, the Commission will consider any identification of underground sources of drinking water and exempted aquifers made by the EPA.

Criterion 5B(5) – At the point of compliance, the concentration of a hazardous constituent must not exceed (a) the approved background concentration of the constituent in groundwater, (b) the respective value of the table in 5C is listed and the background level of the constituent is below the listed value, or (c) an alternate concentration limit established by the Commission.

Criterion 5B(6) – Conceptually, background concentrations pose no incremental hazards and the drinking water limits in shown in Table 7-1 reflect acceptable hazards. But, at a specific site neither of these concentration limits may be achievable. Licensees may propose alternate concentration limits that present no significant hazard. The licensee must provide the basis for any proposed limit including consideration of practicable corrective actions, that limits are ALARA and other information necessary to make a decision about the alternate concentration limit. If the Commission finds that the proposed limit is ALARA, after considering practicable corrective actions and will not pose a substantial present or potential hazard, the alternative concentration may be approved. In making that determination, the Commission will consider (a) potential adverse effects on groundwater quality based on the same 9 listed considerations and (b) potential adverse effects on hydraulically-connected surface water quality based on the same 10 listed considerations.

Criterion 5C – Maximum values for Groundwater protection (**s**hown in Table 7-1).

Virginia-specific comment: Drinking water standards for non-carcinogens are based on the assumption that thresholds exist for certain toxic effects. The Maximum Contaminant Limit Goal (MCLG) and the enforceable MCL are based on the reference dose (RfD), which is an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Only arsenic and the radioactive constituents in Table 5C are carcinogens. Radionuclides are regulated as though there is no threshold for cancer risk. Therefore, the MCLG is zero.

Criterion 5D – If the groundwater protection standards are exceeded at a licensed site, a corrective action program must be put into operation as soon as is practicable and no later than 18 months after the standards have been exceeded. The licensee must propose a corrective action plan and supporting rationale prior to putting the program into operation, unless otherwise agreed. The objective of the program is to return concentration levels to meet the standards. The program must address removing hazardous constituents at the point of compliance or treating them in place. It must also address removing or treating any hazardous constituents that exceed limits between the point of compliance and the down-gradient facility property boundary.

Criterion 5E – In developing and conducting groundwater protection programs, applicants and licensees shall also consider the following: (1) installation of bottom liners, (2) mill process designs which provide maximum practicable recycle of solutions and conservation of water to reduce net input of liquid to the tailings impoundment, (3) dewatering of tailings by process devices or in-situ drainage systems, and (4) neutralization to promote immobilization of hazardous constituents.

Criterion 5F **–** Where groundwater impacts are occurring at an existing site due to seepage, action must be taken to alleviate conditions that lead to excessive seepage impacts and restore groundwater quality. The specific seepage control and groundwater protection method, or combination of methods, to be used must be worked out on a site-specific basis. Technical specifications must be prepared to control installation of seepage control systems. Quality assurance, testing, and inspection program, that includes supervision by a qualified engineer or scientist, must be established to assure the specifications are met.

Criterion 5G **–** The applicant or operator shall supply information concerning the following: (1) the chemical and radioactive characteristics of the waste solution, (2) characteristics of the underlying soil and geologic formations particularly as the will control transport of contaminants and solutions, and (3) location, extent, quality, capacity and current uses of any groundwater at and near the site.

Virginia-specific comment: If Virginia were to become an agreement state, VDH could add requirements that other characteristics of private wells within a specified distance from the tailings impoundment or property boundary be documented as to depth to water, maximum pumping rate and presence or absence of constituents in Table 5C prior to granting a license.

Criterion 5H – Steps must be taken during stockpiling of ore to minimize penetration of radionuclides into underlying soils. Methods might include lining or compaction of ore storage areas.

Virginia-specific comment: Given concerns about extreme rainfall events, VDH could require a concrete ore storage pad with the stipulation that potential rainfall overflow would be contained on the site until it could be evaporated.

7.1.6 Criterion 6 – Disposal of Waste Byproduct Material

Criterion 6(1) – Licensees shall place an earthen cover, or approved alternative, over tailings or waste at the end of milling operations and shall close the waste disposal area in accordance with a design that provides reasonable assurance of control of radiological hazards (1) to be effective for 1,000 years, to the extent reasonably achievable, and for at least 200 years, in any case and (2) limit releases of radon-222 and radon-220 to the atmosphere so as not to exceed an average release rate of 20 pCi/m^2-sec throughout the effective design life. Direct gamma exposure from the tailings or waste should be reduced to background levels.

Criterion 6(2) – As soon as reasonably achievable after emplacement of the final cover, the licensee shall verify through appropriate testing that the design and construction of the radon barrier is effective at limiting the release to 20 pCi/m^2s.

Criterion 6(3) – When phased emplacement of the final radon barrier is included in the reclamation plan, verification of radon release rates required above must be conducted for each portion of the pile as the radon barrier for that portion is emplaced.

Criterion 6(4) – Results of testing required in 6(2) and 6(3) showing that release levels of Rn-222 do not exceed 20 pCi/m^2s must be reported within 90 days after completion of the testing. The licensee must maintain records of the measurements and calculations until termination of the license.

Criterion 6(5) – Materials used in the near surface of the cover (the top 3 meters) may not include waste or rock that contains elevated levels of radium. Soils used for the surface should have essentially the same levels of radium as soils surrounding the facility.

Criterion 6(6) – Design requirements for longevity and control of radon releases apply to any portion of a licensed site unless such portion contains a concentration of radium in land, averaged over areas of 100 square meters (m^2), which as a result of byproduct material, does not exceed background by more than 5 pCi/g or radium-226 or radium-228 averaged over the top 15 centimeters (cm) and 15 pCi/g of radium-226 or radium-228 averaged over any other 15 cm layer below the surface.

This criterion also describes the "unity" rule by which mixtures of radionuclides found within the same 100 m^2 area must not result in a total effective dose equivalent of 100 mrem/yr when all radionuclides are considered. A calculation of the radium standard (not including radon) on the site must be submitted for approval.

Criterion 6(7) – The licensee shall also address non-radiological hazards associated with wastes in planning and implementing closure. To the extent necessary to prevent threats to human health and environment, the licensee shall control, minimize, or eliminate post-closure escape of non-radiological hazardous constituents, leachate, contaminated rainwater, or waste decomposition products to the ground or surface waters or to the atmosphere.

7.1.7 Criterion 6A

Criterion 6A(1) – The final radon barrier for impoundments containing uranium byproduct materials must be completed as expeditiously as practicable considering technological feasibility after cessation of operations in accordance with the approved reclamation plan. The deadline for completion of the final radon barrier may also include milestones for retrieving windblown tailings, if any, for placement on the pile and interim stabilization. Erosion protection barriers or features necessary for long-term control of tailings must also be completed in a timely manner.

Virginia-specific comment: Given the relatively humid climate of Virginia, wind-blown dispersal of tailings may not be as significant an issue as it is in dry, windy climates.

Criterion 6A(2) – A licensee's request to extend the performance period of milestones related to emplacement of the final radon barrier may be granted, after providing an opportunity for public participation, the licensee has adequately demonstrated the releases of radon-222 do not exceed 20 pCi/m^2-sec. If delayed, an annual verification must be conducted to demonstrate that the radon limit has not been exceeded. After providing an opportunity for public input, the final date for completion of the radon barrier may be extended on the basis of cost if the Commission finds that the licensee is making good faith efforts to emplace the final barrier, the delay is consistent with the definition of available technology and radon released during the delay will not result in a significant incremental risk to the public.

Criterion 6A(3) – The Commission may authorize, upon licensee request, a portion of the impoundment to accept uranium byproduct material or materials similar to uranium mill tailings and associated wastes from other sources during the closure process. Such authorization will not be made if it results in a delay or impediment to emplacement of the final radon barrier over the remainder of the impoundment in a manner that will limit radon levels to those below the standard.

Virginia – specific comment: The provision that tailings or similar waste may be added to a licensee's impoundment has been used at some western sites to allow waste from cleanup of tailings from formerly contaminated communities as part of DOE's UMTRAP or the Formerly Utilized Sites Remedial Action Program (FUSRAP), now administered by the Army Corps of Engineers. It is unlikely that would be a consideration in Virginia.

7.1.8 Criterion 7

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

Virginia Specific Comment: Section 5 includes recommendations for augmenting the pre-operational monitoring program to meet Commonwealth-specific conditions.

Criterion 7A – The licensee shall establish a detection monitoring program such that site-specific groundwater protection standards may be established as per Criterion 5B(1). The licensee will propose in license conditions those constituents that are to be monitored. The program has two purposes: (1) detect leakage of hazardous constituents from the disposal area, and (2) if leakage is detected to generate data and information needed for the Commission to establish standards under Criterion 5B. Once site-specific groundwater standards have been set, the licensee shall establish and implement a compliance monitoring program and ultimately, a corrective action monitoring plan

7.1.9 Criterion 8 – Milling Operations

Milling operations must be conducted so that airborne effluent releases are reduced to levels that are ALARA, primarily by emission controls. Institutional controls, such as extending the site boundary, may be employed to ensure that offsite exposure limits are met, but only after all practicable measures have been taken to control emissions. Aside from radon exposure, dusting from dry surfaces of the tailings disposal area and emissions from yellowcake drying and packaging are the greatest potential sources of offsite radiation exposure.

Virginia-specific comment: A license condition may be added that requires that ore storage areas and tailings beaches be kept damp to control dusting. The criterion mentions yellowcake drying as a potential source of dust. Modern vacuum dryers are accepted by the NRC as having no particulate effluent.

Checks must be made and logged hourly of all parameters that determine efficiency of yellowcake stack emissions. The log shall be retained for 3 years after the last entry in the log is made. Effluent control devices must be operative at all times during drying and packaging operations. Drying and packaging must terminate when controls are inoperative.

Virginia-specific comment: As mentioned above, there will be no emissions from a vacuum dryer. Nevertheless, the stack from the packaging area would still need to be monitored as described in the criterion.

- To control dusting from tailings, the portion of the tailings not covered by standing liquids must be wetted or chemically stabilized to prevent blowing and dusting to the maximum extent reasonably achievable. This requirement may be relaxed if tailings are effectively sheltered from wind, perhaps as in a below grade impoundment. Operators shall develop written operating procedures specifying control methods that will be used.
- Except for doses from radon-220 and its daughters, milling operations involving thorium byproduct material must be conducted to limit annual dose equivalent to a member of the public to 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other organ, as a result of exposures to planned discharge of radioactive materials to the general environment.
- Uranium and thorium byproduct materials must be managed so as to conform to applicable provisions of 40 CFR 440.
- **Criterion 8A –** Daily inspections of tailings or waste retention systems must be conducted and documented by a qualified engineer or scientist. The daily inspection record shall be retained for 3years after the documentation is made. The appropriate NRC regional office 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 if any unusual conditions that if not corrected could indicate the potential or lead to failure of the system and result in a release into an unrestricted area.

7.1.10 Criterion 9 – 11 –Financial Criteria, Surety Bonding, and Site and Byproduct Material Ownership

Financial criteria, surety bonding and byproduct material ownership requirements are found in an Interim Report of the DEQ/Department of Mines, Minerals and Energy (DMME) Uranium Project and are not repeated here.

7.1.11 Criterion 12 - Long-term Site Surveillance

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. Annual, or more frequent, site inspections must be conducted by the regulator responsible for long-term care of the disposal site to confirm its integrity and determine the need for maintenance or monitoring. Results of the inspections will be reported annually within 90 days of the last inspection in a calendar year. Any unusual damage or disruption will require a preliminary site inspection report to be submitted within 60 days. More frequent inspections may be required.

7.1.12 Criterion 13 - Hazardous Constituents in Secondary Groundwater Protection Standards

Secondary groundwater protection standards required by Criterion 5 are concentrations for individual hazardous constituents. Criterion 13 lists approximately 250 constituents for which standards must be set and complied with if the specific constituent is reasonably expected to be in or derived from the byproduct material and has been detected in groundwater.

8.0 SUMMARY AND CONCLUSIONS

The recommendations developed in this report address water quality, mine waste disposal, methods to achieve ALARA, environmental monitoring, and NRC regulations related to uranium mining and milling in the Commonwealth of Virginia. These issues are necessary and relevant for effective life cycle regulation of uranium mining and milling in Virginia.

The recommendations are prefaced with technical explanations, examples, comparisons, and references. The document intends to optimize VDH's understanding of uranium mining and milling for the development of a consistent and uniform set of policies and regulations.

The final report for this project will reiterate all recommendations made, and the respective location of their derivation and justification. The final report will endeavor to coordinate the VDH assessment of surface water and groundwater monitoring plan elements, with those of DEQ and DMME, to the level that is reasonably effective, in order to minimize duplication of effort and maximize value to the Commonwealth.

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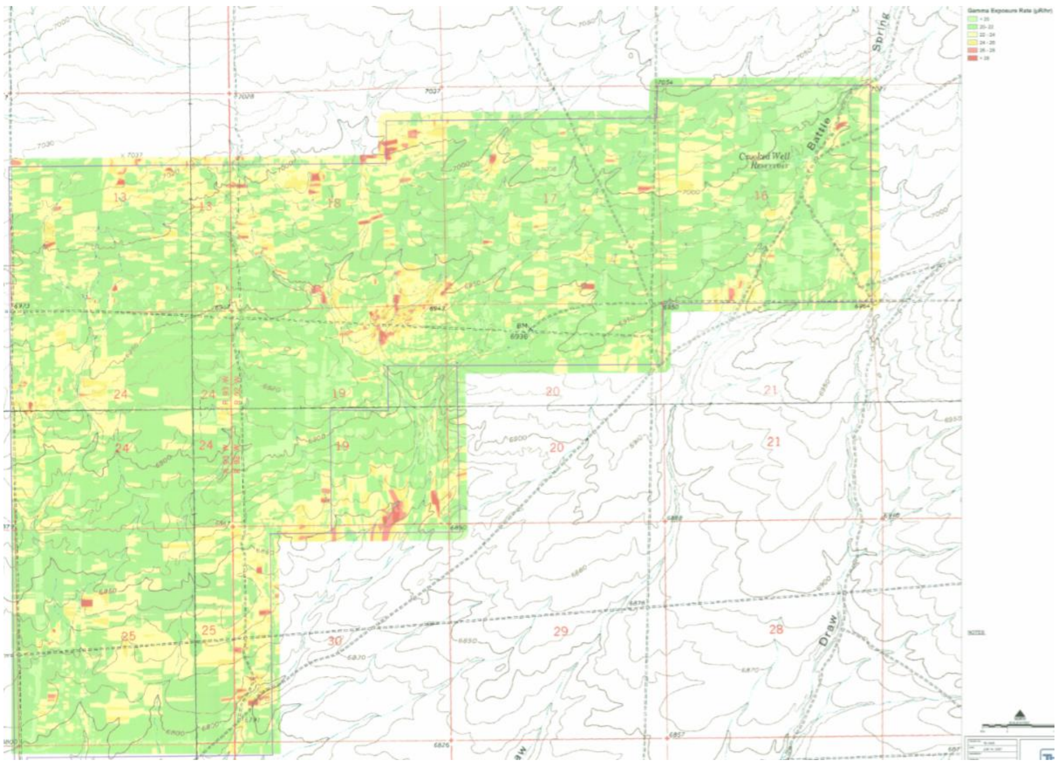
FIGURES

Figure 6-1 A solar-powered Air Sampling System

Figure 6-2 Kriged gamma exposure rates within the Lost Creek uranium ISR site boundary (extracted from the 2008 Lost Creek License Application, at www.nrc.gov)



TABLES

Table 2-1 Church Rock Dam Failure Causes and Recommendations

CAUSE	EXPLANATION	COMMENTS/CURRENT REGULATORY REQUIREMENTS/RECOMMENDATIONS
Siting	The tailings pond was located on the banks of an arroyo without secondary containment to catch spills.	Current federal criteria and recommendations in Interim Report #1 contain requirements for secondary containment structures downstream of a tailings confinement system.
Siting and Design	The 25-foot tall dam was constructed on alluvial soils overlying bedrock having an irregular surface (differences of up to 80 feet) providing a condition conducive to differential settling under load. This condition was known to exist at the time the license application was submitted; however, the placement and design were approved by the state engineer for dam construction. Large differential settlement was determined to be the immediate cause of the dam failure.	Current federal criteria strengthen the siting and dam design requirements to avoid conditions that existed at the Church Rock tailings dam. More detailed and thorough analyses of geologic, hydrologic, and soils conditions and capabilities are required. It is critical that the evaluation and approval of siting and design of impoundments be done by properly trained and experienced engineers and scientists who have the authority to make decisions regarding approval or disapproval of siting and design. Current federal criteria for tailings confinement systems provide that the prime option for systems location is below grade thus reducing the need for tall embankments.
Design	The Church Rock tailings pond was an unlined pond, which allowed liquids within the tailings to penetrate into and weaken the embankment.	Current federal criteria require that all tailings ponds be lined to prevent leakage of liquids and contaminates from the pond. This also prevents leakage of fluids into embankments.
Operational Procedures	At the time of the dam failure, the Church Rock Mill was not maintaining a beach between the ponded liquids in the pond and the embankment structure thus allowing these liquids to penetrate and weaken the embankment.	This was a reoccurring problem at the Church Rock Mill; on November 8, 1979, less than four months after the dam failure, an inspector from New Mexico observed that freestanding liquids were again in contact with the embankment and ordered the mill to stop producing tailings. It is standard practice to provide a beach surrounding ponded liquids to prevent the liquids from coming in direct contact with the embankments. Current federal criteria require that the tailings impoundments be operated in such a manner that a beach is maintained between ponded liquids and embankments. The current federal criteria, which require all ponds to be lined, enhance the protection of embankments from seepage of liquids into the embankment.

Table 2-2 Estimated Releases of Uranium and Gross Alpha from Mine Dewatering and Dam Failure

COMPONENT	MINE WATER RELEASES	TAILINGS DAM FAILURE
Uranium	560 metric tons	1.5 metric tons
Gross Alpha	260 curies	46 curies

Table 2-3 Potential Doses Estimated from Air Sampling Data

ORGAN OF CONCERN	CALCULATED 50-YEAR COMMITTED DOSE (mrem)
Bone	17
Spleen	1-3
Endosteum	5-15
Lungs	2-4

Table 2-4 Potential Human Doses Resulting from Consumption of Domestic Animals

ANIMAL	ORGAN CONSUMED	CALCULATED 50-YEAR TOTAL BODY COMMITTED DOSE (mrem)
Cow	Muscle	0.5 - 0.7
	Liver	7.4 - 35.0
	Kidney	58.0 - 120.0
	Bone (soup)	0.3 - 2.5
Sheep	Muscle	16.0
	Liver	17.0 - 190.0
	Kidney	26.0 - 440.0
Goat	Muscle	3.3 - 120.0
	Liver	120.0
	Kidney	300.0

Table 6-1 Recommended Meteorological Station Instrumentation

Level	Instrumentation	Range	Accuracy
2 Meters	Temperature sensor (with fan-aspirated shield)	-30 to +50 °C	± 0.5 °C (delta T: 0.1 °C)
	Relative humidity sensor	0 to 100%	± 7 % RH
	Solar radiation sensor	0 - 1,300 w/m^2	± 5%
10 Meters	Horizontal Wind speed sensor	0 to 50 m/s	± 0.2 m/s
	Horizontal wind direction sensor	0 to 360 degrees	± 3 degrees
	Temperature sensor (with fan-aspirated shield)	-30 to +50 °C	± 0.5 °C (delta T: 0.1 °C)
Enclosure Cabinet	Data acquisition and storage	0 to 500 millivolts with (a minimum) of 5 differential terminal inputs)	0.1% of FSR
Tower	10-meter tower	N/A	N/A
0.5 Meters	Tipping bucket rain gauge	0.01 inch per tip	0.5 % at rate up to
Ground Level	Evaporation Pan and Gauge	0 to 2 inches	± 10%

[1] The instrumentation in this table meets the requirements of NRC Guide 3.63, EPA Handbook and EPA Guidance

Notes:

%	Percent
Delta T	Delta Temperature (temperature difference between 2 and 10-meter probes)
FSR	Full scale range
mm	Millimeters
RH	Relative humidity
°C	Degree Celsius
m/s	Meter per second
w/m^2	Watt per square meter
N/A	Not applicable

(Note that a tower height of 30 m rather than 10 m may be required.)

Table 7-1 Criterion 5C – Maximum Values for Groundwater Protection

Constituent or Property	Maximum Concentration Limit
Milligrams per liter	
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.05
Selenium	0.002
Silver	0.01
Endrin (1,2,3,4,10,10-hexachloro-1,7 -expoxy-1,4,4a,5,6,7,8,9a-octahydro-1, 4-endo, endo-5, 8- dimethanonapthalene)	0.05
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.0002
Methoxychlor (1,1,1-Trichloro-2,2-bis (p-methoxyphenylethane)	0.004
Toxaphene (C_{10} H_{10} $C1_{6}$, Technical chlorinated camphene, 67-69 percent chlorine)	0.1
2, 4-D(2,4-Dichlorophenoxyacetic acid)	0.005
2, 4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.1
Picocuries per liter	
Combined radium-226 and radium-228	5
Gross alpha-particle activity (excluding radon and uranium when producing uranium byproduct material or radon and thorium when producing thorium byproduct material)	15

APPENDIX I

Chemical and Radiological Properties of

Tailings Wastes Generated by the Model Mill

Chemical and Radiological Properties of Tailings Wastes Generated by the Model Mill

Parameter	Value	EPA Reported Value[b]
Dry Solids		
U308 , wt % c	0.007	
U nat, pCi/gc	39	
Ra-226, pCi/g	280	
Th-230, pCi/g	280	
Tailings Liquid		
pH	2	
Aluminum, mg/L	2,000	700 - 1,600
Ammonia, mg/L	500	
Arsenic, mg/L	0.2	0.1 - 3.4
Calcium, mg/L	500	
Carbonate, mg/L		
Cadmium, mg/L	0.2	0.08 -5
Chloride, mg/L	300	
Chromium, mg/L		0.02 -2.9
Copper, mg/L	50	0.7 -8.6
Fluoride, mg/L	5	1.4-2.1
Iron, mg/L	1,000	300 -3,000
Lead, mg/L	7	0.8 -2
Magnesium, mg/L		400 -700
Manganese, mg/L	500	100 -210
Mercury, mg/L	0.07	
Molybdenum, mg/L	100	0.3 -16
Nickel, mg/L		0.13 -1.4
Selenium, mg/L	20	
Sodium, mg/L	200	
Sulfate, mg/L	30,000	
Vanadium, mg/L	0.10	0.1 -120
Zinc, mg/L	80	700 - 1,600
Total dissolved solids, mg/L	35,000	
U nat, pCi/L	3,300	
Ra-226, pCi/L	250	
Th-.230, pCi/L	90,000	
Pb-210, pCi/L	250	
Po-2l0, pCi/L	250	
Bi-2l0, pCi/L	250	

[a]Based on:

- M.B. Sears et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Guides--Milling of Uranium Ores, ORNL-TM-4903, 1975.
- WIN Reports on Uranium are Analysis, U.S. AEC Contract 49-6-924, various reports 7 January 1957 through 10 July 1958.
- United States Mineral Resources, Geological Survey Professional Paper 820, 1973.
- Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 667, 1975.

[b]Environmental Study on Uranium Mills, by Jackson, Coleman, Murray and Scints, TRW, Inc., for U.S. Environmental Protection Agency, Contract #68-03-2560, EPA Effluents Guidelines Division.

[c] A picocurie of natural uranium (U nat) weighs 1.5 ~g and contains 0.49 pCi each of U-238 and U-234, and 0.023 pCi of U-235.

Source: NUREG 0607, Table 5.3

APPENDIX II

Health Risks Associated with Fine (PM2.5) and Coarse (PM10) Particulates and Diesel Exhaust Particles

Health Risks Associated with Fine ($PM_{2.5}$) and Coarse (PM_{10}) Particulates and Diesel Exhaust Particles

Particulates

Source - $PM_{2.5}$ is produced mainly by combustion of fossil fuel, either by stationary sources or by transportation. A relatively small number of broadly defined source categories, account for the majority of the observed PM mass. For example, quite different mobile sources such as trucks, farm equipment, and locomotives rely on diesel engines and ancillary data is often required to resolve these sources. A compilation of study results shows that secondary sulfate (SO42) – (derived mainly from sulfur dioxide [SO_2] emitted by Electricity Generating Units [EGUs]), nitrate (NO_3) – (from the oxidation of nitrogen [NO_x] emitted mainly from transportation sources and EGUs), and primary mobile source categories, constitute most of $PM_{2.5}$ (and PM_{10}) in the Eastern U.S.

The PM_{10} is mainly primary in origin, having been emitted as fully formed particles derived from abrasion and crushing processes, soil disturbances, plant and insect fragments, pollens and other microorganisms, desiccation of marine aerosol emitted from bursting bubbles, and hygroscopic fine PM expanding with humidity to coarse mode. Gases such as nitric acid (HNO_3) can also condense directly onto preexisting coarse particles. Suspended primary coarse PM can contain iron (Fe), silicon (Si), aluminum (Al), and base cations from soil, plant and insect fragments, pollen, fungal spores, bacteria, and viruses, as well as fly ash, brake lining particles, debris, and automobile tire fragments.

Health Effects

Summary of causal determinations for short-term exposure to $PM_{2.5}$

Outcome	Casualty Determination
Cardiovascular Effects	Causal
Respiratory Effects	Likely to be causal
Mortality	Causal

Cardiovascular Effects

Epidemiologic studies that examined the effect of $PM_{2.5}$ on cardiovascular emergency department (ED) visits and hospital admissions reported consistent positive associations (predominantly for ischemic heart disease [IHD] and congestive heart failure [CHF]), with the majority of studies reporting increases ranging from 0.5 to 3.4% per 10 micrograms per cubic meter ($\mu g/m^3$) increase in $PM_{2.5}$. These effects were observed in study locations with mean 24-hour average $PM_{2.5}$ concentrations ranging from 7-18 $\mu g/m^3$. Results of multicity epidemiologic studies demonstrated consistent positive associations between short-term exposure to $PM_{2.5}$ and cardiovascular mortality and also reported regional and seasonal variability in risk estimates. The multi-city studies evaluated reported consistent increases in cardiovascular mortality ranging from 0.47 to 0.85% in study locations with mean 24-hour average $PM_{2.5}$ concentrations above 12.8 $\mu g/m^3$.

Controlled human exposure studies have demonstrated $PM_{2.5}$-induced changes in various measures of cardiovascular function among healthy and health-compromised adults. The most consistent evidence is for altered vasomotor function following exposure to diesel exhaust (DE) or Concentrated Ambient Particles (CAPs) with ozone (O_3) (Section 6.2.4.2). Although these findings provide biological plausibility for the observations from epidemiologic studies, the fresh DE used in the controlled human exposure studies evaluated contains gaseous components (e.g., carbon monoxide [CO], NO_x), and therefore, the possibility that some of the changes in vasomotor function might be due to gaseous components cannot be ruled out. Furthermore, the prevalence of ultrafine particles (UFPs) in fresh DE limits the ability to conclusively attribute the observed effects to either the ultrafine fraction or $PM_{2.5}$ as a whole. An evaluation of toxicological studies found evidence for altered vessel tone and microvascular reactivity, which provide coherence and biological plausibility for the vasomotor effects that have been observed in both the controlled human exposure and epidemiologic studies (Section 6.2.4.3). However, most of these toxicological studies exposed animals via intratracheal (IT) instillation or using relatively high inhalation.

In addition to the effects observed on vasomotor function, myocardial ischemia has been observed across disciplines through $PM_{2.5}$effects on ST-segment depression, with toxicological studies providing biological plausibility by demonstrating reduced blood flow during ischemia. There is also a growing body of evidence from controlled human exposure and toxicological studies demonstrating $PM_{2.5}$-induced changes on heart rate variability (HRV) and markers of systemic oxidative responses. Additional but inconsistent effects of $PM_{2.5}$ on blood pressure (BP), blood coagulation markers, and markers of systemic inflammation have also been reported across disciplines. Toxicological studies have provided biologically plausible mechanisms (e.g., increased right ventricular pressure and diminished cardiac contractility) for the associations observed between $PM_{2.5}$ and CHF in epidemiologic studies.

Together, the collective evidence from epidemiologic, controlled human exposure, and toxicological studies is sufficient to conclude that a causal relationship exists between short-term exposures to $PM_{2.5}$and cardiovascular effects.

Respiratory Effects

Recent epidemiologic studies report consistent positive associations between short-term exposure to $PM_{2.5}$ and respiratory ED visits and hospital admissions for chronic obstructive pulmonary disease (COPD) and respiratory infections (Section 6.3). Positive associations were also observed for asthma ED visits and hospital admissions for adults and children combined, but effect estimates are imprecise and not consistently positive for children alone. Most studies reported effects in the range of ~1% to 4% increase in respiratory hospital admissions and ED visits and were observed in study locations with mean 24-h average $PM_{2.5}$ concentrations ranging from 6.1-22 μg/m^3. Additionally, multi-city epidemiologic studies reported consistent positive associations between short-term exposure to $PM_{2.5}$ and respiratory mortality as well as regional and seasonal variability in risk estimates. The multi-city studies evaluated reported consistent, precise increases in respiratory mortality ranging from 1.67 to 2.20% in study locations with mean 24-hour average $PM_{2.5}$ concentrations above 12.8 μg/m^3. Evidence for $PM_{2.5}$-related respiratory effects was also observed in panel studies, which indicate associations with respiratory symptoms, pulmonary function, and pulmonary inflammation among asthmatic children. Although not consistently observed, some controlled human exposure studies have reported small decrements in various measures of pulmonary function following controlled exposures to $PM_{2.5}$.

Controlled human exposure studies using adult volunteers have demonstrated increased markers of pulmonary inflammation following exposure to a variety of different particle types; oxidative responses to DE and wood smoke; and exacerbations of allergic responses and allergic sensitization following exposure to DE particles (Section 6.3). Toxicological studies have provided additional support for $PM_{2.5}$-related respiratory effects through inhalation exposures of animals to CAPs, DE, other traffic-related PM and wood smoke. These studies reported an array of respiratory effects including altered pulmonary function, mild pulmonary inflammation and injury, oxidative responses, airway hyperresponsiveness (AHR) in allergic and non-allergic animals, exacerbations of allergic responses, and increased susceptibility to infections.

Overall, the evidence for an effect of $PM_{2.5}$ on respiratory outcomes is somewhat restricted by limited coherence between some of the findings from epidemiologic and controlled human exposure studies for the specific health outcomes reported and the sub-populations in which those health outcomes occur. Epidemiologic studies have reported variable results among specific respiratory outcomes, specifically in asthmatics (e.g., increased respiratory symptoms in asthmatic children, but not increased asthma hospital admissions and ED visits) (Section 6.3.8). Additionally, respiratory effects have not been consistently demonstrated following controlled exposures to $PM_{2.5}$ among asthmatics or individuals with COPD. Collectively, the epidemiologic, controlled human exposure, and toxicological studies evaluated demonstrate a wide range of respiratory responses, and although results are not fully consistent and coherent across studies the evidence is sufficient to conclude that a causal relationship is likely to exist between short-term exposures to $PM_{2.5}$and respiratory effects.

Mortality

An evaluation of the epidemiologic literature indicates consistent positive associations between short-term exposure to $PM_{2.5}$ and all-cause, cardiovascular-, and respiratory-related mortality. The evaluation of multicity studies found that consistent and precise risk estimates for all-cause (non-accidental) mortality that ranged from 0.29 to 1.21% per 10 μg/m^3 increase in $PM_{2.5}$ at lags of 1 and 0-1 days. In these study locations, mean 24-hour average $PM_{2.5}$ concentrations were 12.8 μg/$m^3$and above (Table 6-15). Cardiovascular-related mortality risk estimates were found to be similar to those for all-cause mortality; whereas, the risk estimates for respiratory-related mortality were consistently larger (i.e., 1.01-2.2%) using the same lag periods and averaging indices. The studies evaluated that examined the relationship between short-term exposure to $PM_{2.5}$ and cardiovascular effects provide coherence and biological plausibility for $PM_{2.5}$-induced cardiovascular mortality, which represents the largest component of total (non-accidental) mortality (~ 35%), as noted by the American Heart Association in 1989 and 2009. However, as noted in Section 6.3, there is limited coherence between some of the respiratory morbidity findings from epidemiologic and controlled human exposure studies for the specific health outcomes reported and the subpopulations in which those health outcomes occur, complicating the interpretation of the $PM_{2.5}$ respiratory mortality effects observed. Regional and seasonal patterns in $PM_{2.5}$ risk estimates were observed with the greatest effect estimates occurring in the eastern U.S. and during the spring. An examination of effect modifiers (e.g., demographic and socioeconomic factors), specifically air conditioning use as an indicator for decreased pollutant penetration indoors, has suggested that $PM_{2.5}$ risk estimates increase as the percent of the population with access to air conditioning decreases. Collectively, the epidemiologic literature provides evidence that a causal relationship exists between short-term exposures to $PM_{2.5}$ and mortality.

Appendix II information derived from: Integrated Science Assessment for Particulate Matter, National Center for Environmental Assessment-RTP Division, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 2009, EPA/600/R-08/139F.

APPENDIX III

The Navajo Experience

The Navajo Experience

The Navajo Nation (Navajo: Naabeehó Bináhásdzo) is a semi-autonomous Native American-governed territory covering more than 27,000 square miles, and occupying portions of northeastern Arizona, southeastern Utah, and northwestern New Mexico. It is the largest land area assigned primarily to a Native American jurisdiction within the U.S. (http://www.bia.gov/FAQs/index.htm). Until the latter part of the 20th century, the majority of the Navajo people lived a rural, agricultural lifestyle, depending on sheep and cattle herding, wool and yarn production, blanket and rug production, and jewelry making for their livelihoods. Many of the people did not speak English, and lived a traditional lifestyle, tied closely to family, clan and community. Salaried jobs were scarce.

The vast lands of the Navajo Nation contain extensive mineral resources that, until the second half of the 20th century, were largely untapped. The Navajo Nation's extensive mineral resources (see the three volumes produced by the Bureau of Indian Affairs 1955–1956: Kiersch, 1956) are thought to be among the most valuable held by Native American nations within the United States (Triefeld, 2007). During the latter part of the 20th century, mining, especially of coal and uranium, provided significant income to the tribe, in the form of leases and royalties. Many adult male Navajos were hired to work in the mines, providing much-needed income to Navajo families.

However, the experience of the Navajo Nation with uranium mining during the Cold War era has left a legacy of undesirable impacts for this group of people:

More than 1000 uranium mines were scattered across the Navajo Nation, ranging from large, company-owned open-pit and underground mines to the many small, dog hole mines that were largely operated by families, using pick and shovel and wheelbarrows to haul ore and waste rock. All of the mines were poorly regulated at the time, but the dog hole mines, in particular, lacked any form of ventilation. Five uranium processing facilities (mills and upgrading facilities) also operated on the Navajo reservation.

The lack of regulation and oversight in the operation of uranium mines and mills resulted in significant impacts to the Navajo people, much of which has been discussed and documented in the Interim Reports, but which is summarized here.

Abandoned mines, radioactive waste rock and overburden, contaminated water sources.

In 2008, the U.S. Congress authorized a five-year, multi-agency cleanup of uranium contamination on the Navajo Nation reservation; identification and treatment of contaminated water and structure has been the first priority. Certain water sources have been closed, and numerous contaminated buildings have been taken down. By the summer of 2011, EPA had nearly completed the first major project of removal of 20,000 cubic yards of contaminated earth from the Skyline Mine area, to controlled storage on the plateau. (http://www.epa.gov/region09/superfund/navajo-nation/index.html).

Five hundred twenty discrete mines have been identified as needing clean-up and closure. These mines and their associated waste materials continue to present a danger to local residents, having sometimes served as stables for animals, unregulated contaminated water from mine sites being used in stock ponds, and radioactive waste rock and mine overburden providing material for constructing homes and other occupied buildings (EPA 2007).

Church Rock Uranium Mill tailings pond dam breech – this event has been extensively discussed in Section 2 of this report, and was a result of poor engineering and lack of regulation.

Health impacts

A 1995 report published by American Public Health Association found: *excess mortality rates for lung cancer, pneumoconioses and other respiratory diseases, and tuberculosis for Navajo uranium miners. Increasing duration of exposure to underground uranium mining was associated with increased mortality risk for all three diseases… The most important long-term mortality risks for the Navajo uranium miners continue to be lung cancer and pneumoconioses and other nonmalignant respiratory diseases* (Roscoe, et al. 1995).

Although there have been almost no studies of potential health impacts on non-worker health (see Shields LM, et al. 1992, Lapham SC, et al. 1989) Navajo families often lived near uranium mines, traveling with the workers to mining camps, where they were exposed to dust, contaminated clothing and mining wastes.

In addition to physical health outcomes, Dawson and Madsen have researched the psychosocial impacts of uranium mining on Navajo people (Dawson SE. 1992 Dawson and Madsen 2011). Former workers often reported experiencing depression and anxiety, and community members talk about the cultural disruption of uranium mining on the Navajo Nation (www.dinecollege.edu/institutes/DPI/Docs/Uranium_policy_brief.doc).

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