EXPOSURE PATHWAYS REPORT

IN SUPPORT OF THE RADIOACTIVE MATERIAL LICENSE APPLICATION

PIÑON RIDGE URANIUM MILL
Montrose County, Colorado

Submitted to:

Radiation Management Unit
Colorado Department of Public Health and Environment

Prepared for:

Energy Fuels Resources Corporation
44 Union Blvd., Suite 600
Lakewood, Colorado 80228

Prepared by:

SENES Consultants Limited
Englewood, Colorado

November 2010

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Approved: 11/11/10

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1.0 INTRODUCTION

Energy Fuels Resources Corporation (EFR) proposes to license, construct and operate a conventional acid leach uranium and vanadium mill at the Piñon Ridge Mill site (the "Site") in western Montrose County, Colorado. Site facilities will include an administration building, a mill covering 17 acres, tailing ponds totaling 90 acres, a 40-acre evaporation pond (expandable capacity to 80 acres), a 6-acre ore storage pad, and an access road. The mill will process ore produced from mines within a reasonable truck-hauling distance and will have a capacity of 500 tons per day, but is designed to accommodate subsequent expanded production capacity of up to 1,000 tons per day. The expected operating life of the mill is 40 years, but may be extended for 10 years or more if economic conditions warrant.

The Site is located in the Paradox Valley at 16910 Highway 90, approximately 12 miles west of Naturita, in Montrose County, Colorado. The Site's legal description is the Southwest ¼ of the Southeast ¼ of Section 5, all of Section 8, the North ¼ of Section 17, and the Southeast ¼ of the Northwest ¼ of Section 17, Township 46 North, Range 17 West, of the New Mexico Principal Base and Meridian. The Site is located on both the Davis Mesa Quadrangle and Bull Canyon Quadrangle 1:24,000 United States Geological Survey (USGS) topographic/geologic maps. The Site location with respect to major topographic features is shown in Figure 1.1.

The Piñon Ridge Mill is subject to regulation by the State of Colorado with mill licenses (Radioactive Material Licenses) issued and administered by the Colorado Department of Public Health and Environment (CDPHE). This report presents an overview of the Contaminants of Potential Concern (COPC), their sources, the exposure media and contaminant pathways, de minimis pathways, and a site conceptual model in support of the mill license application. This "Exposure Pathways Report" forms the basis for the risk assessment ("Risk Assessment for Proposed Uranium and Vanadium Mill at the Piñon Ridge Property" - SENES 2010) that assesses the risk associated with primary contaminants pathways. Additional detailed information on radiological and non-radiological impacts of the mill operations on site and in the surrounding environment is provided in two additional documents, "Estimates of Radiation Doses to Members of the Public from the Piñon Ridge Mill" (Little, 2010) and in the "Regional Dust Analysis Report" (Kleinfelder 2010a).

The focus of this report is to describe the potential releases of radioactive and non-radioactive materials from normal mill operations and activities and the consequent potential for exposing plants, animals, and humans to COPC. Further discussion of the effects of exposure to radioactive and non-radioactive emissions described in this report is provided in the risk assessment (SENES 2010), which also discusses the potential exposures and risks arising from malfunctions and accidents.

Pathway analysis is a mature environmental impact assessment technique, which has been used for many years to assess the release, transport and fate of radionuclides and other COPC through environmental media to receptors of interest (human and/or other biota). The pathways analysis links the source of the COPC with the local mechanisms of environmental transport) action of wind, water, etc) through receiving and exposure media (air, soil, vegetation, surface and groundwater, etc) and identifies the exposure mechanisms and receptors of interest. The results can then be used as input for risk and/or dose assessment. Figure 1.2 presents an example of a simplified schematic illustrating pathways of exposure for biota. Detail on the pathway analysis approach used in this report is provided in Section 3.0, Conceptual Site Model.

Additional information on the techniques of human and ecological pathway analysis can be found in, e.g., Till and Meyer 1983; Whicker and Schultz 1982; Chambers and Phillips 2008; UNSCEAR 2009.

Figure 1.1 Site Location with Respect to Major Topographic Features

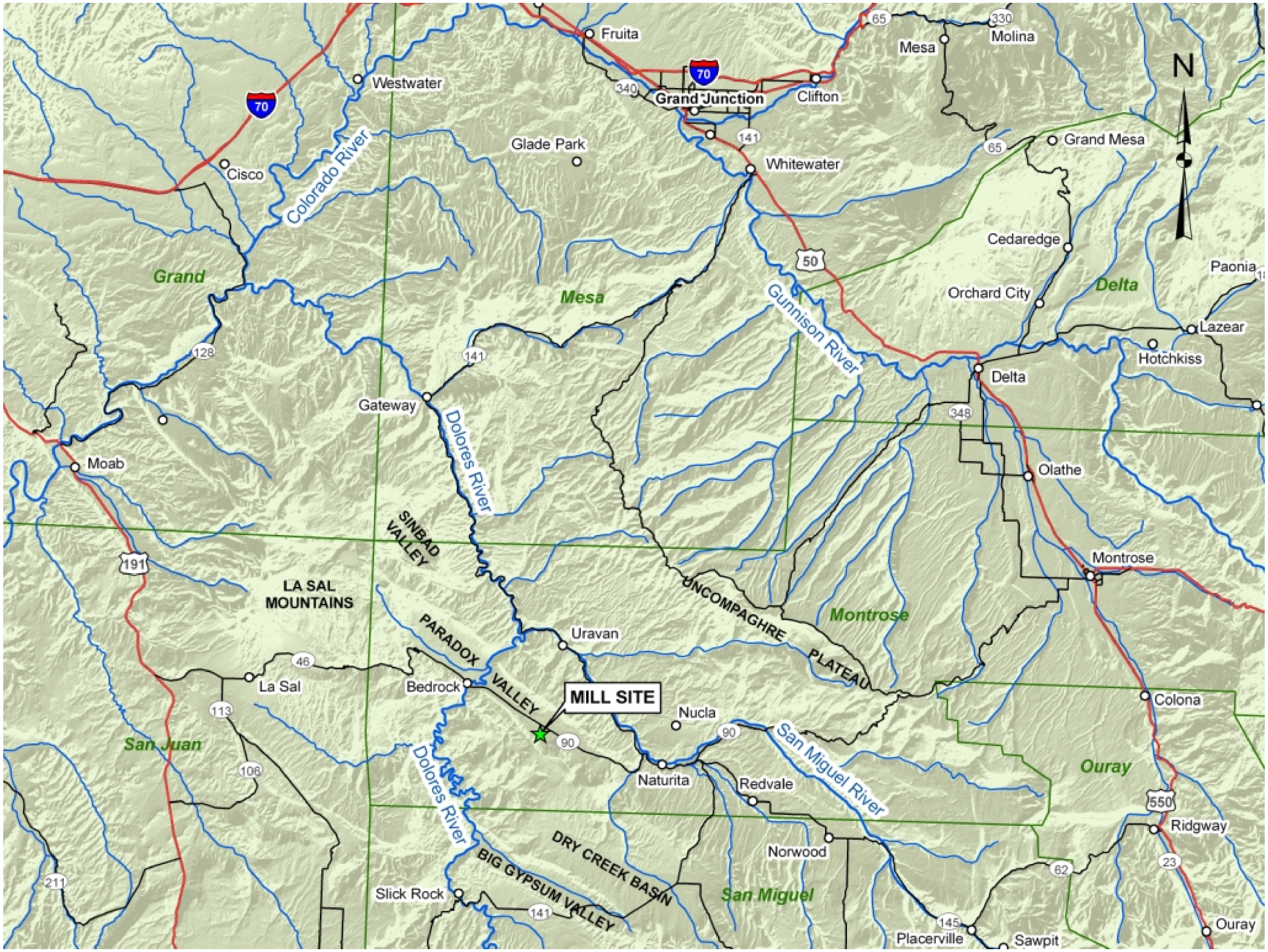
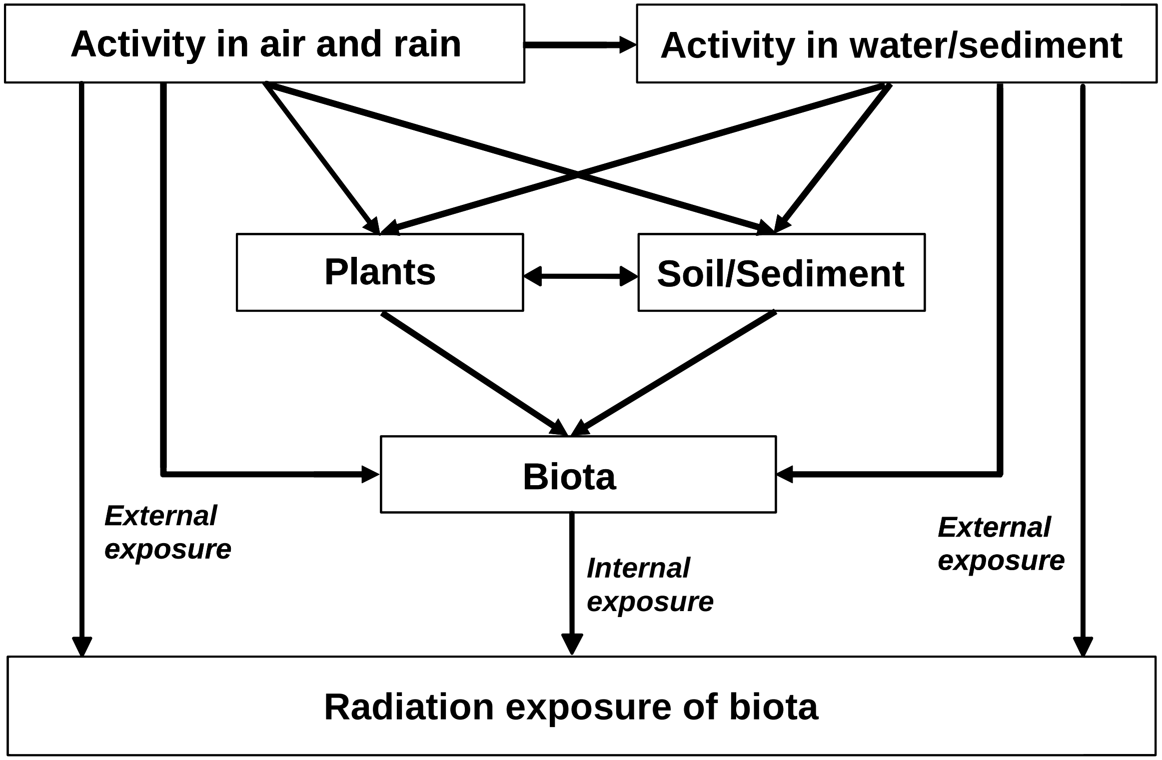


Figure 1.2 Simplified Schematic Illustrating Pathways of Exposure for Biota



2.0 CONTAMINANTS OF POTENTIAL CONCERN (COPC)

The exposure pathways originate with a source of contaminants released to the environment. A review of the mill operations provides an understanding of the sources of the COPC. The general operation of the proposed mill includes the processes provided in Table 2.1. The potential for release of contaminants from each process is also provided in the table.

Table 2.1 Processes and Components of the Operation

The Process	The Process Component	Contaminants of Potential Concern
Transportation	Transport of ore to the mill	Dust (including heavy metals), radionuclides including radon
	Transport of reagents to the mill	Reagents
	Transport of yellowcake from the mill to out-of-state processing plants	Uranium and other radionuclides including radon
	Transport of vanadium concentrate from the mill to out-of-state processing plants	Heavy metals
On-site storage and handling of ore, reagents, and fuels	On-site storage and handling of ore	Dust (including heavy metals), radionuclides including radon
	On-site storage and handling of reagents and fuels	Acids, caustics, petrochemicals
Mineral processing operation including process components in the following areas:	Ore Handling and Grinding	Dust (including heavy metals) and radionuclides (including radon)
	Leaching and CCD Thickeners	radon
	Uranium Solvent Extraction (SX)	Radon, Organics
	Uranium Precipitation, Drying, and Packaging	Uranium dust and radionuclides
	Vanadium Oxidation and Solvent Extraction (SX)	Organics
	Vanadium Precipitation, Drying, and Packaging	Vanadium dust
	Waste Disposal Facilities including Tailings Cells and Evaporation Ponds	Dust, radon

2.1 SOURCES OF RADIONUCLIDES

Radiological exposure pathways originate with a source of radioactive materials. The uranium recovery process for the Piñon Ridge mill is illustrated in Figure 2.1. It consists of several distinct processes that have the potential to release radioactive material during normal operations and activities.

Source terms for the mill operation were considered by the phase of the process in which they will be present as outlined in Table 2.1. Radiological sources are briefly described below along with a short discussion of radionuclides of potential concern. Further details on source term calculations can be found in "Estimates of Radiation Doses to Members of the Public from the Piñon Ridge Mill" (Little, 2010).

- Radionuclides in the uranium-238 decay (U-238) series are illustrated in Figure 2.2. Uranium-238 is the most common isotope of uranium and represents 99.3 percent by mass of natural uranium (and along with its daughter product, uranium 234, about 98% of the radioactivity of the uranium present in uranium ores). Of the 15 radionuclides presented in the uranium-238 decay series, the following radionuclides along with Rn-222 (and its short-lived decay products) are the dominant contributors to dose.

    - U-238
    - U-234
    - Th-230
    - Ra-226
    - Po-210
    - Pb-210

- Uranium-235 is also an isotope of uranium and will be present in natural isotopic ratios based on atomic abundances of 0.9927 U-238 and 0.0072 U-235. Accordingly, U-235 represents a relatively small portion of the dose from natural uranium isotopes. Due to the small percentage of uranium-235 in natural uranium (0.7% by mass), the uranium-235 decay series is not considered further here but was included in the dose assessment (Little 2010).

- U-isotopes (U-238,U-234 and U-235), Ra-226, Th-230, Po-210, and Pb-210 will be present in ore dust that may be generated through ore transfer operations such as truck travel on the ore pad, dumping the ore from trucks onto the pad, picking up the ore and dumping it into the grizzly, and subsequent crushing and grinding. Ore dust is also generated from wind erosion of the ore pile. The size of the dust particles generated by the various mill activities can be an important factor in determining dose. The MILDOS-AREA code considers the effects of particle size on its calculation of dose (Little, 2010).

Figure 2.1 Recovery Process for the Piñon Ridge Mill

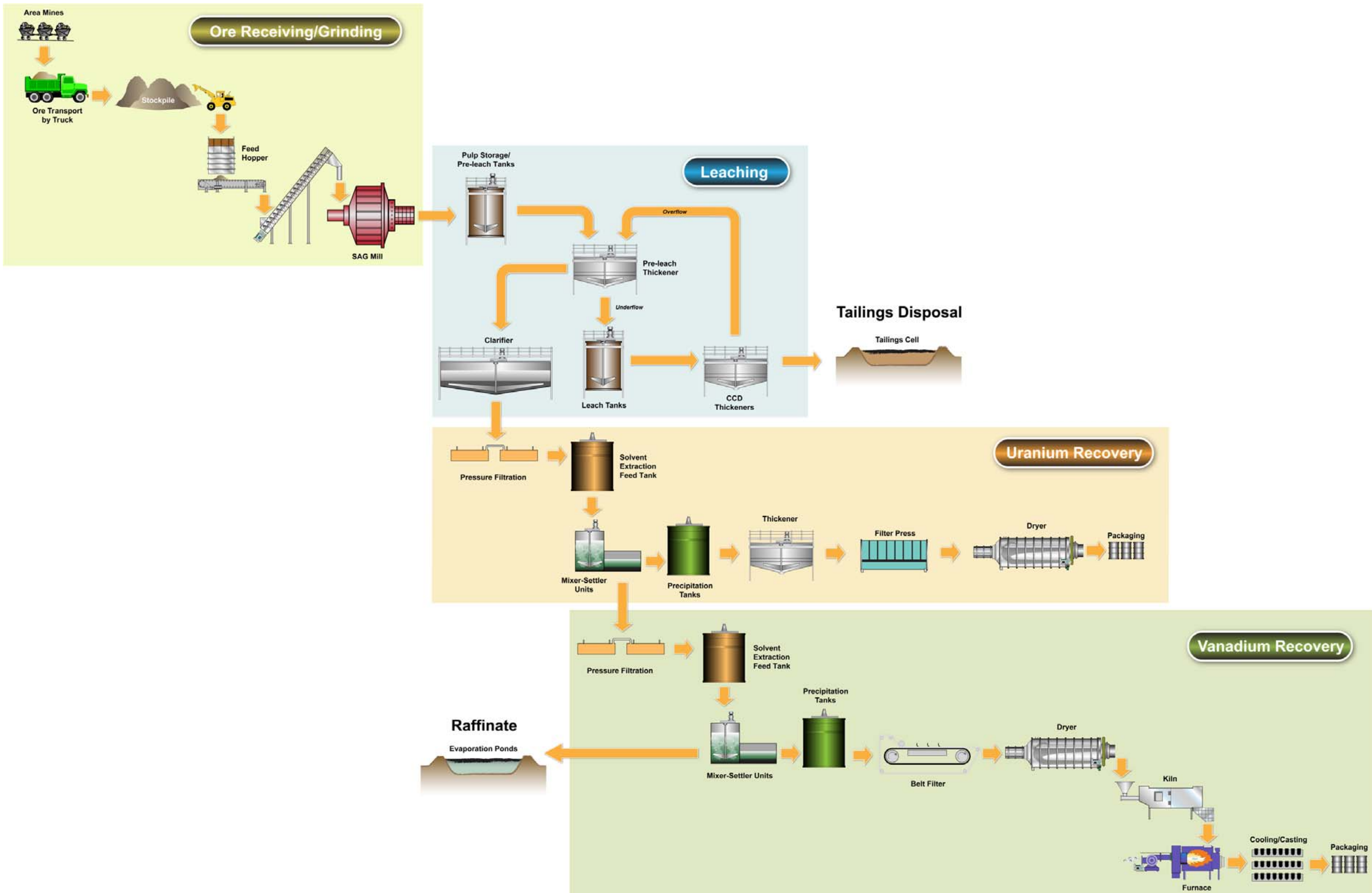
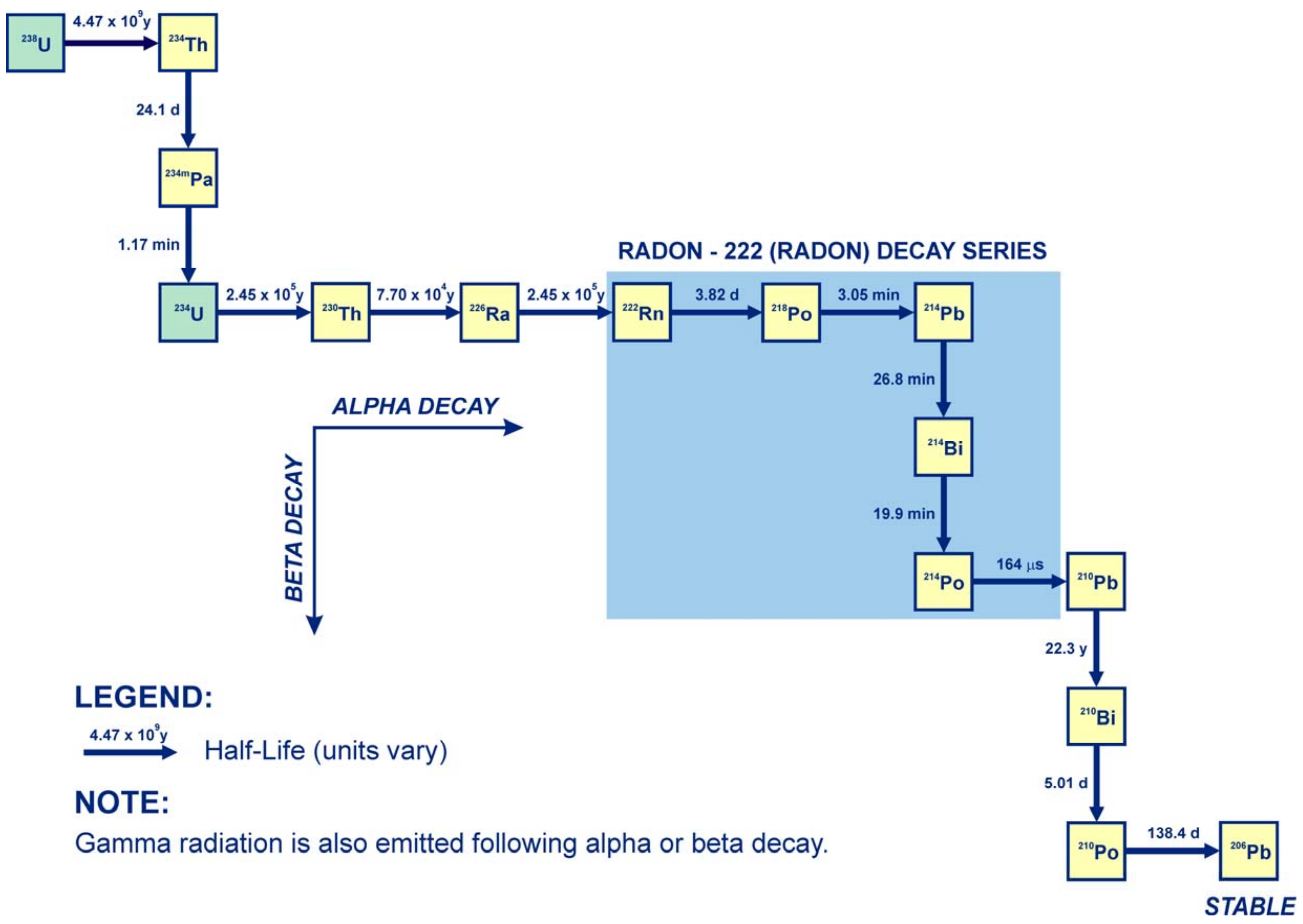


Figure 2.2 Radionuclides in the Uranium-238 Decay (U-238) Series



- Polonium – 210, although with a relatively short half life, can exist in the ecosystem since it is a decay product of Pb-210 (and in turn, of Rn-222) and is potentially important radiologically in the ingestion pathway. However, as discussed in Section 4.3 and presented in Table 4.1, for this site, ingestion pathways (consumption of meat, milk and vegetation) contribute only a very small percentage of the dose.

- Generation of dust from activities such as haulage, ore stockpile activities and tailings disposal, is typically controlled with water sprays and dust suppressant chemicals. Uranium-238 series radionuclides are present in equilibrium with the U-238 parent in the ore. Thus, in dust originating from ores, all U-238 series radionuclides must be considered. In the mill, once the uranium has been separated from the bulk of the ore, the uranium isotopes are the primary COPC.

- Once ore enters the mill, it is mixed with water and ground into a pulp. From that point onwards, the uranium ore is in a slurry form with relatively little potential for dust generation until concentrated and dried. Once the uranium is separated from the remainder of the ore, the uranium isotopes are the primary radionuclides of interest. This is especially true once the uranium is concentrated and sent for drying and packaging. The final product, yellowcake, consists mainly of uranium oxides and their hydrates (e.g., UO_4, UO_3 with H_2O). The yellowcake will be packaged in drums and shipped via truck from the mill for further processing. These activities are closely monitored and potential dust sources carefully controlled through a combination of isolation and dust control at the source. Air exhausted from the mill process areas is directed through high efficiency dust collectors, namely:

    1. The feed system dust collector stack, which collects dust from the unloading of ore to the grizzly and feed conveyor (uranium and decay chain nuclides).
    2. The semi-autogenous grinding (SAG) mill process vent stack from the SAG mill dust scrubber (uranium and decay chain nuclides). This dust collection system has an efficiency of 99.99 %.
    3. The leach train vent gas scrubber stack (uranium and decay chain nuclides progeny). This dust collection system has an efficiency ≥ 99%.
    4. The yellowcake drying and packaging dust collection and venting system, which is a “zero discharge stack”, emitting negligible amounts of radionuclides (see discussion and references on particulate effluents from modern vacuum dryers in Section 4.0).
    5. The vanadium dryer dust collector and packaged bed scrubber stack. This dust collection system also has an efficiency ≥ 99%.

- The mill stacks release only very limited quantities of radionuclides due to the use of highly efficient effluent control systems in the mill as documented in Kleinfelder 2009b and Little 2010. These stacks are considered minor pathway sources. Emissions from these stacks are quantified in the Air Permit Application (Kleinfelder, 2009b).

- Dust from the wet processing activities (acid leach digestion, solvent extraction and precipitation) is minimal although care must be taken to ensure rapid clean-up of any spill which could dry and then present a potential source of airborne dust.

- Essentially all of the Ra-226, Th-230, Pb-210, and Po-210 and limited amounts (on the order of 4%) of U-238 and U-234 will be present in the tailings placed in the tailings cells. Application of tailings solution or raffinate on the tailings beaches will minimize dust generation, but some tailings solids may dry out on the beaches and become airborne. Radon will be produced from the beaches and, to some degree, from tailings solutions. The dust and radon are considered pathway sources for exposure to humans and animals. Liquids containing these sources will be prevented from entering pathways to plants, animals, and/or humans by the lining system under the tailings.

- Rn-222 is an inert noble gas arising as the decay product of Ra-226. Thus, Rn-222 is produced wherever Ra-226 is present. At the mill site radon is released from the ore storage pad, from processing the ore in the mill and from the mill tailings in the tailings cells. The radon which is released into the air from those sources is dispersed by local winds and air currents.

- Th-232 and its decay products could be present in some uranium ores in the future. This decay chain consists of 12 elements of which radium and thorium are long-lived radionuclides However, characterization of ores currently expected to be sent to the Piñon Ridge mill do not indicate elevated levels of natural thorium. Accordingly, Th-232 in ore dust and/or in tailings dust is not considered a COPC for this analysis.

- During the milling process, the concentration of radionuclides including Ra 226 is enhanced in the acidic leached solution. After selective extraction of uranium and vanadium, the leached radionuclides remain in the raffinate and the tailings. Therefore, evaporation ponds and tailings are potential sources of Rn-222.

2.2 SOURCES OF NON – RADIOLOGICAL CONTAMINANTS

Non-radioactive source terms are defined in Table 4 of the U.S. Nuclear Regulatory Commission (USNRC) Regulatory Guide 3.59, “Methods for Estimating Radioactive and Toxic Airborne Source Terms for Uranium Milling Operations”. The sources and emissions are provided in Table 2.2.

Table 2.2 Sources and Emissions of Non-Radionuclides

Source	Emission
Ore storage and crushing/grinding	Ore dust including heavy metals
Leaching tanks vent	Sulfuric acid mist, sulfur dioxide
Solvent extraction vent	Organic Solvent (kerosene/Isodecanol)
Yellowcake precipitation	Ammonia
Yellowcake centrifuge or filter and dryer	Ammonia
Laboratory hood	Miscellaneous vapors
Tailings pile	Tailings dust including heavy metals
Burning of fuel oil	SO_2, NO_2

The analyses of the ores from several mine sites in the area were reviewed to identify metal COPC. As shown in Table 2.3, identified metal COPC include V, As, Pb, Mo, Cd, Se, Cu, U and Zn. Complete analytical reports for the ore samples are presented in the Material Containment Plan (Energy Fuels, 2009a).

Table 2.3 Analyses of the Ores from Several Mine Sites

Metal	Unit	Whirlwind Mine-1	Whirlwind Mine-2	Whirlwind Mine-3	Slick Rock Mine	Paradox Valley Mine	Packrat Mine	Energy Queen Mine	Mean Value
Arsenic	mg/kg-dry	221	387	387	9.6	12.9	112	43.2	168
Cadmium	mg/kg-dry	ND	2.2	0.6	2.0	3.8	1.0	3.5	2.2
Copper	mg/kg-dry	4.0	10.1	12.7	15.6	30.9	14.4	29.2	16.7
Lead	mg/kg-dry	852	117	1470	43.1	23.6	32.2	181	388
Molybdenum	mg/kg-dry	1.2	39.6	40.0	21.8	45.1	1.7	71.3	31.5
Selenium	mg/kg-dry	282	28.7	410	64.2	97.9	120	57.4	151
Uranium	mg/kg-dry	474	4000	5100	1160	984	883	12100	3529
Vanadium	mg/kg-dry	8020	3940	14500	5980	3920	14500	9150	8573
Zinc	mg/kg-dry	36.3	355	59.5	45.0	58.0	69.6	240	123

During the milling process, the concentration of these heavy metals is enhanced in the acidic leach solution, raffinate, and tailings solution.

Based on a comparison of the concentrations of 21 elements in raffinate process water to ecological screening levels, neutralization of the acidic raffinate process waters before discharge to surface impoundments would not reduce the metal concentrations in the solution to non-toxic levels for wildlife (Kleinfelder 2008). The dissolved concentrations of boron, cadmium, copper, manganese, selenium, and uranium concentrations exceed ecological screening levels even at neutral pH while several other metals (barium, nickel and zinc) were elevated above screening levels at the pH level of 7.5 in one of the two samples tested. The selenium concentrations observed in the raffinate are of most concern given its toxicity to waterfowl and elevated concentrations compared to the screening level (Kleinfelder 2008).

Acid mists and fumes are potentially emitted from the leach and counter current decantation (CCD) circuits and organic vapors are emitted from the solvent extraction (SX) circuits. The organic reagents used in the uranium and vanadium SX circuits include kerosene (“$C_{14}H_{30}$”), amine (“Alamine 336 (R_3N)”) and isodecanol (“Exxal 13($C_{10}H_{22}O$)”). The organic mixture is nominally 96% kerosene, 3% isodecanol, and 1% Alamine. It is estimated that 36.4 tons/year of volatile organic compounds (VOCs) are emitted from the SX tanks and mixers and an additional 162 tons/year of VOCs are discharged to the tailings cells and evaporation ponds.

Overall, non-radiological COPC considered for this study are:

- Heavy metals and particulate matter from erosion of ore stockpiles, and dry tailings;
- Heavy metals and particulate matter from transportation and handling of ore and yellowcake;
- Heavy metals and particulate matter from ore grinding, uranium/vanadium recovery and drying processes;
- Acid mists and fumes from the leach and CCD circuits;
- Organic vapors from SX circuits;
- Heavy metals in surface runoff and evaporation ponds, tailings impoundments, and beach sands; and
- Acid solutions in evaporation ponds and tailings impoundments.

3.0 CONCEPTUAL SITE MODEL

The Conceptual Site Model (CSM) is the primary tool that is used to conduct the exposure pathways analysis and risk assessment. The CSM links the source of COPC with their environmental fate and transport mechanisms, receiving and exposure media, exposure mechanism, and the receptors. Figures 3.1 and 3.2 illustrate the CSM for human and ecological receptors respectively.

The potential on site* release mechanisms include the following:

- Surface runoff or seepage from areas storing ore and byproduct material (i.e. tailings and raffinate): Releases to surface water, sediment and soil due to erosive action of running water and subsequent transport and redistribution due to precipitation-driven runoff and transport mechanisms.
- Process line leaks: Releases of contaminants to surface and subsurface soils and subsequent transport and redistribution to other locations due to multiple surface and subsurface transport mechanisms.
- Acid and organic emissions from solvent extraction and counter current decantation processes.
- Radon emissions from the milling operation: Radon gas releases to air from ore stockpiles, tailings, evaporation ponds, and the mill building.
- Particulate emissions from ore grinding, uranium or vanadium dryers off gas system.
- Chemical and yellowcake storage: Leaks and accidental spills from the storage areas.
- Particulate emissions (wind erosion) from exposed tailings, ore pads, and evaporation ponds and from movement of heavy operating equipment: Release to air due to direct wind transport and erosive action of wind and subsequent transport and redistribution due to surface deposition.

* Transportation accidents involving “off site” releases are discussed briefly in this report (See section 4.0 and 6.0) but are analyzed in detail in the risk assessment (SENES 2010)

Potential release mechanisms for human receptors (Figure 3.1) and for other ecological receptors (Figure 3.2) are very similar. However, in the case of non-human receptors, effects of acidic conditions (acid drainage, e.g.) and the action of native bacteria are of particular importance as these mechanisms may enhance mobilization of toxic metals to which non human receptors may be particularly sensitive.

Released COPC primarily enter the receiving environmental media via air, surface or subsurface soil, groundwater, surface water, and sediments. In general terms, transport of contamination is driven by volatilization and degassing, wind erosion, runoff, ecological uptake, and surface deposition, including deposition on soil and on vegetation (e.g., foliar deposition). The exposure media include surface water, groundwater, food, soil, vegetation and air. Exposure mechanisms for human and animal receptors include direct exposure, immersion, inhalation, and ingestion.

Off-site human receptors considered in this assessment included infants, children, and adults residing in the following locations:

- Herron residence;
- Boren residence;
- Kinder residence;
- Davis/Fehlman residence;
- Hurdle residence;
- Hogan w/ unknown residents;
- Bedrock;
- Naturita;
- Norwood;
- Montrose;
- Moab, Utah;
- Telluride.

Hypothetical off-site receptors were also assumed at the property boundaries. Potential doses to these “hypothetical” receptors were previously modeled assuming 24-hour per day, 7-day per week occupation at the property boundary (Little, 2010). This is an extremely conservative assumption, as it is unlikely that a residence would ever be built immediately adjacent to the mill.

On-site human receptors considered in this assessment included mill workers, personnel working in the administration building, and truck drivers transporting ore, reagents, and yellow cake.

Mammals and birds living in the vicinity of the mill are also considered as receptors in this assessment. Mammals (excluding humans) included both wildlife and domestic livestock. Birds are listed as a separate wildlife category because they have access to the restricted area of the site that is not accessible to other wildlife due to fencing.

Wildlife surveys were conducted at the site over four seasons. The mammals observed include coyotes, black-tailed jackrabbit, eastern cottontail, elk, mule deer, and domestic cattle. Birds observed include lark sparrows, dusky flycatchers, cliff swallow, western meadowlarks, mourning dove, western scrub-jay, ruby-throated hummingbird, loggerhead shrike, dark-eyed junco, European starling and American crow. Several reptiles, insects and spiders were also observed. The wildlife observed is typical for the habitat and ecosystems found on the Site. The inventory of bird species at the site did not indicate the presence of waterfowl; this is assumed to be due to the lack of suitable habitat on site. Although the presence of the evaporation ponds may attract some wildlife, there are no nearby habitats to support a large number of waterfowl.

Figure 3.1 Conceptual Site Model for Human Receptors

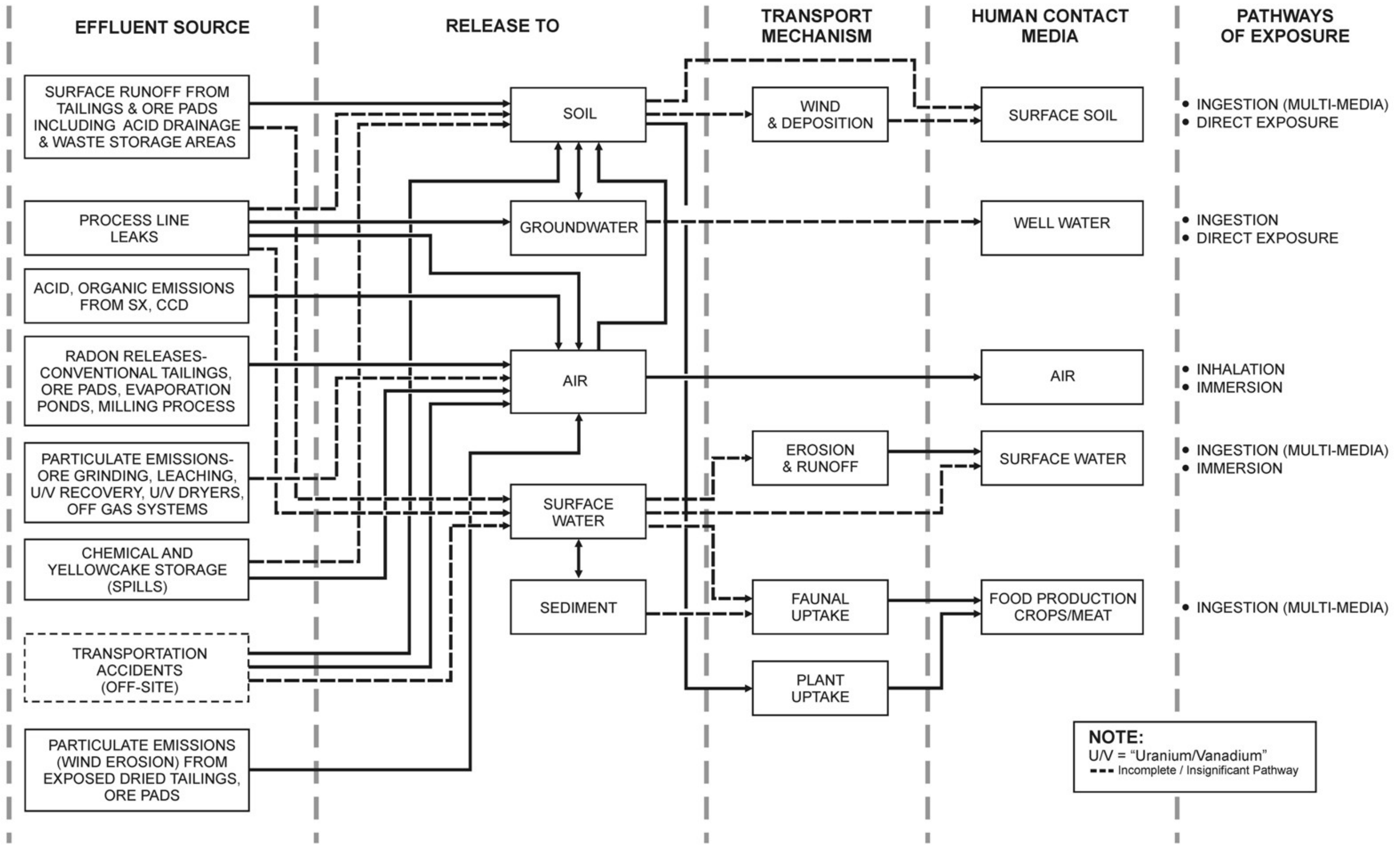
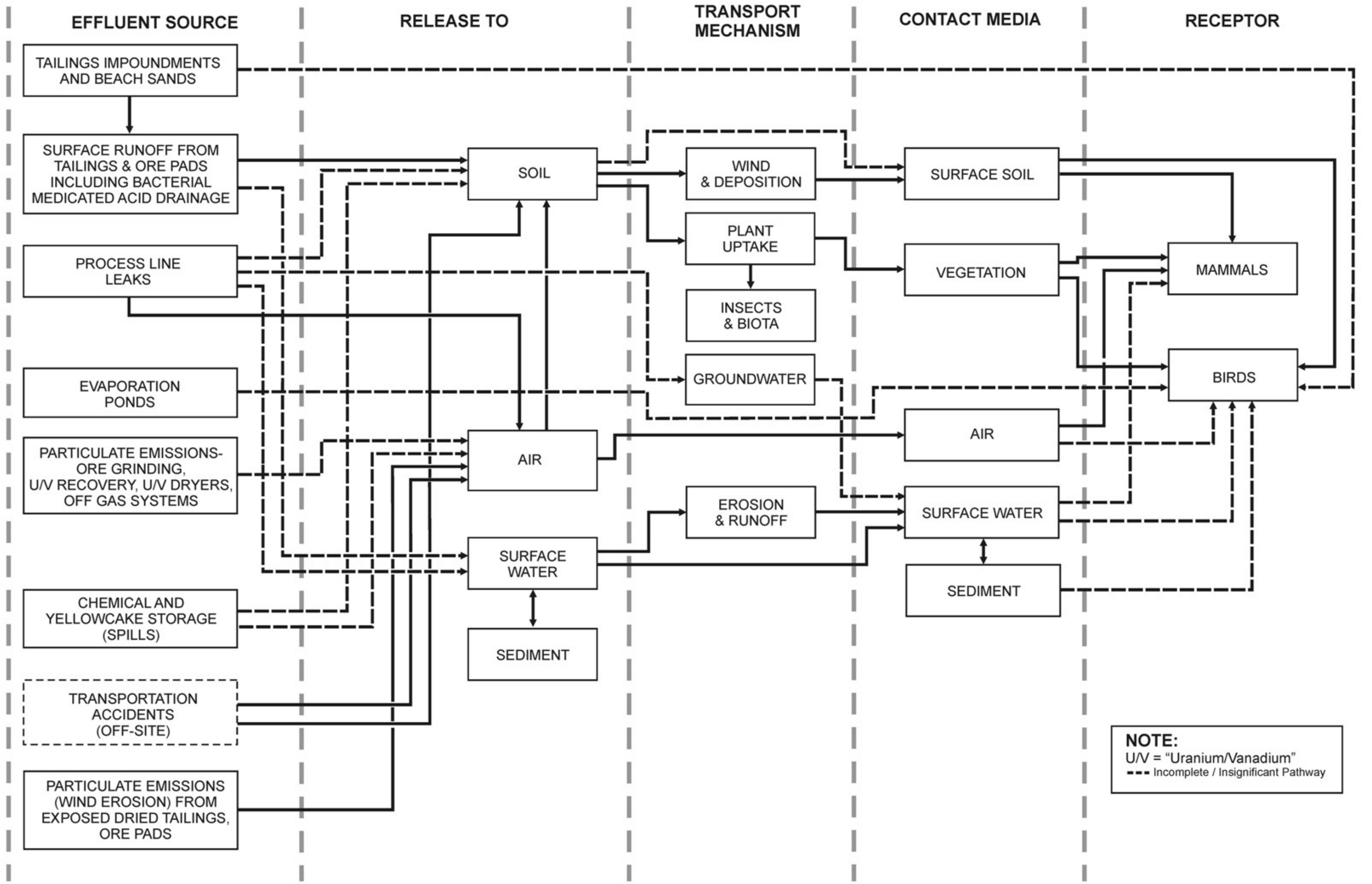


Figure 3.2 Conceptual Site Model for Ecological Receptors



4.0 RADIOLOGICAL PATHWAYS

The environmental fate of radionuclides released from a source is determined through a combination of processes. The released radionuclides are transported through the air or water and subsequently distributed into other environmental media via processes such as deposition to soil or transfer to plants and animals. Radionuclides distributed in the environment can then result in exposure from external radiation (direct exposure, immersion and groundshine) or from the intake of radioactivity in air, water or food. Similarly, plants and animals can be exposed. (See Section 3.0, Conceptual Site Model).

In 1980, the Office of Nuclear Materials Safety and Safeguards at the USNRC published the "Final Generic Environmental Impact Statement (GEIS) on Uranium Milling" (NUREG-0706). The document provided a comprehensive assessment of environmental emissions, pathways, and potential impacts of conventional uranium mills. However, the data and assumptions used by this document represented design and operating conditions 30 to 40 years ago and much of the discussion in NUREG 0706 is no longer relevant to the modern designs and enhancements in the operation of conventional uranium mills today.

For example, in the 1980 GEIS, the model mill ore grinding and crushing technology and equipment and the yellowcake dryers (actually calciners operating at high temperatures) were assumed to release much larger quantities of ore dust and yellowcake respectively into the atmosphere than is the case today with SAG mills and modern low temperature vacuum dryers. In fact, dryer technology has improved to the point where the modern vacuum dryer that will be used in the Piñon Ridge mill will emit negligible amounts of yellowcake dust and is considered a "zero discharge operation" (Faillace et al., 1997; USNRC NUREG-1910, 2009; USNRC NUREG CR/6733, 2001).

The uranium recovery process for the Piñon Ridge mill consists of several distinct processes that have the potential to release radioactive material during normal operations and activities. These processes are listed in Table 2.1. The radioactive emissions from each of these processes are evaluated below to determine potential pathways whereby humans and fauna may be exposed to radiation.

4.1 AIRBORNE RADIOACTIVITY

Among the milling processes listed in Table 2.1, the following processes have a potential for generating sources of airborne radioactivity to humans and flora and fauna.

- Transportation of ore to the mill;
- Transportation of yellowcake from the mill to out-of-state processing plants;
- On-site storage and use of ore;
- Ore Handling and grinding;
- Leaching;
- Uranium recovery including solvent extraction (SX), precipitation, drying, and packaging;

- Waste disposal facilities including tailings cells and evaporation ponds.

Radionuclides released into the atmosphere from the Piñon Ridge mill, as particulates or as radon gas, are dispersed by the local winds. Although the predominant wind direction shifts diurnally between east and west, dispersion occurs in all directions. Data from two meteorological towers on site have been collected for a year and have been entered into the MILDOS computer code for evaluation of the radiation doses to people within an 80-km radius of the Site (Faillace et al 1997). MILDOS uses a Gaussian dispersion of gases and particulates in both horizontal and vertical directions. The results of the MILDOS evaluation of radiation dose are presented in a separate report (Little, 2010). The pathways corresponding to the above processes are described below.

Mill Site

The ore enters the SAG mill where water is added and the ore is ground into slurry. Particulate emissions are very low since the ore is mixed with water producing a slurry. However, during this grinding process, radon will be released to the air inside the mill. During operations, the radon emissions will be monitored by the mill Radiation Safety Officer (RSO) and staff and will be addressed in their evaluation of radiation doses to mill personnel. Ultimately, radon is discharged to the atmosphere by the mill ventilation system or by diffusion through the ventilation system and open doors and windows to the atmosphere. This is evaluated as part of the radon source term for the ore transfer operation using the MILDOS computer model and reported in the MILDOS-AREA assessment report (Little, 2010). Particulate airborne emissions are sent through a treatment and particulate collection system and exit via the mill stack. These emissions have also been evaluated in the MILDOS computer model.

The slurried ore from the SAG mill is temporarily contained in two large pulp storage tanks and then fed into the solvent leaching, thickening, and clarifying units that feed the uranium and vanadium recovery circuits. Radionuclides are sent to a scrubber that is vented through a stack. Emissions from the leach train vent gas scrubber are evaluated in the MILDOS-AREA assessment (Little, 2010).

Uranium in the liquid from the leaching circuit is concentrated in the solvent extraction circuit and then precipitated and dried in the vacuum drier, which is essentially a zero discharge system. For example, in discussing emissions from precipitation and drying, USNRC NUREG CR/6733, Section 2.2.3, Precipitation and Drying comment:

> *"Newer plants usually employ vacuum yellowcake dryers. In a vacuum dryer, the heating system is isolated from the yellowcake so that no radioactive materials are entrained in the heating system or its exhaust. The drying chamber that contains the yellowcake slurry is under vacuum. Therefore, any potential leak would cause air to flow into the chamber, and the drying can take place at relatively low temperature [e.g., 149 ° C (250 ° F)]. Moisture in the yellow cake is the only source of vapor. Emissions from the drying chamber are normally treated in two*

ways. First, vapor is passed through a bag filter to remove yellowcake particulates with efficiency in excess of 99 percent. Any captured particulates are returned to the drying chamber. Then, any water vapor exiting the drying chamber is cooled and condensed. This process captures virtually all escaping particles".

<u>Transportation</u>

Transportation accidents involving semi-truck transport of ore or of yellowcake packaged in 55-gallon drums are possible, but unlikely. The ore trucks will be coming from mines in the region. Given the generally low grade of the ore and the fact that the radionuclides are contained within the matrix of the rock mass, the potential transfer of radionuclides to humans from a spill of ore is negligible. The trucks transporting the yellowcake are operated by trained drivers and equipped with an emergency response kit containing equipment and supplies to minimize the spread of yellowcake that may spill from a breached drum(s). Spilled yellowcake can be spread around the accident site by vehicle traffic and human traffic and is a potential source of airborne contamination. Airborne yellowcake can be inhaled by humans at the accident scene. However, yellowcake is a heavy material, which helps to minimize its dusting potential. Air sampling at the accident scene, uranium in urine bioassay, and/or in vivo counting of personnel who might have inhaled the yellowcake may be conducted or ordered by the accident response personnel. The potential impacts arising from transportation accidents is described and evaluated in Sections 3.1.2, 3.2.2, 4.1.2, and 4.2.2 of the risk assessment report (SENES 2010).

<u>Tailings Disposal and Ore Stockpile</u>

The tailings are discharged from the mill and are the milling byproduct from which most of the uranium has been removed. The tailings consist primarily of a slurry of fine-grained sand and processing solution with a pH of approximately 3. The tailings contain elevated levels of radionuclides and some metals that originate from the same mineralization in which the uranium and vanadium are found. Virtually all progeny originally present in the ore are still present in the tailings after the milling process. The tailings are discharged from the mill as sand-water slurry to the tailings cell where most of the tailings remain wet or damp. The presence of a pool of tailings liquid over a portion of the tailings cell will suppress the generation of tailings dust. However, solid tailings in the beaches above the pond water level can dry and become a source of wind-blown tailings particles, especially during the warmer summer months. EFR will minimize the generation of tailings dust by applying tailings liquid over the solid tailings during operations. These solutions contain high concentrations of salts and are effective in forming a hard crust over the tailings.

When a tailings cell has been filled to capacity, it will be capped with a soil cover to eliminate the potential for wind-blown tailings dust and reduce radon emissions to below federal (40 CFR 61, Subpart W) and CDPHE (6 CCR 1007-1, Part 18, Appendix A) mandated limits of 20 pCi-m^2/sec. It should be noted that drying out of the tailings impoundments prior to the construction of the cap could be a source of dusting. This "worst-case" situation is evaluated in the Regional Dust Analysis Report (Kleinfelder, 2010a) using the MILDOS Area Model.

The ore pad stockpiles will be sprayed with water for dust suppression purposes during the course of routine operations from a trailer-mounted water cannon and/or from an installed dust suppression piping and spraying system. However, fugitive dust will be generated, especially during hot and windy summer days. The potential impacts to receptors are evaluated in the MILDOS-Area assessment (Little, 2010).

Release of Equipment from the Restricted Area

Ore trucks and other equipment operating within the mill license boundary will be monitored when leaving the site to prevent the spread of contamination. Any vehicle or equipment leaving the license boundary area will be washed and surveyed for radiation by a radiation technician. If the equipment is cleared by the radiation survey (with consideration of applicable contamination limits, e.g., per USNRC 2003 – Regulatory Guide 8.30, HP Surveys at Uranium Recovery Facilities), it will be allowed to exit the site. If the truck or piece of equipment is contaminated in excess of these limits, it will be directed to the truck wash station for further decontamination and resurveyed. The truck wash will be a touchless system utilizing high pressure sprays to remove any dirt or mud. Minor amounts of residual contamination on trucks or equipment has the potential to produce dust and radiation after the equipment leaves the mill site.

4.2 WATERBORNE RADIOACTIVITY

The mill is located in a semi-arid environment with an absence of lakes, running streams or tributaries near the site. The dry washes that cross the site from south to north will occasionally contain running water for a short period of time after a significant rain event. Engineering controls, such as diversion channels, will be used to direct runoff away from the facility limiting the potential for this water to come in direct contact with the mill infrastructure. Runoff from the mill itself will be collected and contained on site in the storm water ponds, which will be monitored and maintained by mill personnel. At the Piñon Ridge mill, there will be no releases of water arising from normal operations.

Because of the lack of inhabitants near the mill and the lack of waterborne sources of radioactivity, potential contamination to humans from the surface water pathway is negligible. Evaporation ponds are not a source of drinking water for human receptors and bird netting and fencing are expected to exclude livestock and wildlife including birds from the ponds.

Truck or vehicle accidents involving ore transportation are a potential source of waterborne radioactivity to humans. In a study conducted by SENES Consultants Limited (SENES 2009, *Update of Environmental Assessment of a Credible Transportation Accident Scenario for Cameco McArthur Operation,* Prepared for Cameco Corporation.), impact of the consequences of a spill of uranium ore and solid mineralized waste into a river in the province of

Saskatchewan in Canada was assessed. Although it is recognized that uranium ore from this region of Saskatchewan would be expected to be of higher grade and different chemical composition than ore from the Uravan mineral belt of the Colorado plateau, the physical characteristics of this material related to mobility / transportability in the environment are considered similar and relevant. The assessment showed that even if it was assumed that 100% of the contents of an ore container are washed into the river, the effect on metal and radionuclide concentrations in the surface water would dissipate quickly. The assessment considered As, V, Cu, Pb, Cd, Co, Cr, Mo, Se, U, 226Ra, 230Th, 210Pb, 210Po in the ore solids and liquids as well as in the mineralized waste.

Although considered very unlikely, if an accident involves a spill of yellowcake into a stream or river, the yellowcake would ultimately settle on the bottom of the waterway because the yellowcake is heavy compared to water and minimally soluble in water at neutral to slightly alkaline pH, which is usually the pH of water in streams or rivers. Yellowcake spilled into a waterway is expected to settle to the stream bottom where small amounts of the yellowcake may be available to enter the pathway to humans (i.e., water to fish to humans). Water sampling at the accident scene, uranium in urine bioassay, and/or whole body counting of personnel who might have inhaled the yellowcake may be conducted or ordered by the accident response personnel. The potential exposures arising from these two transportation accidents are described and evaluated in Sections 5.4.2 and 5.4.12 of the risk assessment report (SENES 2010).

It is also of note that Energy Fuels has prepared a comprehensive spill response plan which is presented in Section 4.3 of the Emergency Response Plan which describes the spill response procedures applicable for these and other transportation accidents. Although the transporter is the legally responsible party for implementing the spill response under US Department of Transportation regulations, EFR will assist as necessary, especially in terms of monitoring the cleanup.

4.3 DE MINIMIS PATHWAYS

De minimis is a Latin expression meaning *about minimal things*, normally in *de minimis non curat lex* ("The law does not concern itself with trifles")[1]. In risk assessment, it refers to a level of risk that is too small to be concerned with. Some refer to this as a "virtually safe" level.[2]

For purposes of this pathway analysis, de minimis pathways are those that are considered too small to be of consequence or with a probability of occurrence that is so low as to be “incredible”. For the Piñon Ridge Uranium Mill, the de minimis pathways for radiological COPCs result from incomplete pathways or those pathways that contribute less than 5 % to the overall

[1] see Ehrich, Eugene, *Amo, Amas, Amat and More*, p. 100. Harper Row 1985. ISBN 0-06-27217-1

[2] National Library of Medicine Toxicology Glossary - Risk *De minimis* @ http://sis.nlm.nih.gov/enviro/glossaryr.html

dose. A pathway is considered “incomplete” if the COPC cannot reach the receptor of interest due to absence of the source (no release), and/or the absence of a mechanism of transport (surface or groundwater e.g.) and/or absence of a media of exposure (soil, vegetation, biota in food chain to humans, etc). For example, human exposure due to consumption of fish is an incomplete pathway since there are no perennial surface water bodies in the immediate area that support fish populations. In this case, both the mechanism of transport (run off to surface water) and the media of exposure (fish) are absent. Accordingly, the de minimis pathways include:

- Yellowcake drying and packaging area. This area has its own heating, ventilating, and air conditioning (HVAC) system, and two sets of doors (vestibules) that remain closed at the exits to provide additional containment of air-borne particles. Only authorized operations personnel are allowed within the packaging area and they are required to wear appropriate personal protective equipment, including air-purifying respirators, gloves, and coveralls. A viewing area is provided about the packaging area for guests and non-operations personnel. The yellowcake dryer is a rotary vacuum dryer, with virtually zero particulate emissions (See Section 4.1). The moist air generated by the dryer is drawn through filter socks that are integral to the dryer. An automatic shaker shakes the sock cage and the particles fall back into the dryer. The air from the filter socks is drawn by a vacuum into a condenser where the water and any remaining particulates are removed and pumped to the uranium thickener feed box. The clean air is vented to the uranium packaging room. Negligible emissions are anticipated for this process area.

- Soil. Soil around a uranium mill can contain uranium, Ra-226, Th-230, Pb-210 and Po-210 particles in the form of ore dust or tailings dust that could impact humans as a result of the ingestion or inhalation of soil or resuspended radionuclides. Those particles can be resuspended into the air by winds, vehicle traffic, or moving the soil. Resuspended radionuclides are not considered a major pathway to animals or humans because the air emission levels and consequently, surface deposition are very low and the radionuclides are diluted in the soil particles and dust. Consumption or inhalation of soil or resuspended radionuclides is considered a de minimis pathway as verified by the results of the MILDOS analysis since deposition on soil is very small (Little, 2010). This is demonstrated in Table 4.1, which presents the very small doses associated with the ground deposition pathway.

- Meat, vegetation, and milk. Cattle are grazed seasonally near the mill on some lands in Paradox Valley. Vegetables and milk are not produced in the immediate area of the mill; however, for completeness of the radiological assessment of effluents from the mill, vegetable and meat pathways were included in the computer model MILDOS-AREA. Doses from those pathways were minimal and generally less than 20% (less than 1.25 mrem/yr) of the overall dose (Table 4.1) and are considered de minimis. Consumption of wild game is another pathway of radionuclides to humans. This pathway depends on the uptake of radionuclides by wild game (i.e., from soils to plants to animals) and on the subsequent harvesting and consumption by humans. Since wild game is not expected to preferentially graze on the mill property near the mill buildings and tailings area where radionuclide concentrations may potentially be elevated, their uptake of radionuclides should be minimal. Even though a number of locals consume deer and elk meat, the very small amounts of radionuclides above background in the meat that could result from mill activities will result in this being a De Minimus pathway. The contribution to the TEDE for meat ingestion had a maximum of 3.63% (0.22 mrem/yr) contribution (fence line location). The meat pathway has a maximum of 1.71% contribution to TEDE to an actual resident (not an onsite worker or someone at the fenceline). The maximum contribution to TEDE from vegetable ingestion pathways was 20.6% (1.25 mrem/yr) at the office; however, the vegetable ingestion pathway is not a credible pathway for an onsite worker. The largest contribution to the TEDE for a hypothetical fence line resident was calculated to be 20% (0.56 mrem/yr). The contribution of dose as a result of both meat and vegetable ingestion pathways is tabulated below in Table 4.1, Fraction of TEDE Contributed by Each Pathway to Adult Receptors. As the maximum TEDE was calculated to be 0.504 mrem/yr to an actual offsite receptor (Table 6.2) and a maximum of 8.21 mrem/yr at the fence line (Table 6.1), ingestion pathways represent a small fraction of a mrem/yr to the public.

- Water runoff and groundwater. Consumption of locally-occurring water is not anticipated by humans in the mill area because of the scarcity of perennial surface waters in the area. Animals may drink rainwater when available, but that activity is limited at the Site because of the lack of available water collection areas and low rainfall and should not be a significant pathway of radionuclides to animals. Bird balls will be used to cover the water surfaces in the tailings cells and bird netting will be used to cover the evaporation pond area. These measures will block access by waterfowl and birds that might attempt to drink from the tailing cells or evaporation ponds. Releases of radionuclides to groundwater are not anticipated at the Site in part due to the lining systems under the tailings cells, evaporation ponds, stormwater ponds, and ore pad (Golder, 2008a, 2008b, and 2008c). Even if a leak were to occur, the depth to groundwater beneath the site of 400 feet or more combined with the lack of down gradient potable water wells in the area (Golder, 2009), would rule out the potential for consumption by the public. Monitoring wells will be installed at the Site to monitor for potential releases to the subsurface. In addition, should a release be detected, remedial measures are available to limit the spread of contamination.

Table 4.1 Contribution of Each Pathway Dose (mrem/yr) to Adult Receptors TEDE Source: (Little 2010)

Location	Inh	Ground	Cloud	Veg Ing	Meat Ing
Naturita	6.76E-02	5.19E-04	6.84E-03	1.86E-03	3.44E-04
Herron	4.06E-01	1.55E-03	4.84E-02	3.90E-03	6.92E-04
Boren	2.60E-01	9.74E-04	3.28E-02	3.37E-03	6.14E-04
Kinder	2.59E-01	9.71E-04	3.27E-02	3.36E-03	6.15E-04
Davis/Fehlman	2.26E-01	2.99E-03	2.38E-02	6.24E-03	1.10E-03
Hurdle	1.57E-01	2.67E-03	1.73E-02	5.78E-03	1.02E-03
Hogan	1.49E-01	4.35E-04	1.56E-02	6.74E-04	1.19E-04
Bed Rock	7.20E-02	2.87E-03	7.23E-03	6.51E-03	1.15E-03
Fence 1	2.92E+00	4.05E-02	1.89E-02	7.49E-02	1.29E-02
Fence 2	1.35E+00	3.07E-02	2.06E-02	6.06E-02	1.04E-02
Fence 3	7.32E-01	6.83E-03	1.76E-02	1.16E-02	2.00E-03
Fence 4	1.44E+00	6.78E-03	2.07E-02	9.26E-03	1.49E-03
Fence 5	9.10E-01	2.75E-03	2.33E-02	2.54E-03	3.90E-04
Fence 6	2.29E+00	8.83E-03	4.51E-02	1.18E-02	1.68E-03
Fence 7	5.27E+00	2.55E-02	1.11E-01	3.44E-02	5.93E-03
Fence 8	2.93E+00	1.68E-02	1.27E-01	2.48E-02	4.28E-03
Fence 9	2.17E+00	6.92E-02	7.54E-02	1.37E-01	2.40E-02
Fence 10	1.67E+00	1.59E-01	4.84E-02	3.25E-01	5.74E-02
Fence 11	1.81E+00	2.42E-01	4.25E-02	5.03E-01	8.85E-02
Fence 12	1.83E+00	2.71E-01	3.92E-02	5.63E-01	9.86E-02
Fence 13	4.64E+00	6.01E-01	4.08E-02	1.25E+00	2.18E-01
Fence 14	7.54E+00	1.85E-01	5.16E-02	3.63E-01	6.35E-02
Fence 15	4.63E+00	1.29E-01	4.42E-02	2.58E-01	4.46E-02
Office Bldg	9.88E-01	1.51E-01	1.25E-02	3.13E-01	5.52E-02
Telluride	1.15E-02	5.47E-05	1.48E-03	1.26E-03	2.48E-04
Norwood	2.46E-02	1.36E-04	3.30E-03	1.43E-03	2.78E-04
Montrose	8.65E-03	4.43E-05	1.12E-03	9.03E-04	1.78E-04
Moab	2.04E-02	6.38E-05	2.73E-03	1.92E-03	3.77E-04

Inh – Inhalation
Ground – Groundshine
Cloud – Cloud Immersion
Veg Ing – Vegetation Ingestion
Meat Ing – Meat Ingestion

- Transportation accident. Spill of yellowcake or ore into the water would potentially result in a localized impact on the aquatic environment. However, such an accident, especially for the transport of yellowcake, is unlikely (NUREG-0706, NUREG-1508) and spills would be cleaned up immediately. The workers involved in responding to spills or accidents of this type will have specific training in how to respond to the incident and recover the spilled materials to prevent personnel contamination and further spread of the materials. Energy Fuels Resources has developed a comprehensive spill response plan which is described in Section 4.3, Transportation Accidents of the Piñon Ridge Mill Emergency Response Plan (October 2009). Although the transporter is the party legally responsible for implementing the spill response, EFR will assist as necessary, especially in terms of monitoring the cleanup.

- Although a transport accident is considered a de minimis pathway, truck accidents have been included in the risk assessment due to concerns expressed by a number of individuals during the public comment process. The Risk Assessment report (SENES 2010, Section 3.1.2) presents details of the radiological dose to the public due to the transportation of ore evaluated by the USNRC. An analysis was also performed by the US Department of Energy (DOE 2007) of a major transportation accident involving uranium ore. For this conservative analysis, the maximally exposed individual was assumed to be located about 33 ft from the site of the accident which was assumed to be the closest an individual (resident) could be to the haul route. It was estimated this individual would receive a radiation dose of 4.9 mrem (< 10% of the CDPHE public dose limit of 100 mrem /yr).

- Based on the above previous analyses by the USNRC and USDOE, the dose projected for an ore transportation accident pathway is considered. See the detailed analysis presented in Section 3.1.2 of the risk assessment (SENES 2010).

- Sprinklers. Sprinklers (or misters) are often used to assist in the evaporation of tailings liquid from the evaporation pond. Winds can carry the spray beyond the edges of the evaporation pond. An analysis of the radon emissions from the evaporation ponds indicated that the emissions from the sprinkler system are extremely insignificant compared to the estimated total emissions from the ponds (approximately 6 orders of magnitude smaller) (SENES 2010a). This pathway is considered de minimis.

- Wildlife and livestock pathways. Limited airborne releases and subsequent deposition to the soil results in soil and offsite surface water concentrations which are likely to be within background levels. In addition, the access to tailings impoundments and evaporation ponds is limited due to the bird netting, bird balls and the presence of an eight-foot high chain-link fence around these facilities. Therefore, pathways to wildlife and livestock are considered to be de minimis. This conclusion is validated by the very low deposition onto soil as suggested by the very low doses from the “worst-case” MILDOS Area analyses (See Table 5-2 in Kleinfelder, 2010a).

- Pathways for future land use. Although future residential development near the mills is theoretically possible, it is anticipated that future land use “at the fence line” is likely to be limited to non-residential, industrial/commercial exposure scenarios. The TEDE for workers at these future facilities would be much less than a full-time receptor at the fenceline (maximum of 8.21 mrem/year, Little 2010). This would be the case since these workers would be exposed for only 40 hours / week (not 24 hrs /day as would be the case of a full time resident) and would not be exposed to some pathways, e.g., those via ingestion that could be relevant for a full-time receptor. Therefore, this pathway is also considered to be de minimis.

See also Table 10.1, which provides a summary of exposure pathways for radiological COPC including the de minimis pathways discussed above.

5.0 NON-RADIOLOGICAL PATHWAYS

5.1 AIRBORNE NON-RADIOLOGICAL CONTAMINANTS

Among the milling processes identified in Table 2.1, the following processes have a potential for generating sources of airborne heavy metals (including V, As, Pb, Mo, Cd, Se, Cu, U and Zn) that could impact humans and flora and fauna.

- Transportation of ore to the mill and associated dust emissions and deposition;
- Transportation of yellowcake from the mill to out-of-state processing plants and associated dust emissions and deposition;
- Dust emissions from onsite storage and handling of ore and yellowcake;
- Dust emissions from ore handling and grinding;
- Dust emissions from uranium/vanadium recovery including drying and packaging; and
- Waste disposal facilities including erosion from dry tailings.

The uranium dryer and its off gas system is “zero emission” equipment with respect to air. The mill facilities that have the potential for release of dust or toxic fumes (e.g. SAG mill, leach tanks, precipitation tanks, vanadium kiln and furnace) are equipped with baghouses or wet scrubbers to minimize emissions of dust or fumes to the atmosphere.

In addition, similar pathways and control mechanisms described in Sections 4.1 are applicable to the release and exposure to dust from ore stockpiles and dry tailings.

The following processes have a potential for generating sources of airborne acid mists and fumes and organic vapors that could impact humans and flora and fauna.

- Acid mists and fumes emissions from the leach and CCD circuits; and
- Organic vapor emissions from SX circuits and evaporation ponds.

The process vessels in the leach, CCD, and SX circuits are closed to minimize the emissions of the acid mists and fumes and organic vapors.

Based on the occupational health and safety measures and other control measures in place at the mill, it is expected that the worker exposure to non-radiological COPC will be monitored, documented and controlled to comply with appropriate regulatory limits and related exposure standards (e.g., those of the American Conference of Governmental Industrial Hygienists). Dust emission controls such as water spraying, baghouses, and scrubbers, will reduce the offsite receptors exposure to dust. In addition, the exposure to acid fumes and organic solvent vapors will also be reduced by process control measures implemented in the acid storage areas and the leach, CCD, and SX circuits.

It is expected that dust emissions from ore handling and grinding and resuspension and erosion of particulate matter originating from soil, ore stockpiles, and dry tailings will be the major sources of exposure to heavy metals. Metals in the emissions from the ore and byproduct material processes were estimated based on the modeled PM_{10} (particulate matter) emissions (Kleinfelder 2010b) and metals concentrations in the ore and tailings. The ore and byproduct material were determined to be 30 and 8 percent of the total PM_{10} emissions, respectively. The balance of the PM_{10} emissions is from roads (61%) and combustion processes (1%). Based on the total PM_{10} emissions and concentrations of various metals in ore and byproduct material, the amount of metals emitted from the mill per year are shown in Table 5.1, below. Tables 5.2 and 5.3 show the annual estimated average metal concentrations in the atmosphere at the property line (maximum location) and at the nearest residence in Paradox Valley based on the modeled PM_{10} concentrations and concentrations of various metals in ore and byproduct material. These concentrations, which are in micrograms per cubic meter (ug/m^3), are compared with regulatory criteria in Section 3.2.1 of the Risk Assessment report (SENES 2010).

Table 5.1 Total Metals Emissions
(PM_{10} = 67.26 ton/yr)

	Ore (30%) (lb/yr)	**Tailings (8%)** (lb/yr)	**Total** (lb/yr)
Arsenic	6.78	1.80	8.58
Cadmium	0.09	0.02	0.11
Copper	0.68	0.18	0.85
Lead	15.71	4.17	19.88
Molybdenum	1.28	0.34	1.61
Selenium	6.13	1.63	7.75
Uranium	142.8	1.52	144.30
Vanadium	346.6	13.81	360.45
Zinc	4.99	1.32	6.31

Table 5.2 Maximum Annual Average Concentration at Property Line
PM_{10} = 23.8 micrograms / cubic meter (ug/m^3)

	Ore (30%) (µg/m^3)	**Tailings (8%)** (µg/m^3)	**Total** (µg/m^3)
Arsenic	1.20E-03	3.18E-04	1.52E-03
Cadmium	1.56E-05	4.15E-06	1.98E-05
Copper	1.20E-04	3.17E-05	1.51E-04
Lead	2.78E-03	7.38E-04	3.52E-03
Molybdenum	2.26E-04	5.99E-05	2.86E-04
Selenium	1.08E-03	2.88E-04	1.37E-03
Uranium	2.53E-02	2.68E-04	2.55E-02
Vanadium	6.13E-02	2.44E-03	6.38E-02
Zinc	8.83E-04	2.34E-04	1.12E-03

Table 5.3 Annual Average Concentration at the Nearest Residence
PM_{10} = 1.7 micrograms / cubic meter (ug/m³)

Metal	Ore (30%) (μg/m³)	Tailings (8%) (μg/m³)	Total (μg/m³)
Arsenic	8.56E-05	2.27E-05	1.08E-04
Cadmium	1.12E-06	2.96E-07	1.41E-06
Copper	8.54E-06	2.27E-06	1.08E-05
Lead	1.99E-04	5.27E-05	2.51E-04
Molybdenum	1.61E-05	4.28E-06	2.04E-05
Selenium	7.74E-05	2.06E-05	9.80E-05
Uranium	1.80E-03	1.92E-05	1.82E-03
Vanadium	4.38E-03	1.74E-04	4.56E-03
Zinc	6.30E-05	1.67E-05	7.98E-05

5.2 WATERBORNE NON-RADIOLOGICAL CONTAMINANTS

Among the milling processes identified in Table 2-1, the following processes and release mechanisms have a potential for generating sources of waterborne heavy metals (including V, As, Pb, Mo, Cd, Se, Cu, U and Zn) that could impact humans and flora and fauna.

- Surface runoff from ore stockpiles, storage areas, and process areas;
- Runoff from cleaning and washing the equipment;
- Leaching from ore pads and tailings to groundwater;
- Leaks from the leach, CCD, SX, and precipitation circuits and associated process pipes; and
- Erosion from byproduct disposal facilities including tailings cells and evaporation ponds with subsequent redeposition in drainage areas.

The following processes have a potential for generating sources of waterborne acids, caustics, and organic solvents that could impact humans and flora and fauna.

- Leaks from the leach, CCD, and SX circuits and associated process pipes.

In terms of potential for exposure, process vessels are provided with secondary containment to contain the overflow, and spills in the process areas (See Piñon Ridge Facility Operating Plan, October 2010). The mill process areas, ore pad, tailings cells, and evaporation ponds are designed as “zero discharge” facilities with respect to surface and groundwater. Onsite workers will be protected through careful monitoring and compliance with workplace exposure standards as defined by the Mine Safety and Health Administration (MSHA) and other applicable agencies. Groundwater monitoring will also be provided.

Similar pathways and control mechanisms described in Sections 4.2 are applicable to the release and exposure to non-radiological COPC.

Human exposure to waterborne non-radiological COPC is unlikely due to incomplete pathways such as the lack of permanent surface water bodies in the vicinity of the site, and deep groundwater levels. The only open waters at the site are evaporation ponds and tailings cells and the small amount of water that may collect in stormwater ponds after a major precipitation event.

Screening level risk calculations indicated that the waste management facilities (tailings cells and evaporation ponds) represent the primary potential sources of exposure pathways to wildlife (Kleinfelder 2008). Because of their elevated metal and radionuclide concentrations, the tailings and raffinate solutions can be acutely and chronically toxic to wildlife; especially birds and bats that may attempt to drink from or land on the ponds. Several measures will be implemented to minimize wildlife access to the tailings cells and evaporation ponds. These measures will include the following:

- Eight-foot-high chain-link fence will be installed around the entire perimeter of the tailings cells and evaporation ponds; the fence will be inspected daily and repaired, as necessary, to prevent access to the area by wildlife.
- Bird balls will be placed on top of the ponded portion of the tailings area to prevent birds from landing on the water.
- Woven bird netting will be installed over and along the sides of the evaporation pond.
- Mill personnel will inspect the tailings cells and evaporation ponds on a daily basis. As part of their inspection, they will identify and record any wildlife mortalities and, where possible, will implement measures to reduce or eliminate future occurrences.

Some wildlife are attracted to salt (e.g. deer) which could be a potential issue for the beach sands. The restricted area fencing is sufficient to prevent mammals from accessing the beach sands; however, birds could land on the salt-encrusted beach sands. The beach sands are acidic and constantly being deposited during operations and would not be expected to support vegetation or a large number of insects; but there is the potential for direct exposure. Generally, metals are much more soluble in acidic conditions and any tailings solution coming in contact with birds is likely to have dissolved metal cations (e.g. uranium, vanadium, arsenic, selenium, chromium) as well as radionuclides. Birds could be exposed by directly drinking this solution or by preening wetted and encrusted feathers.

In the evaluation of potential exposure to birds from the tailings impoundments and evaporation ponds, it is also important to consider that there will be a lack of suitable habitat and food sources to attract birds to those areas. The noise and movements associated with mill activity at the site may also act as a deterrent for some species. The inventory of bird species at the site did not indicate the presence of waterfowl; this is assumed to be due to the lack of suitable habitat on the site for these species. Although the presence of the evaporation and stormwater ponds may attract some birds, there are no nearby habitats to support a large number of waterfowl.

5.3 DE MINIMIS PATHWAYS

De Minimis pathways are those that are considered too small to be of consequence or with a probability of occurrence that is so low as to be “incredible” (See definition of de minimis in Section 4.3). For the Piñon Ridge Uranium Mill, de minimis pathways for non-radiological COPC are either incomplete pathways or those pathways resulting in exposure less than 5% of applicable regulatory limits.

All of the de minimis pathways previously identified for radiological COPC are considered to be de minimis for non-radiological COPC, as the same engineering controls that prevent or minimize radiation exposures also apply to exposure to the non-radiological constituents in the ore, chemical reagents, process solutions, and byproduct material.

Air emission pathways within the mill for non-radiological and non-metal COPC are also considered de minimis because the facility’s emission controls must meet MSHA standards for occupational exposure, which are based on Threshold Limit Values (TLVs) established by the American Conference of Governmental Industrial Hygienists (ACGIH). These exposure standards include TLVs for kerosene, sulfuric acid, ammonia, and other chemical reagents used on the site.

Air emission pathways to off-site receptors, both human and animal, are also considered de minimis because the air permitting completed for the site (Kleinfelder 2009a) shows that the mill is considered a minor source and meets the National Ambient Air Quality Standards (NAAQS) for emissions of particulate matter, NOx, SO_2, CO, Volatile Organic Compounds (VOCs), total Hazardous Air Pollutants (HAPs). Dispersion modeling for PM10 (particulate matter less than 10 microns in size) was performed according to the Colorado Modeling Guideline for Air Quality Permits. Based on the modeled concentrations for the proposed facility, the results are below the NAAQS. Therefore, impacts to air quality in the area of the proposed facility would be less than levels deemed to be protective of human health and the environment and would not degrade the existing air quality.

There are no regulatory standards in place for emission of metal concentrations from the ore pad and tailings facility; however, given the very low metal concentrations estimated in the air at the property boundary and nearest residence, it is believed that these emissions are also de minimis. However, release of heavy metals to air will be assessed further in the Risk Assessment (SENES 2010) for both emissions from the mill site and an off-site transportation accident.

See also Table 10.2, which provides a summary of exposure pathways for non-radiological COPC including the de minimis pathways described above.

6.0 RADIOLOGICAL IMPACTS ON HUMANS

Inhalation is the main pathway of radionuclides from the Piñon Ridge mill to people residing in the vicinity of the mill. Radon progeny, Th-230 and Ra-226, in inhaled dust particles from the tailings impoundments and the milling operations, produce the greatest radiation dose to people in the environment. MILDOS-AREA modeling has been used to assess the magnitude of that impact in units of millirem per year (mrem/yr) to the general public within an 80-km radius of the mill. Comparisons of the modeled radiation doses to the regulatory maximums and to the annual background radiation doses are presented in a separate report (Little, 2010).

MILDOS-AREA is an NRC and CDPHE accepted code for modeling of airborne radioactive exposures. MILDOS-AREA was specifically designed by the Department of Energy (Argonne National Laboratory) for the NRC to model airborne radiation doses from uranium mills. The model was run on Version 2.2, not the most recent Version 3.07 because of concerns about the dusting algorithm (personal communication, Craig Little). The MILDOS-AREA model allows user defined source terms.

The location of each source of radioactive materials, and the height of each source, e.g., pile or a mill stack, is entered in the code. Using the annual wind speed and direction of the local winds, the code calculates the concentration of the particles, the radon concentration, and the concentration of radon decay products that have formed during transit. In addition, as described in Little, 2010, the MILDOS-AREA Code also models the environmental fate of radionuclides through the environment and calculates concentrations of the radionuclides in various environmental media (such as deposition onto soil and via consumption of beef and vegetables, etc.). From those concentrations, the model estimates the radiation dose to individuals in the Paradox Valley and surrounding areas.

The MILDOS-AREA modeling (Little, 2010) estimated a maximum TEDE for an off-site receptor of 8.21 mrem/yr (including radon) compared to the regulatory maximum limit of 25 mrem/yr (40 CFR 190) excluding radon and 100 mrem/yr (Colorado 6 CCR-1007-1, Part 4) including radon (See Table 6.1). However, this estimate was not based on the presence of an existing residence, but rather a theoretical residence located at the property boundary. The estimated maximum TEDE for an actual off-site receptor (i.e., the nearest downwind resident) was estimated to be 0.50 mrem/yr (see Table 6.2).

Table 6.1 Maximum Doses at the Property Boundary (mrem/yr)

Location	TEDE	Effective (excluding radon)	Bone (excluding radon)	Lung (excluding radon)
Location with maximum dose	8.21 (Fence 14)	3.35 (Fence 13)	17.4 (Fence 13)	19.8 (Fence 13)

Table 6.2 Maximum Estimated Doses to the Members of the Public (mrem/yr)

Receptor	TEDE	Effective (excluding radon)	Bone (excluding radon)	Lung (excluding radon)
Infant	5.04E-01	1.03E-01	-	7.98E-01
Child	4.73E-01	4.95E-02	1.28E-01	3.84E-01
Teen	4.62E-01	2.70E-02	1.61E-01	2.01E-01
Adult	4.61E-01	2.29E-02	1.78E-01	1.68E-01

*Infant doses do not include bone doses as the pathway is home grown vegetables, which are not typically consumed by infants

The pathways that result in radiological impact to mill employees and visitors are exposure to gamma rays from radionuclides in the mill and exposures from the inhalation of yellowcake dust, ore and tailings dust, and radon progeny. The ongoing radiological impact of mill operations to the mill employees and visitors will be assessed by the mill Radiation Safety Officer and staff. Doses are determined from mill area air samples, breathing zone air samples, uranium in urine bioassay samples, and by direct measurement of radiation in the mill. Procedures for collecting those samples and making the measurements are presented in the Piñon Ridge Mill Health and Safety Plan (EFR, 2009). Radiation doses to workers must be limited to 5,000 mrem/yr per CDPHE by regulations, but EFR's goal is to limit exposure for employees to 100 mrem/yr or less. Radiation doses will be evaluated regularly, including on a daily basis for some operations. Employee dose reports from the Radiation Safety Officer will be sent to employees and the CDPHE. Additionally, copies will be sent to mill management and to the Safety Committee to determine if the doses are "as low as reasonably achievable (ALARA)."

Table 6.3 provides a summary of radiation doses received by uranium mill workers at the Cotter Corporation uranium mill near Canyon City, Colorado for the year 2005 (Cotter Corporation, Annual Report for the Year 2005). Employee doses were calculated for 167 employees during that calendar year. There were 47 employees who worked under 500 hours (average 237 hours), 31 employees who worked from 500 to 999 hours (average 704 hours) and 89 employees who worked 1,000 hours or more (average 2061 hours).

Table 6.3 Summary of Annual Radiation Doses to Workers at the Canyon City Uranium Mill for the Calendar Year 2005

Total Effective Dose Equivalent, mrem	<500 Hours	500 to 999 Hours	>999 Hours
Average	30	110	261
Standard Deviation	25	49	96
Median	30	107	247
Maximum	107	254	577

Health Canada presents in its *2007 Report on Occupational Radiation Exposures in Canada,* occupational radiological exposure data for the year 2005 from numerous industries and job categories in the Canadian nuclear industry. For the category "uranium mine mill workers", the report indicates in its Table 4 (Dose distribution by job category as of the end of 2005) that 87% of the workers in this category received < 200 mrem in 2005 (< 2 mSv) and zero workers received > 500 mrem (> 5 mSv).

The results of MILDOS AREA Calculations showed that the TEDE for the office worker at the mill site is approximately 4.8 mrem/yr.

The dose assessment for the driver transporting the ore and yellowcake was performed using MicroShield Version 8.02 (Grove Software 2009). The results are shown in Table 6.4.

Table 6.4 Annual Effective Doses for Receptors during the Routine Transportation of Radioactive Materials

Receptor	Effective Dose (mrem/y)
Truck Driver - Transporting Yellowcake	39.4
Truck Driver – Transporting Ore	48

Source: SENES 2010

The MicroShield modeling of operator and driver radiation dose described above as well as the independent analysis performed by DOE indicates that the transportation will have a minimal radiological impact on drivers and forklift operators. Doses are projected to be well below the annual public dose limit of 100 mrem/yr (6 CCR 1007-1, Part 4, 4.14). Relative to typical natural radiation background in the region of the mill of 400 - 450 mrem/yr, no significant radiological risks and/or health related impacts to workers are expected from mill operation or from the transportation of yellowcake and ore. (Further details are provided in SENES 2010.)

7.0 RADIOLOGICAL IMPACTS ON ECOLOGICAL RECEPTORS

Radiological impacts on plant and animal receptors result from pathways such as the uptake and physical contact of plants with tailings and/or ore, inhalation of ore dust and tailings dust, and the consumption of vegetation by animals. Inhalation of radionuclides by animals near the mill site may occur, but the magnitude of these exposures is expected to be minimal due to the movement of animals in and out of the area. The radiation doses to animals can be approximated by the radiation doses to humans as calculated by MILDOS, e.g., <10 mrem/yr. The liquids that will be contained in the evaporation ponds and tailings cells have attracted birds, including ducks and geese, at some mill sites. The liquids will have a low pH and elevated concentrations of radionuclides and birds may attempt to drink from, or land on, the ponds. To prevent this from occurring, bird balls will be placed over the tailings water pool and bird netting will be installed over the evaporation ponds. Bird balls are floating plastic balls that are placed on the surface of the tailings liquid. In addition, the evaporation ponds will be covered with netting to prevent access and a chain link fence will be installed around the perimeter of the tailings cells and evaporation ponds to prevent access to the area by terrestrial wildlife.

The maximum gamma exposure rate in the vicinity of a typical uranium mill tailing site is only a few mrem/yr. That rate is very low and will not impact plants significantly. The DOE for example has concluded that for a facility in compliance with the dose limits for humans, the total doses to plants and animals should be well below the recommended dose limit for animals of 0.1 rad/day and the higher limit of 1 rad/day for plants (DOE 2002). Additionally, it is generally considered that when radiological doses to humans are small, doses to animals are similarly small (Whicker and Schultz 1982).

8.0 NON-RADIOLOGICAL IMPACTS ON HUMANS

Toxicology is the study of the adverse effects of chemicals on living organisms. Of all the radioactive materials in the uranium-238 and uranium-235 decay chains, uranium is singled out in the State of Colorado radiation control regulations as important to regulate based on chemical toxicity (chemotoxic impact on renal system, i.e., kidney). “Notwithstanding the annual dose limits, the licensee shall limit the soluble uranium intake by an individual to 10 milligrams in a week in consideration of chemical toxicity” (CDHPE, 2005). Another reason for addressing the chemical toxicity of uranium is that it is a heavy metal that can concentrate in the bones of mill workers. At the Piñon Ridge Uranium Mill, uranium will be monitored using a uranium-in-urine bioassay program which monitors the levels of uranium in the human body.

Uranium will be monitored in the mill using breathing-zone air samples that sample uranium in the air while workers conduct specific high-uranium-concentrations tasks. Area air samplers will also be used to monitor uranium concentrations in specific work areas of the mill. In the environment around the tailings cells and evaporation ponds, environmental air samplers will monitor uranium concentrations in the air. The toxicity of non-radioactive materials in the mill is addressed in SENES, 2010.

In addition to uranium, concentrations of other heavy metals, ammonia, sodium hydroxide, and sulfuric acid will be controlled to comply with the Mine Safety and Health Administration (MSHA) regulations and the Threshold Limit Values (TLVs) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH).

It is expected that dust emissions from ore handling and grinding and resuspension and erosion of particulate matter originating from soil, ore stockpiles, and dry tailings will be the major sources of exposure to heavy metals. However, these emissions are expected to be quite low (See Tables 5.1 thru 5.3). Dust emission controls such as water spraying, baghouses, and scrubbers will reduce the offsite receptors exposure to dust. In addition, the exposure to acid fumes and organic solvent vapors will also be reduced by process control measures implemented in the acid storage areas and the leach, CCD, and SX circuits. The Risk Assessment (SENES 2010) evaluates the potential impact to off site receptors for metal concentrations in the air.

9.0 NON-RADIOLOGICAL IMPACTS ON BIOTA OTHER THAN HUMANS (PLANTS AND ANIMALS)

The Piñon Ridge Uranium Mill is designed as a zero discharge mill in terms of surface and groundwater. Process solution is routed from the mill to lined tailings cells and lined evaporation ponds for evaporation. No liquids are released from those structures to runoff channels near or on the property. Without perennial surface water in the area, bioaccumulation of uranium, thorium, radium, and lead and other heavy metals cannot occur in the runoff channels.

Therefore, the waste management facilities (tailings cells and evaporation ponds) represent the potential sources of exposure pathways to the wildlife. Because of their low pH and elevated metal concentrations, the tailings and raffinate solutions can be acutely and chronically toxic to wildlife; especially birds and bats that may attempt to drink from or land on the ponds.

A screening exposure pathway assessment was conducted to estimate the hazard quotients (HQ) for a bird (mallard duck) landing on the tailing cells (SENES 2010). The major exposure pathway considered was drinking the water. The chemical analysis for the tailing solution conducted in April 2003 for International Uranium (USA) Corp (Energy Laboratories Inc. 2003) was used for the HQ estimation. The calculations show that the Screening Index (SI) varies between 1.24×10^{-4} and 2.67×10^{4} for various metals showing adverse effects from exposure of birds drinking from the ponds to some heavy metals. Therefore, the measures discussed in Section 5 will be implemented to eliminate the access of wildlife to the tailings cells and evaporation ponds and make these pathways incomplete.

Aquatic organisms that may be present within the tailings cells and evaporation ponds can take up uranium, thorium, radium, or lead but those organisms will remain in those structures. At the end of the mill life those organisms will be buried under a tailings cover and will not be available to transfer these elements to human or animals as a part of the food chain.

Surface water channels near the mill will contain water after local rains but not for a long enough period of time for aquatic organism to live in the channels and take up uranium, thorium, radium, or lead from dust generated from mill operations.

10.0 CONCLUSIONS

10.1 PRIMARY SOURCES OF EXPOSURE

Human Receptors

The main radiological exposure pathway from the Piñon Ridge Uranium Mill to people in the vicinity of the mill is inhalation of radon progeny and particulates containing Th-230 and Ra-226. The consumption of, or inhalation of, soil or resuspended particles containing heavy metals is an additional source of exposure.

Primary sources of radionuclides and radon progeny include:

- Ore haulage, storage, and handling at the ore pad;
- Grinding of the ore in the mill;
- Transportation accidents involving the release of ore; and
- Mill tailings.

Sources of particulates and heavy metals include:

- Ore haulage, storage, and handling at the ore pad;
- Grinding of the ore in the mill;
- Mill tailings;
- Transportation accidents involving the release of yellowcake and ore; and
- Consumption or inhalation of soil or resuspended particles.

For personnel working in the mill, the main radiological exposure pathway is from inhalation of yellowcake dust, ore dust, and radon progeny, and from exposure to gamma radiation from radionuclides outside their bodies.

Ecological Exposure

While wildlife access to the tailings cells and the evaporation ponds is limited by bird balls, bird netting, and chain-link fence around and over these areas. However, birds could land on the salt-encrusted beach sands. The beach sands are acidic and constantly being deposited during operations and would not be expected to support vegetation or a large number of insects; but there is the potential for direct exposure.

10.2 DE MINIMIS EXPOSURE PATHWAYS FOR RADIOLOGICAL COPC

De minimis exposure pathways are those considered too small to be of consequence or with a probability of occurrence that is so low as to be "incredible" and therefore can be ignored in assessing radiological risk (e.g., < 5 % of radiological dose limits).

- Surface runoff from tailings, ore pads, and other facilities and release to the environment;
- Particulate emissions from uranium recovery and drying off gas systems, and release to the environment;
- Consumption of meat, vegetables, and milk produced locally;
- Consumption of wild game;
- Leaks from process areas;
- Consumption of rainwater, surface water, or groundwater;
- Storage of yellow cake and release to the soil;
- Transportation accidents involving ore and yellowcake trucks; and
- Radon release from sprinklers around the tailings impoundment and evaporation ponds.

10.3 De Minimis Exposure Pathways for Non-Radiological COPC

Negligible exposure pathways or those that are trivial or small enough to be ignored for non–radiological exposures include:

- Surface runoff from tailings, ore pads including acid drainage, and other facilities and release to the environment;
- Particulate emissions from, uranium/vanadium recovery and drying, off gas systems, and release to the environment;
- Consumption of meat, vegetables, and milk produced locally;
- Consumption of wild game;
- Consumption of rainwater, surface water, or groundwater;
- Storage of yellow cake and release to the soil;
- Leaks from process areas;
- Acid mists and fumes from the leach and CCD circuits and acid storage vessels; and
- Organic vapors emitted from the SX circuits and evaporations ponds.

Tables 10.1 and 10.2 summarize the pathways that have been analyzed in this report for radiological and non-radiological COPC.

Table 10.1 Summary of the Exposure Pathways for Radiological COPC

Source	Pathways	Receptors	Comments	De minimis
Surface runoff from tailings and ore pads including acid drainage, and radioactive waste storage areas	Release of uranium and other radionuclides to soil	Ecological receptors	Storm water and surface runoff management reduces access to the ecological receptors, incomplete pathway	Yes
	Release of uranium and other radionuclides to surface water	Ecological and human receptors	No permanent surface water. Control measures for evaporation ponds to limit the access of ecological receptors, no source of surface water as drinking water, incomplete pathway	Yes
	Leach of uranium and other radionuclides to groundwater	Human receptors	Proper linings and mentoring wells are planned, incomplete pathway	Yes
	Release of uranium and other radionuclides to soil and subsequent resuspension	Ecological and human receptors	Storm water and surface runoff management and dust control measures are in place	Yes
Tailings impoundments and beach sands	Soil contamination with uranium and other radionuclides	Ecological receptors	Fence around the tailings impoundments limits the access to the terrestrial receptors. No significant source of food for birds	Yes
Process line leaks	Release of uranium and other radionuclides to soil	Human receptors including the workers	Scheduled maintenance, secondary containment, spill control measures and personal protection equipment minimize the exposure to public and workers	Yes
	Release of radon to air	Human receptors including the workers	Scheduled maintenance, secondary containment, spill control measures and personal protection equipment minimize the exposure to public and workers	Yes
	Release of uranium and other radionuclides to groundwater	Human receptors	Scheduled maintenance, secondary containment spill control measures, and great depth to groundwater make it an incomplete pathway	Yes
Radon releases from tailings, ore pads, evaporation ponds, milling process	Release of radon to air	Human receptors including the workers	Radiological doses to public were estimated via the MILDOS computer code and determined to be much less than regulatory limits (Little 2010)	No

Table 10.1 Summary of the Exposure Pathways for Radiological COPC (Cont'd)

Source	Pathways	Receptors	Comments	De minimis
Radon emissions from sprinklers	Release to air	Human receptors including the workers	Insignificant release amount	Yes
Yellowcake storage	Release of uranium and other radionuclides to soil	Human receptors including the workers	Spill control measures minimize the exposure to public and workers	Yes
	Radon emission to air	Human receptors including the workers	Negligible as radium-226, the parent of radon has been separated from uranium (send to tailings)	Yes
Particulate emissions from U/V recovery and drying, off gas systems,	Release of uranium and other radionuclides and radon to air	Ecological and human receptors	Dust control measures including filters and scrubbers. Incomplete pathway for yellowcake dryer (zero emissions)	Yes
Particulate emissions from ore grinding	Release of uranium and other radionuclides and radon to air	Ecological and human receptors	Dust control measures including filters, and scrubbers.	Yes
Particulate emissions from exposed dry tailings and ore stockpiles (wind erosion)	Release of uranium and other radionuclides and radon to air	Ecological and human receptors	Dust control measures including water spraying	No
	Release of uranium and other radionuclides to air, subsequent deposition, transfer to food source (through food chain	Ecological and human receptors	Dust control measures including water spray	Yes
	Release of uranium and other radionuclides to air and subsequent deposition to surface water	Ecological and human receptors	Dust control measures including water spray	Yes
Offsite transportation accidents	Release of uranium and other radionuclides and radon to air	Ecological and human receptors	Spill response plan in-place, short-term exposure	No
	Release of uranium and other radionuclides to soil or surface water	Ecological receptors	Spill response plan in place , sort-term exposure	Yes

Table 10.2 Summary of the Exposure Pathways for Non-Radiological COPC

Source	Pathways	Receptors	Comments	De minimis
Surface runoff from tailings and ore pads including acid drainage, and radioactive waste storage areas	Release of heavy metals to soil	Ecological receptors	Storm water and surface runoff management reduces access to the ecological receptors, incomplete pathway	Yes
	Release of heavy metals to surface water	Ecological and human receptors	No permanent surface water. Control measures for evaporation ponds to limit the access of ecological receptors, no source of surface water as drinking water, incomplete pathway	Yes
	Leach of heavy metals to groundwater	Human receptors	Proper linings and mentoring wells are planned, incomplete pathway	Yes
	Release of heavy metals to soil and subsequent resuspension	Ecological and human receptors	Storm water and surface runoff management and dust control measures are in place	Yes
Tailings impoundments and beach sands	Soil contamination with heavy metals	Ecological receptors	Fence around the tailings impoundments limits the access to the terrestrial receptors. No significant source of food for birds	Yes
Process line leaks	Release of heavy metals, acids, caustics, and organic solvents to soil	Human receptors including the workers	Scheduled maintenance, secondary containment, spill control measures and personal protection equipment minimize the exposure to public and workers	Yes
	Release of organic solvent vapor and acid fume to air	Human receptors including the workers	Scheduled maintenance, spill control measures and personal protection equipment minimize the exposure to public and workers	Yes
	Release of heavy metals, acids, caustics, and organic solvents to groundwater	Human receptors	Scheduled maintenance, secondary containment spill control measures, and great depth to groundwater make it an incomplete pathway	Yes
Acid mists and fumes from CCD and leach circuits and organics from SX circuit	Release of organic solvent vapor and acid fumes to air	Human Receptors	Enclosed process vessels and emission control measures at the mill	Yes

Table 10.2 Summary of the Exposure Pathways for Non-Radiological COPC (Cont'd)

Source	Pathways	Receptors	Comments	De minimis
Particulate emissions from U/V recovery and drying off gas systems,	Release to air	Ecological and human receptors	Dust control measures including filters and scrubbers. Incomplete pathway for dryer (zero emissions)	Yes
Particulate emissions from ore grinding off gas systems,	Release to air	Ecological and human receptors	Dust control measures including filters and scrubbers. Incomplete pathway for dryer (zero emissions)	Yes
Particulate emissions from exposed dry tailings and ore stockpiles, (wind erosion)	Release of heavy metals to air	Ecological and human receptors	Dust control measures including water spraying	No
	Release of heavy metals to air, subsequent deposition, transfer to food source (through food chain	Ecological and human receptors	Dust control measures including water spraying	Yes
	Release of heavy metals to air and subsequent deposition to surface water	Ecological and human receptors	Dust control measures including water spraying, lack of permanent surface water bodies around the site	Yes
Offsite transportation accidents	Release of heavy metals to air	Ecological and human receptors	Spill response plan in-place, short-term exposure	No
	Release of heavy metals to soil or surface water	Ecological receptors	Spill response plan in place , sort-term exposure	Yes

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