RISK ASSESSMENT FOR PROPOSED URANIUM AND VANADIUM MILL AT THE PIÑON RIDGE PROPERTY

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1.0 Introduction

1.1 BACKGROUND

Energy Fuels Resources Corporation (Energy Fuels) proposes to license, construct, and operate a conventional acid leach uranium and vanadium mill at the Piñon Ridge Property in western Montrose County, Colorado. The proposed Piñon Ridge Mill Facility is located at 16910 Highway 90, approximately 7 miles east of Bedrock, Colorado and 12 miles west of Naturita, Colorado. The Mill Facility includes an administration building, a 17-acre mill, tailing ponds of approximately 90 acres, a 40-acre evaporation pond (expansion capacity to 80 acres), an approximately 6-acre ore storage pad, and access roads. The mill is designed to process ore produced from mines on the Colorado Plateau located within a reasonable truck-haul distance. The mill will initially process 500 tons of ore per day and is designed for future expansion capable of accommodating a production capacity of 1,000 tons per day.

Energy Fuels is submitting a mill license application to the Colorado Department of Public Health and Environment (CDPHE) for the Piñon Ridge Mill facility. In support of this application, SENES Consultants Limited (SENES) has, in this report, characterized the radiological and non-radiological hazards and risks associated with operating the mill including associated accident analysis.

1.2 SCOPE OF THE ASSIGNMENT

This report covers the following aspects of the mill operation:

- Transport of ore and reagents to the mill and transport of yellowcake and vanadium concentrates from the mill to out-of-state processing plants
- On-site storage and use of ore, reagents, and fuels
- Mineral processing operation including process components in the following areas:
    - Ore Handling and Grinding
    - Leaching
    - CCD Thickeners and Tailings Disposal
    - Uranium Solvent Extraction (SX)
    - Uranium Precipitation, Drying, and Packaging
    - Vanadium Oxidation and Solvent Extraction (SX)
    - Vanadium Precipitation, Drying, and Packaging
    - Reagents Storage
    - Waste Disposal Facilities including Tailings Cells and Evaporation Ponds

The following reagents, fuels, and process streams will be present in the mill and were considered in the analysis:

- Kerosene
- Ammonia
- Ammonium Sulfate
- Sodium Hydroxide
- Sodium Carbonate
- Sulfuric Acid
- Sodium Chlorate
- Hydrogen Peroxide
- Alamine 336
- Isodecanol
- Diesel Fuel and Gasoline
- Propane
- Uranium/Vanadium Ore and Ore Pulp
- Water Treatment Residuals
- Tailing Slurry
- Raffinate
- Yellowcake (U3O8)
- Black Flake (V2O5)

The assessment provides analysis of transportation and mill operation risks under both normal conditions and accidents including estimates of the frequencies of accidents as well as the impacts/consequences of operations and accidents on the health of workers, the public and wildlife, as applicable. Due to its location and limited provisions for site access, the effects on wildlife are mainly associated with birds landing on/in evaporation ponds covered with bird netting and tailings cells covered with bird balls.

1.3 OBJECTIVES

The objective of this assessment is to characterize the radiological and non-radiological hazards and risks associated with operating the Piñon Ridge Mill including analysis of credible accidents. The report will be used in support of the mill license application submitted to the Colorado Department of Public Health and Environment (CDPHE) for the Piñon Ridge Mill. Specifically, this report supports requirements to assess the environmental impact of a new uranium mill under 6 CCR 1007-1, Part 18, RH 18.4 of the Colorado regulations as well as to demonstrate that radiological exposures and risks to workers will be maintained within established limits and as low as reasonably achievable (ALARA) in accordance with 6 CCR 1007-, Part 4, 4.6 and 4.14.

2.0 Preventive and Mitigative Measures

Energy Fuels is implementing numerous preventative and mitigative measures during the design, construction, and operation of the mill. These measures minimize risks and help ensure that:

1. The normal operation of the mill is safe for workers, members of the public, and is protective of the environment, and that potential impacts from radioactive and other hazardous materials will be maintained ALARA.
2. The frequency and probability of accidents and malfunctions are reduced; and
3. During a potential accident and malfunction event, the consequences and potential impact to health, safety, and environment will be minimized.

Safety and mitigative measures are classified as follows:

- Design of mill components to limit potential releases including "zero discharge" wastewater systems, "zero emission" air treatment systems, and provisions for secondary containment in mill and waste disposal systems
- Compliance to applicable regulatory requirements, such as those of the Environmental Protection Agency (EPA), Mine Safety and Health Administration (MSHA), Department of Transportation (DOT), Colorado Division of Oil and Public Safety (CDOPS), and the Colorado Department of Public Health and Environment (CDPHE)
- Implementation of comprehensive monitoring programs for workers and the environment
- Implementation of the Health and Safety Plan (Energy Fuels 2009a), Emergency Response Plan (Energy Fuels 2009b), Materials Containment Plan (Energy Fuels 2009c), and the Spill Prevention, Control and Countermeasure (SPCC) Plan (Energy Fuels 2009d) under a formal program of work control
- Implementation of a comprehensive training program
- Restriction of wildlife access to the site
- Implementation of comprehensive site security

The details of these measures are discussed as applicable in subsequent sections of this document.

3.0 Impacts to Public and Wildlife from Normal Operations

The effects of normal operation were assessed for the following receptors:

- Member of the Public at the Plant Boundary and Nearest Residence
- Wildlife (Mostly Birds, Mallard Duck)

Table 3.1 summarizes the exposure pathways to the identified receptors.

Table 3.1 Public and Wildlife Exposure Interactions

Receptors	Exposure Pathway					
	Gamma	Yellowcake Dust	Radon and Daughter Products	Ore Or Tailings Dust	Chemical Dust, Vapor, or Fume	Through Food Chain
Member of the Public at the Plant Boundary and Nearest Resident	*	*	*	*	*	*
Wildlife	*					*

3.1 Radiological Impacts from Routine Mill Operation

3.1.1 Mill Operation

Members of the Public

Energy Fuels will implement radiological monitoring and assessment programs to protect the public and environment that comply with the following regulations and related guidance:

- CDPHE 6 CCR 1007 -1 Parts 4 – Standards for Protection Against Radiation
- CDPHE 6 CCR 1007 -1, Part 18 - Licensing Requirements for Uranium and Thorium Processing
- CDPHE 6 CCR 1007 -1, Part 18, Appendix A - Criteria Relating to the Operation of Uranium Mills and the Disposition of the Tailings or Wastes From These Operations
- US EPA 40 CFR 190 – Environmental Radiation Protection Standards for Nuclear Power Operations
- US EPA 40 CFR 192 – Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings
- US EPA 40 CFR 61, Subpart W – National Emissions Standard for Radon Emissions from Operating Mill Tailings

For example, radon gas and dust containing radionuclides can be released to the environment during mill facility operation. Facility design and monitoring will demonstrate that the radon concentrations at site boundaries are below the unrestricted area concentration limit for radon in Table 4B1, Part 4 of 10^{-8} µCi/ml (10 pCi/L) and that releases of any radioactive material will not result in exposure to a member of the public of > 100 mrem/yr.

The mill process areas, ore pad, tailings cells, and evaporation ponds are designed as "zero discharge" facilities. The uranium vacuum dryer and its off gas components is designed as a "zero-emission" system. The mill facilities with potential for release of radioactive dust or fumes (e.g. dryers, precipitation tanks) are equipped with bughouse and wet scrubbers to minimize radioactive dust or fumes from discharges to the atmosphere.

Two Lines Inc. Radiation Risk Consultants conducted an assessment of off-site radiation doses from normal operations and the results are provided under a separate report "Estimates of Radiation Doses to Members of the Public from the Piñon Ridge Mill" (Two Lines 2009). In that report, the MILDOS-AREA model, developed by Argonne National Laboratory, is used with site-specific weather information and the proposed project components to estimate radiation doses at the property boundary and off-site.. The MILDOS AREA modeling of off-site radiation dose indicates that the mill will have a minimal radiological impact within an 80-km radius of the mill. All of the doses are below the 100 mrem/yr dose limit for individual members of the public, including radon and its progeny, but excluding natural background radiation (Colorado Radiation Control regulations (6 CCR 1007-1- 4.14).

The maximum Total Effective Dose Equivalents (mrem/year) at any receptor point for various age groups at the property boundary are summarized in Table 3.2.

Table 3.2 Total Effective Dose Equivalent (mrem/yr) for Various Age Cohorts

Receptor	Total Effective Dose Equivalent (mrem/yr)
Infant	9.04
Child	7.91
Teen	7.56
Adult	7.58

Since the mill is designed as a zero discharge facility, the only potential source of radionuclides in the food change pathway is the atmospheric deposition on the soil and through agricultural products. It was indicated in the MILDOS AREA modeling report (Two Lines, Inc., 2009) that the agricultural productivity of the land surrounding the proposed mill is modest. Therefore, the fraction of total annual livestock feed requirements to be satisfied by pasture grass or locally grown stored feed was set at 50% or 0.5. Subsequently, it was indicated that the dose to the public through food chain is very small.

With a very low solubility in fat (and therefore very low octanol-water partition coefficient), uranium, radium, and other radionuclides typically are expected to have very poor bioaccumulation through the food chain. Uranium shows poor bioaccumulation or bioconcentration factor in aquatic environments with sorption being the main mechanism rather than the uptake from the food chain. Uranium is also transported poorly from soils to plants. Greater plant uptake is expected to occur in soils that contain higher levels of available uranium such as sandy soil (i.e., less sorption of uranium to soil particles or formation of soluble uranium complexes). The uptake of uranium by plants, expressed as plant/soil concentration ratio (CR), grown near a mining and milling complex was reported as 0.8 (ATSDR 1999). Additionally, this document shows that aquatic organisms such as fish, snails, clams, and algae can bioaccumulate radium from water. The radium-226 bioconcentration factors for fish living in streams or lakes receiving uranium-processing waste effluent have ranged from 1 to 60 for flesh portions (ATSDR 1999). However, it was shown that the radium is transported poorly to the plant. The soil-plant concentration ratio for radium-226 has been reported as 3×10^{-3} for fruits and 0.1 for forage and hay. As for radium-226 transfer to cattle, the mean ratio of radium-226 in milk to that in the animal's diet has been estimated to be 3.8×10^{-3}. A similar ratio for flesh was 6.8×10^{-3}. These values indicate a poor transfer to animals from the feed.

Wildlife

The waste management facilities (tailings cells and evaporation ponds) are the major potential sources of exposure pathways to the wildlife. Because of their elevated metal and radionuclide concentrations, the tailings and raffinate solution 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 radiation dose to a bird (mallard duck) landing on the tailing cells. The major exposure pathways considered was drinking the water and direct gamma exposure to the duck. A chemical analysis for the tailing solution from a conventional uranium mill, conducted in April 2003 (Energy Laboratories Inc. 2003) was used for the dose estimation. The calculations show that the total dose from Ra-226, Pb-210, Th230, and Th232 could be as high as 1,400 mGy/d, which exceeds the benchmark of 5 mGy/d (Garisto 2005) for birds (See appendix A1 for details of calculations).

Therefore, several measures will be implemented to eliminate the access of wildlife to the tailings cells and evaporation ponds. These measures will include the following.

- A six-ft high chain-link fence topped by three strands of barbed wire 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 placed on top of the ponded portion of the tailings area to prevent birds from landing on the water. The hollow balls are made of plastic and float on top of the water concealing the water surface and creating a physical barrier.
- Woven bird netting will be installed over and along the sides of the evaporation pond.
- Mill personnel will inspect the tailings cells 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.

3.1.2 Transportation

Transportation of radioactive materials to and from the mill can be classified into two categories:

- Shipments of yellowcake from the mill to a uranium hexafluoride conversion facility
- Shipments of ore from mines located in the Colorado Plateau to the mill

The yellowcake products are packed in 55-gallon, 18-gauge drums holding an average of 900 lb of yellowcake. The drums are classified by the Department of Transportation (DOT) as Type A packaging (10 CFR Part 71) and are capped with DOT-approved lid and clamping ring. The bulk ore is transported by haul trucks from the mine to the mill. The ore is covered with tarps to reduce dusting and falling debris during transportation. The ore, which is being shipped from the mine, contains a significant amount of moisture and has a lower percentage of fines than ore that has been crushed. Thus, no significant dust emission is expected during routine shipment of the ore and products. Any minor spillages of ore from trucks during transport would add little additional radioactivity to the mineralized natural environment of the Colorado Plateau. Therefore, the radiological impact of transportation on the members of the public and the wildlife is very small.

The US Department of Energy performed an analysis to estimate exposures of the public from transportation shipments containing uranium ore in DOE 2007. Four representative scenarios were evaluated:

1. An individual in a vehicle stopped in traffic next to a uranium ore truck. This individual would be exposed to one shipment of uranium ore for 30 minutes.
2. An individual in a vehicle who passes a uranium ore truck going the opposite direction. This individual would be exposed to one shipment of uranium ore.
3. An individual in a vehicle stopped at an intersection when a haul truck passes by. This individual would be exposed to one shipment of uranium ore.

4. A nearby resident located 33 ft from a road used by haul trucks. This individual would be exposed to all shipments of uranium ore over the course of a year.

Table 3.3 presents the radiological dose to the public from these four exposure scenarios as evaluated by DOE. The largest radiation dose would be for the nearby resident, who would receive a dose of 0.22 mrem per year from the passing haul trucks. The DOE calculated that after 10 years of having 120 to 150 shipments of ore pass per day, the resident's lifetime probability of getting cancer would increase from 220,000 in 1 million (national average) to 220,001 in 1 million.

Table 3.3 Exposure of the Public from Routine Transportation of Uranium Ore (DOE 2007)

Scenario	Estimated Public Dose
Individual in traffic jam	0.026 mrem
Individual in passing vehicle	7.4×10^{-6} mrem
Individual in vehicle intersection	1.5×10^{-5} mrem
Nearby resident	0.22 mrem / yr

3.2 NON-RADIOLOGICAL IMPACTS FROM ROUTINE MILL OPERATION

3.2.1 Mill Operation

Members of the Public

While hazardous chemicals are used at the mill facilities, the amount and variation of such chemical usage is small compared to large chemical facilities. The reagents are stored on site in pre-packaged totes, barrels, and bulk bags within weatherproof buildings and/or in closed bulk storage tanks. Containers are labeled with both the name of the product and safety placards that meet the requirements outlined in the DOT Emergency Response Guidebook (US Dept. of Transportation - ERG 2008). The containers are chemically and physically compatible with the media stored in them and meet applicable local, state and federal storage regulations, including for secondary containment as applicable.

The mill process areas, ore pad, tailings cells, and evaporation ponds are designed as "zero discharge" facilities. The vanadium dryer and its off gas system is zero-emission equipment. The mill facilities with potential for release of dust or toxic fumes (e.g. dryers, precipitation tanks) are equipped with bughouse and wet scrubbers to minimize emissions of dust or fumes to the atmosphere.

The impact of the routine use and handling of these chemicals during routine mill operations on the members of the public and wildlife is expected to be zero.

Wildlife

The waste management facilities (tailings cells and evaporation ponds) are the major potential sources of exposure pathways to the wildlife. Because of their low pH and elevated metal concentrations, the tailings and raffinate solution 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. The major exposure pathways 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 unlikely exposure of birds to some heavy metals. (See appendix A2 for details of calculations). Therefore, the measures discussed above in section 2.1.1 will be implemented to eliminate the access of wildlife to the tailings cells and evaporation ponds.

3.2.2 Transportation

Shipments of hazardous material will follow U.S. Department of Transportation hazardous materials shipping regulations and requirements (49 CFR Parts 171, 172, 173, 177, 178, and 179). Most of the reagents are transported to the mill site in prepackaged totes, barrels, and bulk bags. The bulk materials are typically transported by closed tanker trucks. Any bulk material transported in open trucks is covered with tarps to reduce dusting and falling debris during transportation.

No significant dust or fume emission is expected during routine shipment of the ore and products. Therefore, the non-radiological impact of transportation on the members of the public and the wildlife is very small.

4.0 Impacts to Occupational Health and Safety from Normal Operations

The effects of normal operation on the following receptors were assessed:

- Operational Worker at the Mill and Waste Management Area
- Office Worker at the Mill
- Transportation Truck Driver

Table 4.1 summarizes the exposure pathways to the identified receptors.

Table 4.1 Worker Exposure Interactions

Receptors	Exposure Pathway				
	Gamma	Yellowcake Dust	Radon and Daughter Products	Ore Or Tailings Dust	Chemical Dust, Vapor, or Fume
Office Worker at the Mill					*
Operational Worker at the Mill and Waste Management Area	*	*	*	*	*
Transportation Truck Driver	*	*		*	*

With consideration of the above exposure pathways, the impacts on the receptors are discussed in the following sections.

4.1 Radiological Impacts from Routine Mill Operation

4.1.1 Radiological Exposure during Routine Mill Operation

The modern state-of-the-art design of the Piñon Ridge mill (monitoring systems, containment and control of radioactive materials, process controls, etc) combined with the implementation of the health and safety plan, extensive training program, availability of personal protection equipment, and implementation of Federal (e.g., MSHA, USNRC) and Colorado (CDPHE) regulations and guidance will ensure that occupational health and safety limits are not exceeded and that a safe workplace is maintained at all times.. Examples of applicable regulations and guidance that will be followed to ensure low risk of radiological exposures of workers include:

- CDPHE 6 CCR 1007 -1, Part 4 – Standards for Protection Against Radiation
- CDPHE 6 CCR 1007 -1, Part 18 - Licensing Requirements for Uranium and Thorium Processing
- CDPHE 6 CCR 1007 -1, Part 18, Appendix A - Criteria Relating to the Operation of Uranium Mills and the Disposition of the Tailings or Wastes From These Operations
- American National Standards Institute Practices for Respiratory Protection, ANSI Z88.2
- US Nuclear Regulatory Commission Regulatory Guide 8.30 - Health Physics Surveys at Uranium Recovery Facilities
- US Nuclear Regulatory Commission Regulatory Guide 8.31 – ALARA Programs at Uranium Recovery Facilities
- US Nuclear Regulatory Commission Regulatory Guide 8.22 – Bioassay at Uranium Mills
- MSHA 30 CFR 57.5037 to 57.5047 – Radiation Protection Standards (as may be applicable to surface operations)

Workers are potentially exposed to radiation and/or radioactive materials above background in a uranium mill, either from external sources (direct gamma exposure from sources outside the human body – in ore handling, tailings and yellowcake areas) or from internal sources as result of inhalation and/or ingestion of radioactive materials in the work place.

Numerous radiation exposure monitoring systems are utilized at the Piñon Ridge Mill Facility to identify potential radiation sources and measure and document exposure of workers to ensure that radiation exposures received by workers above background are maintained ALARA. The radiation monitoring program and procedures are directed by the facility's Radiation Safety Officer (RSO) whose qualifications must be approved by the CDPHE and are documented in the mill's Health and Safety Manual. Routine work in the mill is performed in accordance with the approved Radiation Health ("RH") procedures which are identified in Table 4.2 below:

Non-routine work tasks (i.e., activities for which established procedures may not exist) require a Radiation Work Permit, administered by the RSO, that outlines special radiological monitoring and assessments, PPE and other health / safety related measures required while doing the work. (Health and Safety Procedure RH 060)

Stationary and portable air monitors are used throughout the mill to monitor the concentrations of radioactivity in the air. Workers involved in operations at locations where airborne radioactivity can occur wear breathing-zone air monitors to measure the radioactivity in the air that they breathe. They may also wear canister-type respirators that are provided for use in these areas. For those workers potentially exposed to higher concentrations of airborne radioactivity, bioassays are conducted to determine the amount of uranium that has been inhaled and/or ingested.

Table 4.2 Radiological Control Procedures

RH No.	Title	RH No.	Title
010	Radiological Health and Safety Training	150	Occupational Breathing Zone Monitoring
020	Decontamination	151	Calibration of Air Samplers Using the Bubble Method
030	Posting	160	Source Leak Test, Shutter Test, and Inventory
040	Radiation Exposure Action Levels	170	Nuclear Density Gauge
050	Bioassay	200	Personnel Release Surveys
060	Radiation Work Permits	210	Personal Radiation Monitors
070	Release of Equipment to Unrestricted Areas	300	Radiological Dose Calculation
100	Shipment of Yellowcake, Ore or Contaminated Equipment by Truck	301	Worker Exposure to Long-lived Radionuclides in Airborne Particulate Matter
110	Beta and/or Gamma Exposure Rate Surveys	302	Radionuclide Concentrations in Air Samples
120	Alpha Beta Gamma Contamination Surveys	303	Dose Calculation Procedures
130	Occupational General Air Particulate Survey	310	Instructions for Pregnant Women
140	Radon -222/Radon-220 Decay Product Surveys		

Workers exposed to large quantities of ore and/or milling products wear dosimeters ("TLD badges") which measure gamma exposure. Other protections to reduce radiation exposure include regular power washing of equipment and vehicles, monitoring (and if necessary controlling) the amount of time workers are in areas where they are potentially exposed to radiation, and implementation of good housekeeping and personal hygiene measures.

The yellowcake packaging area has its own heating, ventilating, and air conditioning ("HVAC") system, and two sets of doors (vestibules) remain closed at the exits to provide additional containment of air-borne particles. Only required operations personnel are allowed within the packaging area and they are required to wear appropriate PPE including air-purifying respirators, gloves, and coveralls.

Expected Radiation Doses to Workers from Normal Operations

It is Energy Fuels policy to take all practical steps to ensure exposure to workers from radiation and/or radioactive materials will be maintained as low as reasonably achievable (ALARA). It is Energy Fuels objective to limit exposures of workers to $\leq$ 100 mrem / year above background.

Although external exposure associated with uranium mills is typically expected to be low, the potential exists for internal exposure as a result of inhalation of airborne radioactivity in ore and tailings handling and yellowcake processing areas. Engineering controls include process containments and HVAC systems; administrative processes include formal work control programs underpinned by rigorous radiological control procedures (see above). Comprehensive radiation safety training programs are designed to minimize risks of significant radiological exposure of workers at the mill.

Table 4.3 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 4.3 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 (< 2mSv) and zero workers received > 500 mrem (> 5 mSv)

Older, historical data on radiation exposure to US uranium mill workers is provided in the USNRC's NUREG 0706, (NRC 1980) Final Generic Environmental Impact Statement on Uranium Milling. Unfortunately, since this document was published in 1980, the data is based on an older, previous generation of uranium mills relative to the much more modern design of the Piñon Ridge mill. The estimates of occupational exposures to radiation in NUREG 0706 are based principally on worker exposures measured at seven operating uranium mills in Wyoming and New Mexico. The seven mills were visited from fall 1975 to spring 1977 by the NRC staff. Results were obtained from individual mill monitoring programs, and the average exposure levels as reported in that document are summarized in Table 4.4 (doses in mrem). It must be recognized that at that time, radiation dose was measured and recorded in accordance with ICRP

2 methodologies ("critical organ dose" concept) vs. later and current ICRP 26/30 Effective Dose Equivalent (EDE) and Committed Effective Dose Equivalent (CEDE) concepts (ICRP 1982) and therefore comparisons to present circumstances are limited.

TABLE 4.4 Summary of Radiation Exposure (mrem/yr) to Uranium Mill Workers, 1975 – 1977 from NUREG 0706

Source	Whole Body	Bone	Lung
External	380	380	380
Ore Dust	45	1250	1410
Yellowcake Dust	21	353	2320
TOTAL	447	1980	4111

For the reasons described above, typical worker exposures at the Piñon Ridge mill from routine operations are expected to be a few hundred mrem/ yr CEDE or less. The Piñon Ridge mill is designed with state-of-the-art controls and programs (i.e., containment and isolation of radioactive materials, HVAC systems, formal work control and training program, etc) to achieve ALARA exposure levels. 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 the routine operation of the Piñon Ridge uranium mill.

4.1.2 Transportation

Transportation of radioactive materials to and from the mill can be classified into two categories:

- Shipments of yellowcake from the mill to a uranium hexafluoride conversion facility
- Shipments of ore from mines located in the Colorado Plateau to the mill

The yellowcake products are packed in 55-gallon, 18-gauge drums holding an average of 900 lb of yellowcake. The yellowcake drums are classified by the Department of Transportation (DOT) as Type A packaging (10 CFR Part 71) and are capped with DOT-approved lid and clamping ring. The bulk ore is transported by haul trucks from the mine to the mill. The ore is covered with tarps to reduce dusting and falling debris during transportation.

Yellowcake characteristics and chemical analysis of the ore (average 0.23% U_3O_8) provided by Energy Laboratories Inc to Energy Fuels Resources Corporation in 2007 were used to estimate the radiation dose to a forklift operator and a truck driver transporting the yellowcake and ore.

For this assessment, it was assumed that a truck driver is expected to make 15 deliveries per year from the mill site to a conversion facility in Metropolis, Illinois. The 26-ton truck contains approximately 60 drums (55 gallon) of yellowcake. The estimated exposure time while driving or resting in the cabin is approximately 22 hours per delivery. In addition, the truck driver will perform a load inspection prior to departure and upon arrival at the destination; each inspection was assumed to take 30 minutes.

It was assumed that the forklift operator moves 60 drums from each truck. The conservative estimated exposure time for the forklift driver is 5 minutes per drum. It was conservatively assumed that one worker operates the forklift to move all the drums for each delivery for all 15 deliveries each year. Therefore, the exposure time is approximately 5 hours (300 minutes) per delivery and 75 hours per year (i.e., 5 hours per delivery x 15 deliveries per year).

The assumed exposure time for the truck driver transporting uranium ore was 3 hours per day and 200 days per year. Therefore, total exposure time was assumed to be 600 hours per year.

The dose assessment was performed using MicroShield Version 8.02 (Grove Software 2009). The details of the calculations are provided in Appendix A3 and the summary of the results is shown in Table 4.5.

Table 4.5 Annual Effective Doses for Receptors during the Routine Transportation of Radioactive Materials

Receptor	Effective Dose (mrem/y)
Truck Driver - Transporting Yellowcake	39.4
Forklift Driver - Moving Drums Containing Yellowcake	7
Truck Driver – Transporting Ore	48

The US Department of Energy performed an analysis of radiation dose to transportation workers associated with uranium mining and milling (DOE 2007) and concluded that the maximally exposed transportation worker would be an truck driver hauling uranium ore This person was assumed to be driving a haul truck containing uranium ore 1000 hours / year and would receive a radiation dose of 14 mrem / year.

The MicroShield modeling of operator and driver radiation dose described above as well as the independent analysis performed by DOE indicate 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 the transportation of yellowcake and ore.

4.2 NON-RADIOLOGICAL IMPACTS FROM ROUTINE MILL OPERATION

4.2.1 Mill Operation

The modern state-of-the-art design of the Piñon Ridge mill (monitoring; containment and control of hazardous materials, dust and fume emissions; HVAC systems; process control; etc) combined with the implementation of the health and safety plan, extensive training program, availability of personal protection equipment, and compliance with Federal (e.g., MSHA, EPA) and Colorado (CDPHE, CDOPS) regulations will ensure that occupational health and safety limits are not exceeded and that a safe workplace is maintained at all times. Therefore, no significant non-radiological risks and/or health related impacts to workers are expected from the routine operation of the mill. Examples of applicable regulations and guidance that will be followed to ensure low risk of chemical exposures of workers include:

- 30 CFR Subpart C, Fire Prevention and Control
- 30 CFR Subpart D, Air Quality and Physical Agents
- 30 CFR Subpart O, Materials Storage and Handling
- 30 CFR 56.20014, Prohibited Areas for Food and Beverages
- Mine Improvement and New Emergency Response Act of 2006 (MINER Act)
- 40 CFR Part 68, Chemical Accident Prevention Provisions.
- 40 CFR Part 355, Emergency Planning and Notification.
- 40 CFR Part 302, Designation, Reportable Quantities, and Notification
- 7 CCR 1101-5 Boiler and Pressure Vessel Regulations
- 7 CCR 1101-14, Storage Tanks Regulations
- 49 CFR Parts 130. 171, 172, 173, 177, and 178, Various DOT Regulations
- 2 CCR 601-8, Traffic Regulations Governing the Use of the Tunnels on the State Highway System
- 8 CCR 1507-25, Rules and Regulations Concerning the Permitting, Routing & Transportation of Hazardous and Nuclear Materials and the Intrastate Transportation of Agricultural Products in the State of Colorado
- American Conference of Governmental Industrial Hygienists – Threshold Limit Values and Biological Exposure Indices

For example, airborne concentrations of potentially hazardous materials to which workers could be exposed at the mill will be controlled to the Threshold Limit Values (TLV) as recommended in ACGIH 2009. Examples are provided in Table 4.6 below.

Table 4.6 Examples of Applicable ACGIH TLV Values

Substance	TLV (mg/m^3)
Ammonia	18
Sulfuric Acid	1
Sodium Hydroxide	2
Propane	Asphyxiant – maintain Oxygen content > 18 %
Hydrogen Peroxide	1.5

4.2.2 Transportation

The hazardous material shipments will follow U.S. Department of Transportation hazardous materials shipping regulations and requirements (49 CFR Parts 171, 172, 173, 177, 178, and 179). Most of the reagents are transported to the mill site in pre-packaged totes, barrels, and bulk bags. The bulk materials are transported by closed tanker trucks or. The bulk material in open trucks is covered with tarps to reduce dusting and falling debris during transportation.

No significant dust or fume emission is expected during routine shipment of the ore, chemical reagents and other hazardous materials. Therefore, no significant non-radiological risks and/or health related impacts to the driver are expected from the routine transportation of the reagents and hazardous materials.

5.0 Impacts to Public and Occupational Health and Safety from Accidents

The environmental effects of accidents involving the release of radioactive materials or hazardous chemicals that could occur at the mill site are described in this section.

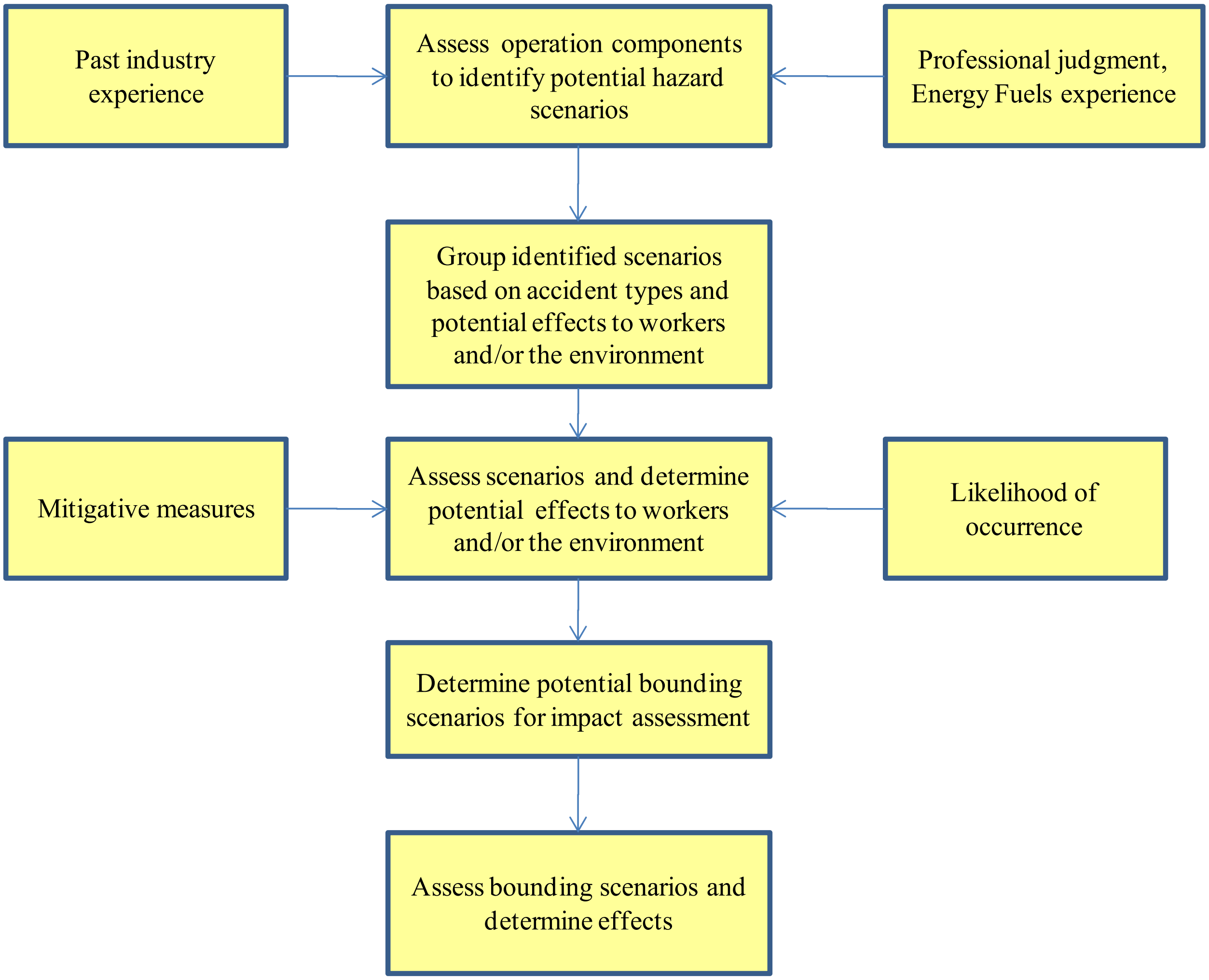
During over four decades of commercial nuclear facility operation in the US, the frequency and severity of accidents have been markedly lower than those in related industrial operations (construction, chemical and petrochemical, farming, manufacturing, etc). This can be attributed to the rigorous regulatory framework and well-developed plans and procedures for safe operation of nuclear facilities including uranium mining and milling operations. The experience gained from the few accidents that have occurred has resulted in improved engineered safety features and operating procedures, and the probability that similar accidents might occur in the future is considered low.

The radioactive materials handled at a uranium mill have relatively low specific activities (amount of radioactivity per unit mass, e.g., µCi/g). The low specific activities require the release of exceedingly large quantities of material in order to be of concern; driving forces (energy sources - initiating events for accidents) for such releases are generally lacking or extremely unlikely in the milling operation. In light of past experience, it is believed that even if major accidents did occur radiation exposures would be too small to cause any measurable deleterious effect on the health of the human population. A well-trained workforce operating under rigorous emergency response procedures will minimize occupational impacts from occurrence of accidents and unplanned events.

5.1 METHODOLOGY FOR ACCIDENT RISK ASSESSMENT

A consistent methodology was applied to evaluate the potential accident scenarios for the facility operations. This methodology is shown in Figure 5.1 below.

Figure 5.1 Methodology for the Assessment of Malfunctions and Accidents



5.2 HAZARD IDENTIFICATION

The mill facility components and activities were reviewed to determine the potential accident scenarios. For this assessment, the process description provided in the Facility Operating Plan (Energy Fuels 2009e) was used to identify the specific major components of the mill facility. Professional judgment, industry experience, and particularly Energy Fuel's experience were used to identify the potential radiological and conventional (non-radiological) accident sequences that were determined to be credible.

It was determined that sources of hazards were attributed to the existence of the following materials on site:

- Radioactive materials

- Flammable materials
- Toxic materials

The list of materials, stored, handled, or transported in the mill facility is provided in Section 1.2. Table 5.1 below lists the identified potential accidents for each process component and activity.

Table 5.1 Summary of the Identified Accident Scenarios

Component	Accident Scenarios
Construction	Conventional accidents and personnel injury due to typical project activities such as working at heights, working with heavy equipment, power tools, high voltage, etc Potential injuries include falls, trips, strains, electrocution, crushing, pinching, etc.
	Spill of construction materials, e.g. cement
	Spill of fuel from mobile and stationary storage during refueling and maintenance
	Spill of engine fluids on-site from heavy equipment
Ore Handling and Grinding	Personnel injury due to working with heavy equipment
	Spill of wash water
	Failure of baghouse and dust release
	Failure of Venturi scrubber and dust release
	Spill of pulp from pulp storage tanks, piles, and pumps
Leaching	Failure of Venturi scrubber and release of acidic fume from pre-leach and leach tanks
	Failure of the tanks, pipes, and pumps and release of acidic leach solution
	Overflow of the tanks and release of acidic leach solution
CCD Thickeners and Waste Disposal	Failure of the thickeners, pipes, and pumps and release of acidic solution
	Overflow of the thickeners and release of acidic leach solution
	Failure of the tailings pipes and pumps and release of tailings
	Failure of the raffinate pipes and pumps and release of raffinate and wastewater
	Failure of tailings embankment and release of tailings
Solvent Extraction	Failure of the, pipes, filters, and pumps and release of pregnant solution or raffinate
	Failure of the, pipes, filters, and pumps and release of kerosene and amine extractant

Component	Accident Scenarios
	Overflow of the tanks and release of pregnant solution
	Overflow of the tanks and release of kerosene and amine extractant
	Accidental release of caustic/sodium carbonate solution from tanks, pipes, and pumps
	Accidental release of sodium chlorate from tanks, pipes, and pumps
	Accidental release of ammonia from transfer line
	Fire involving organic solvents
Uranium Precipitation and Drying	Accidental release of hydrogen peroxide from tanks, pipes, and pumps
	Accidental release of uranium precipitate form pipes, filter, and process tanks
	Propane explosion in uranium dryer
	Failure of the air cleaning system (baghouse) and release of yellowcake dust
Vanadium Precipitation and Drying	Accidental release of ammonium sulfate from tanks, pipes, and pumps
	Accidental release of ammonia from transfer line
	Failure of wet scrubber and release of ammonia fumes
	Propane explosion in the kiln
	Propane explosion in the fusion furnace
	Failure of the air cleaning system (baghouse and scrubbers) and release of vanadium oxide dust
Chemical Storage	Spill of liquid chemicals during offloading of trucks
	Release of ammonia during transfer from truck to the storage tanks
	Overflow of storage tanks and chemical release
	Failure of pumps, pipes, valves and release of chemicals
	Release of solid chemicals during on-site transfer and handing
	Fire involving organic chemicals in the storage area
	Release of diesel or gasoline during off loading and refueling
	Fire involving fuels
External Events	Airplane crash and catastrophic failure of all containments
	Tornado and high wind and dispersion of contaminants from stockpiles
	Flood and dispersion of contaminants from stockpiles
	Earthquake
	Building fire
Transportation Accidents	Transportation accident resulting in potential release of radioactive materials to the environment (surface)

Component	Accident Scenarios
	Transportation accident resulting in potential release of non-radioactive materials to the environment (stream)
	Transportation accident resulting in a fire and release to air
	Transportation accident and release of ammonia to air

5.2.1 Classification of Accidents

Identified accident scenarios were classified based on the type of the accidents and their potential health and environmental impacts. The grouping process reduced duplication between different process components. This was done in order to facilitate the identification of potential bounding scenarios for assessment of health, safety and/or environmental effects.

5.2.2 Identified Bounding Scenarios

A bounding accident scenario for each group was selected that encompasses the impact of all accident scenarios in each group. Following are the selected bounding case scenarios:

1. Conventional accidents and personnel injury due to typical project activities such as working at heights, working with heavy or processing equipment during construction or plant operation
2. Spill of radioactive materials from storage tanks, transfer lines, valves, pumps, and other process equipment as well as during offloading
3. Spill of non-radioactive materials and fuel from storage tanks, transfer lines, valves, pumps, and other process equipment as well as during offloading
4. Failure of air cleaning systems and release of toxic fumes and/or radioactive dust
5. Spill of tailings slurry from transfer line, pumps, or due to tailings cell embankment failure
6. Fire involving flammable liquids in the storage area and SX circuit
7. Propane explosion in boilers, kiln, dryer, and fusion furnace
8. Airplane crash and catastrophic failure of all containments
9. Tornado and high wind and dispersion of contaminants from stockpiles
10. Flood and dispersion of contaminants from stockpiles
11. Building fire
12. Transportation accident resulting in potential release of materials to the environment (streams)
13. Transportation accident resulting in a fire and release to air
14. Transportation accident and release of ammonia to air

5.3 METHODOLOGY FOR ASSESSMENT OF BOUNDING SCENARIOS

The risk of bounding scenarios was assessed qualitatively and/or semi-quantitatively, as applicable to the scenario, to determine the potential effect to mill workers, the public and/or the environment that would result from each type of accident. Risk may be defined as the multiplication of the frequency of occurrence and the severity of the consequence of a hazardous event:

*Risk = Frequency * Severity of the Impact*

A simple and effective way of mapping the risk for identified hazard scenarios is using a risk matrix such as that shown in Figure 5.2.

Figure 5.2 A Typical Risk Ranking Matrix

IMPACT RANKING	***Large***	*3*	**3**	**6**	**9**
	Moderate	*2*	**2**	**4**	**6**
	Small	*1*	**1**	**2**	**3**
			1	*2*	*3*
			Low	***Medium***	***High***
			FREQUENCY RANKING		

5.3.1 Likelihood Assessment

The frequency of the occurrence of any accident scenario is a combination of the frequency of the initiating events and the conditional probabilities of the hazard scenario occurring.

*Frequency of Hazard Scenario = Frequency of the Initiating Event * Conditional Probabilities*

The conditional probabilities are dependent on mill operating conditions. For example the frequency of a spill reaching the environment is the product of frequency of tank overflow (or a tank failure) and the conditional probability of failure of secondary containment during the original release (other features, as designed or natural, that minimize the probability that the spill can reach an unrestricted area). Provisions of secondary containment and comprehensive monitoring dramatically reduce the frequency of a spill reaching the environment.

5.3.2 Impact Analysis

The assessment of the impact of the identified bounding scenarios was consistent with the following sections of NUREG-1910 (NRC 2009) and NUREG-0706 (NRC 1980).

- Radiological Impacts to Public and Occupational Health and Safety from Accidents
- Non-radiological Impacts to Public and Occupational Health and Safety from Accidents

In the above documents, accident risk assessment included processes, storage, and transportation activities. The Nuclear Regulatory Commission (NRC) Generic Environmental Impact Statement for In Situ Leach Uranium Facilities (NUREG 1910) categorized the potential environmental impacts using significance levels. According to the Council on Environmental Quality, the significance of impacts is determined by examining both context and intensity. Context is related to the affected region, the affected interests, and the locality, while intensity refers to the severity of the impact, which is based on a number of considerations. NUREG 1910 used the significance levels identified in NUREG–1748 (NRC 2009). These significance levels are simply:

- SMALL Impact: The environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource considered.
- MODERATE Impact: The environmental effects are sufficient to alter noticeably, but not destabilize, important attributes of the resource considered.
- LARGE Impact: The environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource considered.

The assessment of impacts was consistent with the above classification.

5.4 ASSESSMENT OF BOUNDING SCENARIOS

Extensive health and safety procedures and training programs will be in place to minimize the occurrence of and reduce the potential extent of personnel injuries. Hazards to construction personnel and operators will be controlled or minimized through the implementation of MSHA and CDPHE compliance programs through the use and implementation of appropriate personal protective equipment, signage, training, standard work procedures, and controlled access where applicable

In addition, to minimize the probability of personnel injuries from accidents, Energy Fuels has prepared the following plans, which will be implemented throughout the operating life of the Mill Facility.

- Health and Safety Plan: This plan is designed to inform Mill personnel of the rules, procedures, and work practices that are in place to protect them from injury. (Energy Fuels Resources Corporation, 2009a)
- Emergency Response Plan: This plan identifies possible emergency incidents that may occur and provides identification and response procedures for those incidents. (Energy Fuels Resources Corporation, 2009b)
- Material Containment Plan: This plan identifies the hazardous materials on site, their location, quantities, use and hazardous characteristics. It also provides instructions for containment and cleanup in the event of a spill or release (Energy Fuels Resources Corporation, 2009c)
- Spill Prevention Control and Countermeasure (SPCC) Plan: This plan identifies fuels, oils, and other petroleum products on site, their location, quantities, inspections, spill response, and spill reporting procedures (Energy Fuels Resources Corporation, 2009d)

Due to the extensive preventive and mitigative measures established in these plans, the probability of accidents occurring and the potential impact associated with an accident will be reduced.

5.4.1 Conventional Accidents and Personnel Injury

The risks of events such as trips and falls, strains, electrocution, crushing, and pinching associated with project activities such as working at heights, working with heavy equipment both during construction and during routine operation of the plant will not be different from those on any other industrial project of similar scope and duration.

5.4.2 Spill of Radioactive Materials

Uranium bearing solutions are stored in storage tanks, handled in process vessels, and transported through piping systems. A spill of these solutions could occur as a result of the following events:

- Overflow of storage or process vessels
- Leaks or rupture in storage tanks and process vessels
- Failure of valves or other piping system components
- Failure of the pumps

- Failure of other process components such as screens and filters

The occupational and environmental impact of a radioactive material spill is bounded by the spill of yellowcake slurry. In a study by Mackin, et al. (2001), the failure of a yellowcake thickener and potential release of radionuclides to the atmosphere through a thickener failure was assessed. For the purposes of the analysis, it was assumed that a tank failure or pipe break causes the yellowcake slurry to spill, with 20 percent of the thickener content being spilled inside and outside the building. Analysis was done for a variety of wind speeds, stability classes, release durations and receptor distances. For receptor distances of 100 and 500 m (330 and 1,600 ft) doses from such spills were calculated to be 0.25 and less than 0.01 mSv (25 and 1 mrem), respectively. Both of these are less than 25 percent of the CDPHE annual dose limit for the public of 100 mrem.

For the proposed mill, the distance of the mill process buildings from the property boundary and from the administration building is larger than 100 m, therefore no significant radiological risks and/or health related impacts to the office worker in the administration building and a member of the public are expected from a spill in the mill process buildings.

In the case of such spill, doses to the unprotected worker could exceed the 0.05 Sv (5 rem) annual dose limit specified in the Colorado Radiation Control Regulations (6 CCR 1007-1, Part 4) if workers did not evacuate the area relatively quickly after the accident. It should be noted that in the above analysis, no expedited response or cleanup and no credit for personal protection equipment (respirators, e.g.) was assumed. The analysis also used ICRP Class Y solubility (“insoluble”) instead of more realistic class W or D solubility for uranyl peroxide that is produced today. This adds another layer of conservatism that resulted in potential overestimation of the occupational doses.

To minimize the likelihood and impact of spills, Energy Fuels has prepared the Materials Containment Plan and Emergency Response Plan, which will be implemented throughout the operating life of the Mill Facility. The mill facilities are designed to contain process controls and monitoring of instrumentation to reduce the exposure to workers and effluent release to the environment in the event of an accident. The spills or leaks will normally be detected by leak detection systems, loss of system pressure, observation, or flow imbalance.

Design features including the selection of the appropriate materials of construction in combination with regular inspections and maintenance will minimize the potential for leaks or failures in major process equipment and components important to safety. Secondary containment is provided for reagent storage, reagent offloading areas, processing buildings, and waste disposal areas so that any leaks or spillage from primary containment does not affect the surrounding environment (i.e., soils, surface water, and groundwater) nor become a source term for air borne release. In particular, inside the process buildings, tanks and major process vessels are located on the concrete floor and enclosed within a concrete stem walls or curbs around their perimeters, which provide secondary containment. The secondary containment volume will be equal to the volume of the largest tank plus 10 percent. Process and reagent lines, which are not within a curbed secondary containment area, are placed inside an outer pipe sleeve, lined pipe rack, or lined trench. Collection basins and bermed areas are equipped with sumps and sump pumps so that any spilled material can be recovered quickly. Floor sumps in the mill are also equipped with secondary containment and leak detection monitoring between the primary and secondary containment walls.

The above measures will reduce the probability of spills occurring, minimize potential consequences to workers when they do occur, and reduce the probability of a spill reaching the environment. In the unlikely event of an uncontrolled spill, doses to the workers could have a moderate impact depending on the type of the spill, but doses to the general public and office workers would have only a small impact, if any at all.

5.4.3 Spill of Non-Radioactive Materials and Fuel

Similar to many other industrial operations, releases of large amounts of hazardous chemicals, which could adversely affect public and occupational health and safety, are possible. However, they are generally considered unlikely, given commonly applied safety practices, extensive comprehensive Federal and State regulations and the history of safe use of these chemicals, particularly at Atomic Energy Act licensed facilities. It should be noted however, that the storage and use of non-radioactive chemicals at the mill is not regulated by NRC or CDPHE, but rather by MSHA, CDOPS, and to a lesser extent, the EPA. The frequency of catastrophic failure of large storage tanks are in the order of 10^{-4} per year (i.e., once every 10,000 years), while the frequency for catastrophic failure of pressure vessels, such as an ammonia storage tank, is in the order of 10^{-5} per year or once every 100,000 years for any similar tank or pressure vessel (CCPS 1989).

These potentially high impact but very low probability events are not assessed in detail in this report based on the premise that the application of common safety practices (as articulated in the mill's Health and Safety, Material Containment, Emergency Response, and SPCC plans) for handling and use of chemicals and other preventive measures are expected to lower the likelihood and potential consequences of these release accidents and therefore lower the risk to very low levels. Additionally, and most importantly, risks (probability of occurrence and severity of impact) associated with this class of events are no different than at any similar industrial facility, independent of the radiological characteristics of a uranium mill. In fact, the risks would be expected to be less than at similar industrial facilities due to the rigorous work control and training programs required at US Atomic Energy Act licensed facilities.

Among hazardous materials stored and used on site, the consequence of accidents involving anhydrous ammonia could potentially bound the consequences of scenarios involving other hazardous chemicals. Catastrophic failure of an ammonia storage tank is a very unlikely scenario. However, in a more probable accident, it is possible that the line connected to the storage tank could be ruptured, in which case the release rate is assumed to be limited to 100 g/s (0.2 lb/s) of vapor. Based on this release rate and calculated dilution factor, the resulting maximum conservative concentration of ammonia at the distance of 4,000 m (13,200 ft) is estimated at approximately 8.5 mg/m^3 over the entire period of release (see Appendix A4 for details of the dilution factor). This concentration is less than the American Conference of Government Industrial Hygienists Short Term Exposure Limit (STEL) of 27 mg/m^3 (ACGIH, 2009). Thus, the ammonia release at this rate would pose no substantial health risk to the member of public. It is expected that upon any release of ammonia, workers would evacuate the scene of accident immediately. However, if they did not evacuate the area quickly, an unprotected worker could be exposed to higher ammonia concentrations for a short period of time. The Emergency Response Plan (Energy Fuels Resources Corporation, 2009b) would be implemented to mitigate the impact.

Strong bases such as ammonia (NH_3) and sodium hydroxide (NaOH) and strong acids such as sulfuric acid (H_2SO_4) will strongly react with each other, and with water, if accidentally mixed. Therefore, their storage tanks are located in separate secondary containment areas. In addition, precautions are taken to ensure that these chemicals do not inadvertently come into contact with each other during operations.

A spill of toxic or corrosive chemicals, such as sulfuric acid, inside the mill processing areas would pose no significant impact to the public; however, workers in close vicinity of the spill may come into contact with such chemicals. The application of common safety practices and associated safety training for handling and use of chemicals is expected to lower the likelihood of large release events and therefore lower the risk to acceptable levels.

The operation of the mill in accordance with a formal work control program, including comprehensive operating and H/S procedures, will maximize compliance with applicable regulations designed to protect workers and the environment.

In addition to the preventive and mitigative measures described elsewhere, trucks, delivering ammonia, park within a concrete apron that is curbed and drains to the storage tank containment area and storage tanks are located within a reinforced concrete containment structure which also protects it from vehicular traffic. Diesel and gasoline are also stored on-site in double walled storage tanks situated within a common concrete containment, with a floor sump and protective aprons to collect spillage during fueling activities. Employees and contractors will be trained in the proper handling, transfer, storage and use of fuels.

Overall, the offsite impacts of credible accidents involving hazardous chemicals would be small, while impacts to workers could be moderate. However, these are mitigated by formal and rigorous training requirements, operational and emergency response procedures as described above.

5.4.4 Failure of Air Cleaning Systems

In order to control the emission of dust and toxic fumes, baghouses and wet scrubbers will be used throughout the mill facility.

Baghouses are located at the feed hopper, dry (i.e., solid) reagent tanks and bins, and at the yellowcake and vanadium oxide packaging areas. Scrubbers are located at all other process emission points including the emissions from the haghouses in the two packaging areas. The fumes from the leach tanks are vented to the wet venturi scrubber located in the northeast corner of the Grinding and Leach Building.

In case of failure of air cleaning systems, the off gases from the mill will be released to the atmosphere for a short period of time, before the process could safely be shut down (telemetered systems provide early indication to operators in the control room and other locations within the plant). The off-gases from the mill uranium drying operation typically carry entrained solid particles of yellowcake with a rate of 1,400 g/hr (3.1 lb/hr). If the baghouse and scrubber fail, some of this material could be released to the environment. The leach and preleach circuits, which share a common H_2SO_4 scrubber, are interlocked with the scrubber so that if the scrubber fails, the leach circuits will automatically shut down in a controlled manner.

An analysis of unmitigated release of yellowcake dust (for eight hours) from a uranium dryer conservatively estimated that an individual at the distance of 2,000 m (6,500 ft) would receive a 50-year dose commitment to the lung of approximately 86 mrem (NRC 1980, NUREG 0706). There are no residents living within this distance of the mill. The analysis may have also used class Y solubility ("insoluble") for the U_3O_8 product of older mills instead of more realistic class W or D solubility for the uranyl peroxide (UO_4) that will be produced by modern low temperature vacuum dryers. This may result in an overestimate of the dose using the NUREG 0706 analysis.

Although quantitative data are unavailable, catastrophic baghouse and scrubber failure, which would go un-noticed for eight hours, is highly unlikely due to control room alarms and the severe pressure drop that would be identified by operators. Progressive failure, in which case the plugging of vents causes backpressure, would be readily detectable during operational checks and would probably produce inefficiencies, rather than complete failure.

In addition, the uranium drying circuit including operation of the dryer and its off-gas treatment system is frequently checked (twice per shift) as a part of the formal plant procedures. A drop in pressure would indicate failure of either the baghouse and scrubber, in which case drying and packaging operations would be terminated until the baghouse and scrubber were repaired and returned to service.

In the very unlikely event of an unmitigated release of uranium dust, doses to the general public would have only a small impact because of the relatively large distance to the nearest downwind resident (3 miles or about 15,800 feet).

5.4.5 Spill of Tailings Slurry

Accidental release of the tailings slurry to the environment might result from the following events:

- rupture in the tailings piping
- overflow of the tailings slurry from the cells
- failure of the tailings embankment caused by an earthquake, flood-water breaching, or structural failure

The tailings discharge pipes are installed within a lined trench that has vehicle crossings where the trench intersects secondary roads.

The storm water ponds, drainage diversions, ditches and culverts are designed for the 100-year, 24-hour storm volume and peak discharge. The ponds are designed to retain (with no discharge) the 100-year, 24-hour storm volume and include emergency overflow outlets, consisting of a pipe network, sized to convey the peak discharge from a 1,000-year storm event to the evaporation ponds for containment. The evaporation ponds and tailings cells are designed and operated with adequate capacity to contain runoff from the 1,000-year storm event.

Failure of a tailings embankment because of an earthquake would be unlikely since the site is in a zone of low to moderate seismicity (Kirkham and Rogers, 1981) based on the number of sizable earthquakes that have occurred in the historical and more recent record. The largest known natural earthquake in the vicinity of the site was magnitude 5.5 in 1960 earthquake near Ridgway, about 60 km southwest of the site (Sheehan et al, 2003: Blume and Sheehan, 2003). Several earthquakes of magnitude 4 or higher have occurred in this region with the most recent one being a magnitude 4.1 on November 7, 2004, located west of Montrose, The proposed tailings cells are mostly incised with an average depth of about 80 feet and an average embankment height above ground level of about 20 feet. Internal slopes are 3 horizontal to 1 vertical (3H:1V) while external slopes range from 5H:1V to 10H:1V. The three tailings cells were designed in accordance with the International Building Code (IBC) based on a Magnitude 4.8 earthquake occurring at a distance of approximately 10 miles from the site. Minimum static and pseudo-static factors of safety ranged from 2.0 to 4.9 and 1.7 to 2.7, respectively, during the life of the cells, with the highest factors of safety occurring during the post-closure period (Golder, 2008).

From the above discussion, it appears that the probability of catastrophic failure of the tailings embankment is very small. However, sufficient data are not available to estimate the small probability of the occurrence of a natural disaster that could result in a release of tailings slurry to the environment. Tailings slurry releases have occurred in the past and the consequences associated with these events have been documented. The design of the Piñon Ridge Mill embankment retention system will conform to NRC Regulatory Guide 3.11 for new mills (NRC 2008). Table 5.2 contains a summary of recorded incidents in the period 1954 through 1994[1]. It is interesting to note that almost all of the failures were due to poor construction, poor operating practices, and/or flooding. Only one embankment failure was related to an earthquake event.

Table 5.2 Chronology of Uranium Tailings Dam Failures (Source: Wise-Uranium Website)

Date	Location	Parent company	Type of Incident	Release	Impacts
(1994)	Zirovski vrh, Slovenia	Rudnik Zirovski vrh, Gorenja vas	ongoing slippage of the slope (7 million t) with the "Borst" tailings deposit (600,000 t) on the top, at velocity of 0.3 m per year	-	-
1994, Feb. 14	Olympic Dam, Roxby Downs, South Australia	WMC Ltd.	leakage of tailings dam during 2 years or more	release of up to 5 million m^3 of contaminated water into subsoil	-
1985	Lengenfeld, Vogtland, Germany	Wismut	localized dam failure	-	minor

1 http://www.wise-uranium.org/mdafu.html

Date	Location	Parent company	Type of Incident	Release	Impacts
1984, Jan. 5	Key Lake, Saskatchewan, Canada	Cameco (67%), Uranerz (33%)	overtopping of process water reservoir, due to poor management	87,330 m^3 of contaminated water	-
1979, Jul. 16	Church Rock, New Mexico, USA	United Nuclear	dam wall breach, due to differential foundation settlement	370,000 m^3 of radioactive water, 1,000 tonnes of contaminated sediment	Contamination of Rio Puerco sediments up to 110 km downstream
1979, Mar. 1	Union Carbide, Uravan, Colorado, USA	Union Carbide	two slope slides, due to snow smelt and internal seepage	-	-
1977, Apr.	Western Nuclear, Jeffrey City, Wyoming, USA	Western Nuclear	Tailings slurry overtopped the embankment because of insufficient freeboard space, considerably less slope than the requisite 3 horizontal to 1 vertical, and a loss in structural integrity caused by the melting of snow interpersed with the fill used to construct the embankment.	40 m^3 of tailings and 8,700 m^3 of liquid	"no offsite contamination"
1977, Feb. 1	Homestake, Milan, New Mexico, USA	Homestake Mining Company	dam failure, due to rupture of plugged (frozen) slurry pipeline	30,000 m^3 of tailings and 7,600 - 30,000 m^3 of liquid	no impacts outside the mine site
1976, Apr. 1	Kerr-McGee, Churchrock, New Mexico, USA	Kerr-McGee	dam failure, due to differential settlement of foundation soils	"minor quantity"	-
1971, Mar. 23	Western Nuclear, Jeffrey City, Wyoming, USA	Western Nuclear	dam failure, due to break in tailings discharge line	-	"no offsite contamination occured"
1971, Feb. 16,	Petrotomics, Shirley Basin, Wyoming, USA	Petrotomics	secondary tailing dike failure	7.6 m^3 of liquid	liquid lost to unrestricted area

Date	Location	Parent company	Type of Incident	Release	Impacts
1967, Jul. 2	Climax, Grand Junction, Colorado, USA	?	tailing dike failure of unapproved retention system	1,200 - 12,000 m^3 of waste liquid	effluent release into Colorado river
1967, Feb. 6	Atlas Corp., Moab, Utah, USA		auxiliary decant failure, overflow from main tailings pond overflowed aux. decant system	1700 m3	
1963, Jun. 16	Utah Construction, Riverton, Wyoming, USA	-	The dam was intentionally breached and a 2-ft depth of effluent was released to prevent uncontrolled release of the impoundment contents during heavy rain		-
1962, Jun. 11	Mines Development, Edgemont, South Dakota, USA	-	dam failure, due to unreported causes	100 m^3	tailings released reached a creek and some were carried 25 miles to a reservoir downstream
1961, Dec. 6	Union Carbide, Maybell, Colorado, USA	Union Carbide	dam failure from unreported causes	280 m^3	effluent released did not reach any stream
1960	Gunnar mine, Beaverlodge area, Saskatchewan, Canada	Gunnar Mines Ltd.	dam failure	-	tailings release into Lake Athabasca, creating Langley Bay tailings delta
1959, Aug. 19	Union Carbide, Green River, Utah, USA	Union Carbide	dam failure during flash flood	8,400 m^3	tailings and effluent reach a creek and river
1958, Apr.	Mayluu-Suu tailing #7, Kyrgyzstan		dam failure after earthquake and heavy rain	600,000 m^3	a lot of houses in the town destroyed, people were killed, and the tailings were spread over 40 km down by the river, contaminating flood plains (UNEP/GRID-Arendal)

Date	Location	Parent company	Type of Incident	Release	Impacts
1954	Lengenfeld, Vogtland, Germany	Wismut	dam failure during flooding event	50,000 m^3	tailings spread 4 km down by the river, create wetland by damming up

From these historical data, the average releases from tailings embankment failure or flooding were approximately 5.5 x 10^7 L (1.4 x 10^7 gallons) of liquids and 1.4 x 10^7 kg (3.2 x 10^7 lb) of solids (NRC 1980). The extent of the area covered would depend upon the specifics of the failure and the terrain and is difficult to calculate here. Scaling from previous estimates on the basis of the total mass of tailings released, the material may be assumed to follow the tributary stream channel for a distance of approximately 2,100 m (6,800 ft), covering a width of approximately 130 m (425 ft), and forming a wedge 3 cm (1-1/4 inches) in average thickness (NRC 1980). However, the maximum release from one of the Piñon Ridge Tailings Cells, would be approximately two orders of magnitude smaller in volume due to the limited areal extent of the cells (i.e., 30 acres) and the relatively small height of the embankments above surface grade (i.e., 20 feet). The extent of area covered would, accordingly be only one percent of that calculated for the historic releases. It is also reasonable to assume that none of these historical events described above involved tailings embankments and impoundments designed per US NRC Regulatory Guide 3.11.

The main radiological concern associated with the deposition of the tailings material is the increase in background radiation levels in the affected and adjacent areas and the eventual transport of these low levels of contamination by wind and rain. These long-term effects would be prevented by removing the contaminated material from the environment via expedient response and clean up actions.

5.4.6 Fire Involving Flammable Liquids

Apart from conventional impacts (e.g. burns and related injuries) to workers, the most significant impact from a fire in the solvent extraction circuit could potentially result in the release of airborne radionuclides.

NRC reported that the frequency of a major solvent extraction fire occurring at a uranium mill was in the range of 4 x 10^{-4} to l x 10^{-2} per year (NRC 1980). It is expected that the frequency of a large fire would be much smaller in a new mill due to provisions for fire safety and accident prevention. The NRC assessment projected that the maximum individual 50-year dose commitments to the public at 500 m (1,600 ft) and 2,000 m (6,500 ft) resulting from a fire would be approximately 1.36 rem and 0.15 rem to the lung and bone, respectively. This is an extremely conservative estimate, as it was based on dispersion of 1% of the total uranium inventory. In the case of such an unmitigated fire, doses to the unprotected worker could be higher if workers did not evacuate the area quickly after the accident. With consideration of the low likelihood of a large fire resulting in release of radioactive materials, the risk to a member of the public would be small while the risk to a mill worker would be moderate.

In order to reduce the risk, the SX Building is equipped with smoke and heat detectors that activate sprinkler systems and all buildings have fire extinguishers in accordance with building codes and county requirements. Any work task that could potentially generate a spark (e.g., welding, cutting with a torch) requires a Radiation Work Permit with strict controls and monitoring. Additionally, explosion-proof equipment and instrumentation is utilized in accordance with electrical code requirements.

A firewater loop, with hydrants at key locations serves as one component of the overall fire protection system. A large portion of the raw water storage tank is dedicated to fire protection. The tank feeds the firewater loop and the electric water pumps are equipped with a backup diesel generator in the event of power loss. Hose reels are also situated in the various buildings in close proximity to the fire hydrants so that fire hoses can be quickly attached to the hydrants and pulled to the location of a fire, if one were to occur.

5.4.7 Propane Explosion

The off-gas from the dryer is vented to the yellowcake packaging room through a baghouse and a wet scrubber. An explosion in the dryer or the fuel piping however could blow off the ductwork associated with the ventilation system and disperse yellowcake into the room and then into the atmosphere.

The consequences of explosion accidents are limited by the concentration of yellowcake dust that can be maintained in the air. NRC provided an estimate of the public dose due to an explosion in a uranium dryer based on an estimate of 100 mg/m^3 of yellowcake dust in the room's air (NRC 1980). For a room with a volume on approximately 1,000 m^3 (35,000 ft^3), the quantity of yellowcake released to the room air was estimated to be approximately 10,000 g (22 lb). This estimate was based on the conservative assumption that all of the material would be swept out into the environment when the room is ventilated. It was estimated that if 100% of the insoluble particles were in the respirable size range, individuals at the distance of 2,000 m (6500 ft) would receive 50-year dose commitments to the lung approximately 69 mrem. Therefore, the potential impact to a member of the public for this accident would be small, especially since the nearest downwind resident is about 3 miles (15,800 feet) away.

In the case of such an explosion, doses to the unprotected worker could exceed the 0.05 Sv (5 rem) annual dose limit specified in CDPHE regulations if workers did not evacuate the area quickly after the accident. In order to reduce the risk, only required operations personnel are allowed within the packaging area and they are required to wear appropriate PPE including air-purifying respirators, gloves, and coveralls. A viewing area is provided above the packaging area for guests and non-operations personnel. The packaging area is routinely washed down to prevent the accumulation of dust on the surface of equipment and walls. Given the provisions of PPE, the occupational radiological impact during an explosion is expected to be low.

5.4.8 Airplane Crash

Based on a study conducted by Lawrence Livermore National Laboratory (Kimura et. al. 1996), the likelihood of an aircraft crash at sites at locations similar to the proposed mill site is less than 1×10^{-7} per year (i.e., once every 10,000,000 years). This likelihood is dominated by general aviation crashes typically involving small non-commercial, non-military aircraft. The likelihood of a crash by commercial or military aircraft at the PHCF is much less than 1×10^{-7} per year. Because of the low likelihood (essentially “incredible”) of this occurring, airplane crash events are not expected to cause significant risk to workers and members of the public.

5.4.9 Tornado and High Wind

An assessment of impact of release of radioactive materials due to tornado was reported by NRC (NRC 1980). Based on a conservative assumption that the tornado lifts about 11,400 kg (25,100 lb) of yellowcake, the maximum exposure occurs at a distance of approximately 4 km (2.5 miles) from the mill, the 50-year dose commitment to the lungs of an individual was estimated to be 8.3 $\times 10^{-7}$ rem. For individuals at the fence line 500 m (1600 ft) the 50-year dose commitments were estimated to be 2.2×10^{-7} rem.

Between 1950 and 1995, there have been 1,160 tornados in Colorado with various strengths (26 tornados per year)[2]. Given that the area of Colorado is 104,100 square miles, the frequency of tornados will be $2.5\text{x}10^{-4}$ tornados per year per square mile. Assuming that the mill building footprint is approximately 0.25 square miles, the frequency of a tornado striking the mill process buildings is approximately $6\text{x}10^{-5}$ per year. This is a highly conservative estimate since the vast majority of tornadoes occur in eastern Colorado.

With low frequency of occurrence and low impact, the risk of a tornado striking the mill and impacting a member of the general public is judged to be low.

2 http://www.disastercenter.com/colorado/tornado.htmlColorado Tornados

5.4.10 Flood

The mill is located on an elevated pad and the stormwater ponds, drainage diversions, ditches and culverts are designed for the 100-year, 24-hour storm volume and peak discharge. The ponds are designed to retain (with no discharge) the 100-year, 24-hour storm volume and include emergency overflow outlets, consisting of a pipe network, sized to convey the peak discharge from a 1,000-year storm event to the evaporation ponds for containment. The evaporation ponds and tailings cells are designed and operated with adequate capacity to contain runoff from the 1,000-year storm event. No significant impact on the members of the public is expected from flood events and therefore the risk is considered low.

5.4.11 Building Fire

Given the fire prevention and control systems and measures previously described, a building fire with the intensity capable of starting a major fire in the solvent extraction circuit is unlikely. The impact of such a fire would be similar to the accident scenario discussed in Section 4.4.7. Although smaller fires might be expected on a more frequent basis, they would likely be controlled with no major impact off site.

In order to reduce the probability of large building fire, a firewater loop, with hydrants at key locations are designed as one component of the overall fire protection system. Hose reels in close proximity to each hydrant provide mill workers with the means for suppressing fires should one occur. The raw water storage tank, which provides dedicated storage for fire protection, feeds the firewater loop. Non-process buildings and the SX Building are equipped with sprinkler systems and all buildings have fire extinguishers in accordance with building codes and county requirements.

5.4.12 Transportation Accident and Materials Release

Transportation of materials to and from the mill can be classified into four categories:

- Shipments of yellowcake from the mill to a uranium hexafluoride conversion facility in Metropolis, Illinois
- Shipments of V_2O_5 from the mill
- Shipments of ore from the mines located in the Colorado Plateau region to the mill
- Transportation of reagents to the mill by suppliers

Three credible accident scenarios were assessed in this study. They are:

- Scenario 1: Collision of two vehicles (Crash)

- Scenario 2: Roll over into a ditch or down an embankment
- Scenario 3: Roll over directly into a river (considered the worst-case environmental accident).

To assess the probabilities and potential consequences associated with these scenarios, it was considered that a spill into a river is the worst-case environmental event. However, any spill could result in partial release to the atmosphere. It was also assumed that the impact of yellowcake spills will bound the impact of other spills, although due to higher frequency of ore shipment, this also could be a source of concern.

Under most circumstances, a spill onto land would be easily contained, which will allow essentially complete recovery of spilled material by the emergency response team. The consequences of a transportation incident, however, if it were to occur in a populated area, could have significant impacts. Given the precautions taken with such materials, the likelihood of an incident in a populated area is considered low and therefore the overall risk of a high consequence accident is considered small.

Based on the DOT hazardous material transportation accident statistics, transportation route length between the mill and Metropolis conversion facility, and number of annual shipments, the frequencies of transportation accidents (i.e. rollover and crash) involving yellowcake and ore were calculated at 7.9×10^{-4} and 1.7×10^{-2} per year, respectively (see Appendix A5 for details).

A prior transportation analysis (NRC, 1980) estimated risks of transporting yellowcake 2,414 km (1,500 mi) to a conversion plant in Illinois. Yellowcake release during a potential traffic accident was calculated considering the degree of loss of package containment for a range of accident severities and information on the likelihood that an accident of a particular severity class would occur when an accident happens. Two models for package response to accident conditions were considered. Model 1 assumed complete loss of package contents for any accident severe enough to breach packages, whereas Model 2 used results from package tests indicating only partial release of contents for accidents sufficient to breach packages. The resulting population dose estimates for these estimated releases from a single accident in an area containing 61 people per km^2 (158 people per mi^2) (i.e., rural residential population living on a given area of land) were 200 person-rem (2 person-Sv) for Model 1 and 14 person-rem (0.14 person-Sv) for Model 2 (NRC, 1980).

An analysis of the dose to the public by NRC, as a result of accidental release of ore during shipping, indicated that the maximum individual 50-year lung dose commitment of 0.014 rem at 2000 m (6500 ft) from the release location (NRC 1980). This would be approximately equivalent to an effective ("whole body") dose of approximately 1.75 mrem compared to a natural background dose over 50 years of 400 mrem / year X 50 years = 20,000 mrem.

An analysis was also performed by the US Department of Energy (DOE 2007) of a severe transportation accident involving uranium ore. Foe 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 and individual (resident) could be to the haul route. It was estimated this individual would receive a radiation dose of 4.9 mrem.

Previously reported accidents involving yellowcake release indicate up to 30 percent of shipment contents were released (Mackin, et al., 2001; Grella, 1983), which is less than the fraction used in the previously mentioned calculations. In all cases reviewed, spills from accidents have been contained and cleaned up quickly (by the shipper with state involvement) without significant health or safety impacts to workers or the public.

As a result of the low probability and the small consequences, the risk of this scenario of yellowcake and ore transportation accidents on members of the public would be small.

Spill of yellowcake or ore into the water would potentially pose a severe impact on the aquatic environment, as part of the released load could be washed away by the stream and carried a long distance from the accident site. The frequencies of rollover and crash at water crossings is calculated at 4 x 10^{-6} per year (once every 250,000 years) and 8.4 x 10^{-5} per year (once every 12,000 years) for yellowcake and ore shipments, respectively (see Appendix A5 for details).

In a study conducted by SENES Consultants Limited (SENES 2009), impact of the consequences of a spill of uranium ore slurry 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 predicted contaminant concentrations in the river were shown to fall below both the Saskatchewan Surface Water Quality Objectives and the Canadian Drinking Water Quality Guidelines within a short distance downstream of the spill location. However, short-term effects within the areas affected by the spill are expected. The assessment considered As, V, Cu, Pb, Cd, Co, Cr, Mo, Se, U, ^{226}Ra, ^{230}Th, ^{210}Pb, ^{210}Po in the ore slurry solids and liquids as well as in the mineralized waste. The relevance of the SENES analysis described above for the Piñon Ridge risk assessment includes:

- The ore slurry assumed in the Saskatchewan case is much more mobile compared with the ore and yellow cake. The slurry could be easily dispersed and the soluble components in the liquid phase are dispersed in water rapidly.
- Physical circumstances surrounding the accidental release of mineralized waste is more similar to the accidental release of ore
- It is expected that the concentration of chemicals in the mineralized waste be lower than the concentrations in the ore.
- Given the high specific gravity of the ore slurry solids, it was predicted that greater than 80% of the solids would settle to the riverbed within 8 to 13 m of the accident site. However, given the solubility of the uranyl form of yellowcake, longer stretch of the stream may be affected by elevated water concentrations.

It is expected that the majority of the ore solids in the section of the river next to the accident site would be recovered during the cleanup operation under the direction of local and State authorities.. Assessment of the potential effects on sediment contaminant concentrations after clean up in the Saskatchewan study indicated that there could be a measurable increase in some contaminants. The potential long-term effect on benthic invertebrates and other aquatic and terrestrial biota however, was predicted to be within accepted guidelines. In summary, given the very low probability of the accidents involving spills to water, expectation of expedient and comprehensive clean up actions and low to moderate impacts, the risks were predicted to be small.

The US Department of Energy in DOE 2007 considered a transportation accident in which uranium ore was dumped into a surface water source. DOE also concluded that it is unlikely that any adverse impacts to biota would occur because of the relatively low toxicity and low concentrations of the potentially hazardous constituents of uranium ore. If the ore were spilled into a shallow surface water source, it would be removed before water quality could be adversely affected. Most ore would be in large enough sizes (e.g., cobbles) that it would be recovered easily from the water source. The finer particles would be dispersed by stream flow and would not create a radiological hazard to aquatic life. The primary impact to water quality from a spill would be a short-term increase in turbidity and total suspended solids.

In order to further reduce the risk of spill, the trucking companies transporting ore, chemical reagents and fuel to the Facility and yellowcake and vanadium oxide from the Facility to other processing facilities are required under DOT regulations to have an emergency response plan in place for responding to accidents and cargo spills. As part of its contracting program, Energy Fuels verifies that these plans are in place and offers the support of its emergency response teams to carriers of ore, yellowcake and other hazardous material shipments in their emergency management planning. The Energy Fuels response teams have expertise in radiation control and the necessary specialized monitoring equipment that is generally not available to most law enforcement agencies, fire departments, and other first responders. The Energy Fuels response team would also conduct sampling and analysis after the cleanup of any incidents involving radioactive material to verify that the cleanup was thorough and met regulatory requirements.

Licensed haulers deliver ore and the reagents to the site, and yellowcake and vanadium oxide from the site in semi-trailer and tanker trucks using approved USDOT containers, with the majority of deliveries occurring during daylight hours. All the packages will meet specifications of 49 CFR Part 173. The reagents are stored on site in pre-packaged totes, barrels, and bulk bags within weatherproof buildings and/or in closed bulk storage tanks. Containers are properly labeled with both the name of the product and safety placards that meet the requirements outlined in the USDOT Emergency Response Guidebook (ERG 2008). The containers are chemically and physically compatible with the media stored and meet applicable local, state and federal storage regulations, including secondary containment. The additional safety controls for radioactive materials in transport in 10 CFR Part 71 and compliance with both DOT and NRC transportation regulations add confidence that reagents, ore and yellowcake can be shipped safely with a low risk of affecting the environment.

5.4.13 Transportation Accident Fire

Data published by the U.S. Department of Transportation indicates that the fires were involved in less than 0.5% in large truck crashes (U.S. DOT 2006). Given the frequency of traffic accidents involving yellowcake of $7.9x10^{-4}$ per year (see Section 5.4.12) and a conservative conditional probability of 0.005 for fire-related accidents, the frequency of a traffic accident involving fire would be $3.9x10^{-6}$ per year. Additionally, the probability of such fire spreading to the cargo and resulting in the dispersal of a considerable amount of yellow cake is very unlikely. The impact of such a low probability accident would be potentially moderate to high, but these extremely rare potential impact scenarios were not quantified in this document because the probability of occurrence of the event approaches "incredible" proportions (i.e., probability of 10^{-6} essentially means a return period of once every 1,000,000 years compared to the 40 year operating life of the facility).

5.4.14 Transportation Accident and Release of Ammonia

Truck shipments of anhydrous ammonia to the mill, if involved in a severe accident, could result in a significant environmental impact. The number of shipments of anhydrous ammonia to the mill is expected to be approximately 3 times more frequent that as the yellowcake shipments from the mill. However, ammonia is expected to be shipped from a supplier closer to the mill than the conversion facility in Illinois. Therefore, it is expected that the frequency of a rollover and crush of ammonia truck, which could result in catastrophic release of ammonia, be much smaller than that of yellow cake truck ($7.9x10^{-4}$ per year). If a small amount of ammonia is released, the impact to a member of the public is expected to be small, however, the driver, if injured or trapped, could be exposed to elevated ammonia concentrations before being evacuated by emergency response team. If a large amount of ammonia is released, both members of the public and the driver could be exposed to high ammonia concentrations. Unmitigated impact could be high. However, the emergency response team would evacuate the areas affected by the release to reduce the exposure of the public. Large quantities of ammonia, involving numerous shipments, are transported on US highways every day without incident. Although the impacts of an accident could be moderate to large, the probability of an accident occurring would be very low, especially in a populated area,

Catastrophic failure of an ammonia storage tank is a very unlikely scenario. The frequency of catastrophic failure of large storage tanks are in the order of 10^{-4} per year (i.e., once every 10,000 years), while the frequency for catastrophic failure of pressure vessels, such as an ammonia storage tank, is in the order of 10^{-5} per year or once every 100,000 years (CCPS 1989). However, in a more probable accident, it is possible that the line connected to the storage tank could be ruptured, in which case the release rate is assumed to be limited to 100 g/s (0.2 lb/s) of vapor. Based on this release rate and calculated dilution factor, the resulting maximum conservative concentration of ammonia at the distance of 4,000 m (13,200 ft) is estimated at approximately 8.5 mg/m^3 over the entire period of release (see Appendix A4 for details of the dilution factor). This concentration is less than the American Conference of Government Industrial Hygienists Short Term Exposure Limit (STEL) of 27 mg/m^3 (ACGIH, 2009). Thus, an ammonia release at this rate would not pose a substantial health risk to a member of the public. It is expected that upon any release of ammonia, workers would evacuate the scene of the accident immediately. However, if they did not evacuate the area quickly, an unprotected worker could be exposed to higher ammonia concentrations for a short period of time. The Emergency Response Plan (Energy Fuels Resources Corporation, 2009b) would be implemented to mitigate the impact.

6.0 Summary and Conclusions

A summary of the assessment of probability and impacts of the selected bounding case accident scenarios as discussed above are provided in Table 6.1.

Table 6.1 Summary of Probabilities and Impacts for Accident Scenarios

Accident Scenario	Workers			Members of Public and Environment		
	Probability	Impact	Risk	Probability	Impact	Risk
Conventional Accidents and Personnel Injury	Medium	Low	Low	-	-	-
Unscheduled Explosion	Low	Moderate	Low	Low	Low	Low
Spill of Radioactive Materials	Low	Moderate	Low	Low	Low	Low
Spill of Non-Radioactive Materials and Fuel	Low	Moderate	Low	Low	Moderate	Low
Failure of Air Cleaning Systems	Low	Moderate	Low	Low	Moderate	Low
Spill of Tailings Slurry	Low	Low	Low	Low	Low to Moderate	Low
Fire Involving Flammable Liquids	Low	Moderate	Low	Low	Low	Low
Propane Explosion	Low	Moderate	Low	Low	Low	Low
Airplane Crash	Extremely Low	High	Low	Low	Moderate	Low
Tornado and High Wind	Low	Moderate	Low	Low	Low	Low
Flood	Low	Low	Low	Low	Low	Low
Building Fire	Low	Moderate	Low	Low	Low	Low
Transportation Accident and Materials Release	Low	Moderate	Low	Low	Moderate	Low
Transportation Accident Fire	Low	Moderate	Low	Low	Moderate	Low
Transportation Accident and Release of Ammonia	Low	Moderate	Low	Low	Moderate	Low

The above summary indicates that estimates of risks, including considerations for mitigation, of the identified bounding accident scenarios to workers, member of public, and the environment is low. The design of new mills (including the proposed project) follows more recent and robust design and performance criteria that will minimize the occurrence of accidents and chemical spills and releases. Implementation of strict health and safety protocols, chemical management procedures, and emergency response procedures are designed to minimize the potential impact of an accident or release to the environment should it occur.

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Appendix A1 Impact of Tailings on Birds (Radiological)

Mallard

CaseName 37101-3 Rad Total T1

ContRad	TotalDose (mGy/d)
Pb-210	8.63E-02
Ra-226	1.42E+03
Th-230	1.19E+01
Th-232	4.46E-02

Benchmark (mGy/d)	5.00E+00	Garisto (2005)
SI (-)	2.86E+02	

Mallard

CaseName 37101-3 Rad Total T1

ContRad	Pb-210	
WaterConc (Bq/L)	1.74E+02	Max, Cell 1(a)
SedConc (Bq/lgDW)	4.70E+04	Kd:Bechtel Jacobs 1998
BenthosTF (L/kgFW)	5.00E+02	US DOE (2003)
BenthosConc (Bq/kgFW)	8.71E+04	=SWConc(Bq/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.50E+02	Bird & Schwartz (1996)
AqVegConc (Bq/kgFW)	2.61E+04	=SWConc(Bq/L) * AqVegsTF(L/kgFW
IfromWater(Bq/d)	1.04E+01	=SWConc(Bq/L) * WaterI(L/d)
IfromSed(Bq/d)	7.99E+01	=SedConc(Bq/kgDW) * SedI(kgDW/d)
IfromBenthos(Bq/d)	1.63E+04	=BenthosConc(Bq/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(Bq/d)	1.63E+03	=AqVegConc(Bq/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(Bq/d)	1.80E+04	=IWater(Bq/d)+ISed(Bq/d)+IBenthos(Bq/d)+(IAqVeg(Bq/d)
ScaledTF(d/kgFW)	7.94E-01	NCRP (1996)
MallardConc (Bq/kgFW)	1.43E+04	=TotalI(Bq/d)*ScaledTF(d/kgFW)
DCi (Gy/y per Bq/kg)	2.19E-06	Amiro (1997)
Di (Gy/y)	3.14E-02	=MallardConc(Bq/kg) * Di(Gy/y per Bq/kg)
DCe (Gy/y per Bq/m3)	6.08E-10	Amiro (1997)
De	1.06E-04	=WaterConc(Bq/L) * De(Gy/y per Bq/m3) * 1000 L/m3
TotalDose	3.15E-02	=Di(Gy/y) + De(Gy/y)
TotalDose(mGy/d)	8.63E-02	=TotalDose(Gy/y) / 365(d/y) * 1000(mGy/Gy)

Mallard

CaseName 37101-3 Rad Total T1

ContRad	Ra-226	
WaterConc (Bq/L)	6.26E+01	Max, Cell 1(a)
SedConc (Bq/lgDW)	3.07E+05	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	1.00E+03	US DOE (2003)
BenthosConc (Bq/kgFW)	6.26E+04	=SWConc(Bq/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	2.00E+05	US DOE (2003) & Bird & Schwartz (19 96)
AqVegConc (Bq/kgFW)	1.25E+07	=SWConc(Bq/L) * AqVegsTF(L/kgFW
IfromWater(Bq/d)	3.76E+00	=SWConc(Bq/L) * WaterI(L/d)
IfromSed(Bq/d)	5.21E+02	=SedConc(Bq/kgDW) * SedI(kgDW/d)
IfromBenthos(Bq/d)	1.17E+04	=BenthosConc(Bq/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(Bq/d)	7.83E+05	=AqVegConc(Bq/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(Bq/d)	7.95E+05	=IWater(Bq/d)+ISed(Bq/d)+IBenthos(Bq/d)+(IAqVeg(Bq/d)
ScaledTF(d/kgFW)	6.61E-01	Clulow et al (1992)
MallardConc (Bq/kgFW)	5.25E+05	=TotalI(Bq/d)*ScaledTF(d/kgFW)
DCi (Gy/y per Bq/kg)	9.84E-04	Amiro (1997)
Di (Gy/y)	5.17E+02	=MallardConc(Bq/kg) * Di(Gy/y per Bq/kg)
DCe (Gy/y per Bq/m3)	3.20E-11	Amiro (1997)
De	2.00E-06	=WaterConc(Bq/L) * De(Gy/y per Bq/m3) * 1000 L/m3
TotalDose	5.17E+02	=Di(Gy/y) + De(Gy/y)
TotalDose(mGy/d)	1.42E+03	=TotalDose(Gy/y) / 365(d/y) * 1000(mGy/Gy)

Mallard

CaseName 37101-3 Rad Total T1

ContRad	Th-230	
WaterConc (Bq/L)	1.02E+03	Max, Cell 1(d)
SedConc (Bq/lgDW)	1.02E+08	Kd:IAEA (1994)
BenthosTF (L/kgFW)	1.00E+02	US DOE (2003)
BenthosConc (Bq/kgFW)	1.02E+05	=SWConc(Bq/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	5.30E+02	US DOE (2003)
AqVegConc (Bq/kgFW)	5.40E+05	=SWConc(Bq/L) * AqVegsTF(L/kgFW
IfromWater(Bq/d)	6.11E+01	=SWConc(Bq/L) * WaterI(L/d)
IfromSed(Bq/d)	1.73E+05	=SedConc(Bq/kgDW) * SedI(kgDW/d)
IfromBenthos(Bq/d)	1.91E+04	=BenthosConc(Bq/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(Bq/d)	3.37E+04	=AqVegConc(Bq/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(Bq/d)	2.26E+05	=IWater(Bq/d)+ISed(Bq/d)+IBenthos(Bq/d)+(IAqVeg(Bq/d)
ScaledTF(d/kgFW)	1.99E-02	CSA N288.1 (2008)
MallardConc (Bq/kgFW)	4.49E+03	=TotalI(Bq/d)*ScaledTF(d/kgFW)
DCi (Gy/y per Bq/kg)	9.64E-04	Amiro (1997)
Di (Gy/y)	4.33E+00	=MallardConc(Bq/kg) * Di(Gy/y per Bq/kg)
DCe (Gy/y per Bq/m3)	7.15E-12	Amiro (1997)
De	7.29E-06	=WaterConc(Bq/L) * De(Gy/y per Bq/m3) * 1000 L/m3
TotalDose	4.33E+00	=Di(Gy/y) + De(Gy/y)
TotalDose(mGy/d)	1.19E+01	=TotalDose(Gy/y) / 365(d/y) * 1000(mGy/Gy)

Mallard

CaseName 37101-3 Rad Total T1

ContRad	Th-232	
WaterConc (Bq/L)	4.48E+00	Max, Cell 1(f)
SedConc (Bq/lgDW)	4.48E+05	Kd:IAEA (1994)
BenthosTF (L/kgFW)	1.00E+02	US DOE (2003)
BenthosConc (Bq/kgFW)	4.48E+02	=SWConc(Bq/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	5.30E+02	US DOE (2003)
AqVegConc (Bq/kgFW)	2.37E+03	=SWConc(Bq/L) * AqVegsTF(L/kgFW
IfromWater(Bq/d)	2.69E-01	=SWConc(Bq/L) * WaterI(L/d)
IfromSed(Bq/d)	7.62E+02	=SedConc(Bq/kgDW) * SedI(kgDW/d)
IfromBenthos(Bq/d)	8.40E+01	=BenthosConc(Bq/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(Bq/d)	1.48E+02	=AqVegConc(Bq/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(Bq/d)	9.94E+02	=IWater(Bq/d)+ISed(Bq/d)+IBenthos(Bq/d)+(IAqVeg(Bq/d)
ScaledTF(d/kgFW)	1.99E-02	CSA N288.1 (2008)
MallardConc (Bq/kgFW)	1.97E+01	=TotalI(Bq/d)*ScaledTF(d/kgFW)
DCi (Gy/y per Bq/kg)	8.24E-04	Amiro (1997)
Di (Gy/y)	1.63E-02	=MallardConc(Bq/kg) * Di(Gy/y per Bq/kg)
DCe (Gy/y per Bq/m3)	6.22E-12	Amiro (1997)
De	2.79E-08	=WaterConc(Bq/L) * De(Gy/y per Bq/m3) * 1000 L/m3
TotalDose	1.63E-02	=Di(Gy/y) + De(Gy/y)
TotalDose(mGy/d)	4.46E-02	=TotalDose(Gy/y) / 365(d/y) * 1000(mGy/Gy)

Appendix A2 Impact of Tailings on Birds (Non-Radiological)

The values in the following tables are calculated Hazard Quotients (HQ) or Screening Index (SI) which is the ratio of total intake of a chemical and the toxicity reference value (TRV) for that chemical.

SI Values - Non-Radiological Aquatic

37101-3 NonRad Total T1

Contaminant	Mallard
Al	**8.07E+02**
As	**1.99E+03**
B	6.27E-03
Ba	1.24E-04
Cd	**2.02E+02**
Cr	**2.49E+03**
Cu	**7.28E+02**
F	**3.71E+03**
Fe	
Mn	**5.34E+02**
Mo	
Ni	**7.54E+01**
Pb	**3.08E+01**
Se	**7.57E+02**
U	**6.68E+02**
V	**2.67E+04**

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	As	
WaterConc (mg/L)	1.46E+02	Max, Cell 1(a)
SedConc (mg/lgDW)	1.46E+03	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	3.00E+02	US DOE (2003)
BenthosConc (mg/kgFW)	4.38E+04	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	3.00E+02	US DOE (2003)
AqVegConc (mg/kgFW)	4.38E+04	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	8.76E+00	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	8.21E+03	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	8.21E+03	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	2.74E+03	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	1.10E+04	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	1.01E+04	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	5.10E+00	Eco-SSL for Arsenic (U.S. EPA 2005)
SI(-)	**1.99E+03**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Cd	
WaterConc (mg/L)	4.72E+00	Max, Cell 1(f)
SedConc (mg/lgDW)	0.00E+00	Kd:
BenthosTF (L/kgFW)	1.36E+02	Bird & Schwartz (1996)
BenthosConc (mg/kgFW)	6.42E+02	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.86E+04	Bird & Schwartz (1996)
AqVegConc (mg/kgFW)	8.78E+04	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	2.83E-01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	1.20E+02	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	1.20E+02	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	5.49E+03	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	5.61E+03	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	5.18E+03	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	2.56E+01	Eco-SSL (2005)
SI(-)	**2.02E+02**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Cr	
WaterConc (mg/L)	7.17E+00	Max, Cell 1(e)
SedConc (mg/lgDW)	4.80E+03	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	2.00E+03	US DOE (2003)
BenthosConc (mg/kgFW)	1.43E+04	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.20E-01	Bird & Schwartz (1996)
AqVegConc (mg/kgFW)	8.60E-01	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	4.30E-01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	2.69E+03	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	2.69E+03	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	5.38E-02	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	2.70E+03	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	2.49E+03	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	1.00E+00	Sample et al. 1996
SI(-)	**2.49E+03**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Cu	
WaterConc (mg/L)	2.37E+02	Max, Cell 1(e)
SedConc (mg/lgDW)	0.00E+00	Kd:
BenthosTF (L/kgFW)	1.00E+03	NRCC (1983)
BenthosConc (mg/kgFW)	2.37E+05	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.00E+03	NRCC (1983)
AqVegConc (mg/kgFW)	2.37E+05	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	1.42E+01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	4.44E+04	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	4.44E+04	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	1.48E+04	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	5.93E+04	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	5.48E+04	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	7.52E+01	Eco-SSL (2006)
SI(-)	**7.28E+02**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Mo	
WaterConc (mg/L)	5.92E+01	Max, Cell 1(e)
SedConc (mg/lgDW)	5.92E+03	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	4.00E+03	US EPA (1979)
BenthosConc (mg/kgFW)	2.37E+05	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.00E+02	US DOE (2003)
AqVegConc (mg/kgFW)	5.92E+03	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	3.55E+00	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	4.44E+04	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	4.44E+04	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	3.70E+02	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	4.48E+04	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	4.14E+04	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)		no data
SI(-)		=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Pb	
WaterConc (mg/L)	3.81E+00	Max, Cell 1(f)
SedConc (mg/lgDW)	1.03E+03	Kd:Bechtel Jacobs 1998
BenthosTF (L/kgFW)	5.00E+02	US DOE (2003)
BenthosConc (mg/kgFW)	1.91E+03	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.50E+02	Bird & Schwartz (1996)
AqVegConc (mg/kgFW)	5.72E+02	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	2.29E-01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	3.57E+02	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	3.57E+02	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	3.57E+01	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	3.95E+02	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	3.65E+02	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	1.18E+01	Eco-SSL (2005)
SI(-)	**3.09E+01**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	Se	
WaterConc (mg/L)	2.24E+00	Max, Cell 1(a)
SedConc (mg/lgDW)	3.36E+03	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	2.00E+03	US DOE (2003)
BenthosConc (mg/kgFW)	4.48E+03	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	1.55E+03	Bird & Schwartz (1996)
AqVegConc (mg/kgFW)	3.46E+03	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	1.34E-01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	8.40E+02	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	8.40E+02	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	2.16E+02	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	1.06E+03	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	9.82E+02	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	1.29E+00	Eco-SSL (2007)
SI(-)	**7.61E+02**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	U	
WaterConc (mg/L)	1.54E+02	Max, Cell 1(a)
SedConc (mg/lgDW)	5.08E+04	Kd:CSA N288.1(2008)
BenthosTF (L/kgFW)	1.00E+02	US DOE (2003)
BenthosConc (mg/kgFW)	1.54E+04	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	9.00E+02	
AqVegConc (mg/kgFW)	1.39E+05	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	9.24E+00	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	2.89E+03	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	2.89E+03	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	8.66E+03	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	1.16E+04	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	1.08E+04	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	1.60E+01	Sample et al. (1996)
SI(-)	**6.73E+02**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Mallard

CaseName	37101-3 NonRad Total T1	
ContName	V	
WaterConc (mg/L)	3.93E+02	Max, Cell 1(a)
SedConc (mg/lgDW)	0.00E+00	Kd:
BenthosTF (L/kgFW)	0.00E+00	
BenthosConc (mg/kgFW)	0.00E+00	=SWConc(mg/L) * BenthosTF(L/kgFW)
AqVegTF (L/kgFW)	2.00E+03	US NRC (1977)
AqVegConc (mg/kgFW)	7.86E+05	=SWConc(mg/L) * AqVegsTF(L/kgFW
IfromWater(mg/d)	2.36E+01	=SWConc(mg/L) * WaterI(L/d)
IfromSed(mg/d)	0.00E+00	=SedConc(mg/kgDW) * SedI(kgDW/d)
IfromBenthos(mg/d)	0.00E+00	=BenthosConc(mg/kgFW) * FoodI(gFW/d)*frBentho/1000(g/kg)
IfromAqVeg(mg/d)	4.91E+04	=AqVegConc(mg/kgFW) * FoodI(gFW/d)*frAqVeg/1000(g/kg)
TotalI(mg/d)	4.91E+04	=IWater(mg/d)+ISed(mg/d)+IBenthos(mg/d)+(IAqVeg(mg/d)
TotalIBW(mg/d/kg)	4.54E+04	=TotalI(mg/d)/Body wt(kg)
TRV(mg/d/kg)	1.70E+00	LOAEL from Eco-SSL for Vanadium, 2005
SI(-)	**2.67E+04**	=TotalIBW(mg/d/kg)/TRV(mg/d/kg)

Appendix A3 Radiation Dose to the Truck Driver

This appendix summarizes a dose assessment for workers exposed to yellowcake (U_3O_8) stored in 55-gallon drums; the dimensions of a steel drum are (S. Cohen 2005):

Height = 86.36 cm (34 inches)
Diameter = 57.15 cm (22.5 inches)
Drum wall thickness = 0.15189 cm

The effective dose was estimated for workers exposed to the waste in the following scenarios:

1) Truck driver transporting 60 steel drums containing yellowcake. The drums are transported in a 40 foot trailer;

For this assessment, it was assumed that a truck driver is expected to make 3 out of 15 total deliveries per year from the mill site to a conversion facility in Metropolis, Illinois. The 26-ton truck contains approximately 60 drums (55 gallon) of yellowcake. The estimated exposure time while driving or resting in the cabin is approximately 22 hours per delivery. In addition, the truck driver will perform a load inspection prior to departure and upon arrival at the destination; each inspection was assumed to take 30 minutes.

2) Forklift driver operating a forklift to move 60 drums from the truck

The estimated exposure time for the forklift driver moving the drums from the truck is 5 minutes per drum. It was conservatively assumed that one worker operates the forklift to move all the drums from one truck for each delivery. Therefore, the exposure time is approximately 5 hours (300 minutes) per delivery and 75 hours per year (i.e., 5 hours per delivery x 15 deliveries per year).

3) Truck driver transporting uranium ore in a dump truck.

The truck driver is expected to drive 3 hours per day and 200 days per year. Therefore, exposure time 600 hours per year.

The dose assessment was performed using MicroShield Version 8.02 (Grove Software 2009). The assumptions used in the MicroShield runs for each scenario are described below.

1.0 Estimated Effective Dose to Workers

1.1 Truck Driver – Trailer with Drums Containing Yellowcake

During the transport of yellowcake, the worker is exposed while driving the trailer and while performing inspections.

Source Geometry

The internal dimensions of a 40 foot trailer according to (APL Limited 2009) are:

Length	= 1203.2 cm
Width	= 235.2 cm
Height	= 238.5 cm

Other source geometry assumptions included:

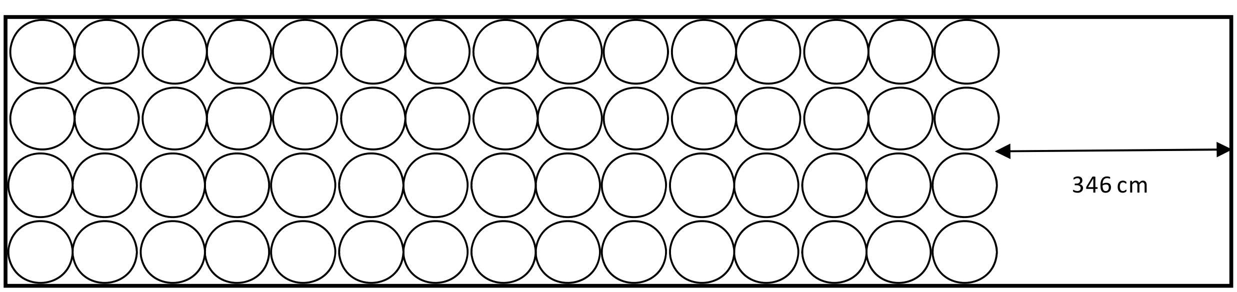
- The walls of the trailer are 1/8th inch (0.3 cm) thick steel; and,
- The wall of the cab was assumed to provide an equivalent of 1/8th inch (0.3 cm) thick steel.

Inside the trailer, the maximum numbers of drums that can fit along the width is four drums. The numbers of drums along the length varies for each scenario and is described below.

There are 60 drums containing yellowcake. For the MicroShield run, the source geometry used was a rectangular volume; the drums are arranged in a 15 (length-wise) by 4 (width-wise) configuration as shown in Figure A3.1. The dimensions of the source are:

Length	= 857.25 cm (i.e., diameter of 1 drum (57.15 cm) x 15)
Width	= 228.6 cm (i.e., diameter of 1 drum (57.15 cm) x 4)
Height	= 86.36 cm (i.e., height of 1 drum (86.36 cm)

Figure A3.1 Drums Containing Yellowcake in Trailer



Source Material

For the MicroShield calculations, U_3O_8 was used for yellowcake.

Source Radionuclides

The yellowcake was assumed to have U-238, U-234, and U-235 present at natural abundances. U-238 was assumed to be in equilibrium with its short-lived decay products; Th-234, Pa-234m, Pa-234 (which has a relative concentration of 0.16% of U-238) and U-234. U-235 was assumed to be in secular equilibrium with Th-231. The concentration of each radionuclide was calculated as shown in equation 1.

$$C_{radionuclide}\left(\frac{Bq}{cm^3}\right) = Activity_{radionuclide}\left(\frac{Bq}{g}\right) \times \rho_{yellowcake} \times \text{Fraction of U in } U_3O_8 \quad (1)$$

where:

$Activity_{radionuclide}$ = Provided in Table 1

$\rho_{yellowcake}$ = 2.055 g/cm^3

Fraction of U in U_3O_8 = 0.848

The concentrations of radionuclides are shown in Table A3.1.

Table A3.1 Activity Concentrations of Radionuclides in Yellowcake

Nuclide	Branching Ratio	Specific Activity (Bq/g)	Concentration (Bq/cm^3)
U-238	1	1.23E+04	2.15E+04
Th-234	1	1.23E+04	2.15E+04
Pa-234	0.0016	1.98E+01	3.44E+01
Pa-234m	1	1.23E+04	2.15E+04
U-234	1	1.23E+04	2.15E+04
U-235	0.046	5.68E+02	9.90E+02
Th-231	0.046	5.68E+02	9.90E+02

Dose Points

Driving: During the time spent driving, the worker is located in the cab of the truck and is exposed from behind (i.e., driver's back towards the width of the source). The driver's cabin was assumed to be 150 cm from the trailer. However, it should be noted that the actual distance from the source is 516.6 m when the thicknesses of the steel wall of the trailer (0.3 cm), wall of the cab (0.3 cm), the space between the driver and the back wall of the cab (20 cm) and the space between the first row of drums and front wall of the trailer (346 cm) are included. In addition, for conservative purposes the worker was assumed to be located at the centre point of the shorter side (width) of the trailer (i.e., half-width and half-height of the source).

Inspection: The driver inspects the truck; prior to departure and upon arrival at the destination. During the inspection, the driver was assumed to be 50 cm away from the side of the truck. In addition, for conservative purposes the worker was assumed to be located at the centre point of the longer side (length) of the trailer (i.e., at half-length and half-height of the source).

Build-up

The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration

The integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were increased until the effective dose converged.

Results

The effective doses to the worker while driving the truck are provided in Table A3.2. The postero-anterior effective dose rate was used because the worker is exposed from behind while driving and the antero-posterior dose rate was used for the worker exposure while inspecting the truck to be conservative.

Table A3.2 Effective Dose to Truck Driver (Scenario 1)

Activity	Hours per delivery	Effective Dose Rate (mSv/hr),	Effective Dose (mSv/delivery)
Driving	22	4.065E-04[b]	8.94E-03
Inspection	1[a]	1.73E-02[c]	1.73E-02
		Total per delivery[d]	2.62E-02
		Deliveries per year	15
		Total per year (mSv/y)[e]	0.394

Note: the values in the table were rounded.

a) 0.5 hours prior to departure and 0.5 hours upon arrival at the destination.

b) Postero-anterior geometry (with build-up).

c) Antero-posterior geometry (with build-up).

d) Sum of driving and inspection effective dose.

e) Total per delivery x Deliveries per year.

1.2 Forklift Driver – Moving Drums Containing Yellowcake

MicroShield was used to estimate the effective dose to a worker who is exposed to a drum containing yellowcake while operating a forklift to move drums from the truck.

Source Geometry
For MicroShield, a cylinder volume - side shields was used for the source geometry. The dimensions of a drum are provided in Section 1.1. As mentioned, the forklift driver moves 60 drums containing yellowcake.

Source Material
The activity concentrations of all radionuclides in yellowcake are provided in Section 1.1, Table A3.1.

Dose Points
The worker driving a forklift will be exposed from the front of the source and was assumed to be 100 cm from the drum. In addition, for conservative purposes the worker was assumed to be located at the centre point of the drum (i.e., half-width and half-height of the source).

Build-up
The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration
As described in Section 1.1, the integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were increased until the effective dose converged.

Results
The effective doses to the worker while operating a forklift are provided in Table A3.3. The antero-posterior effective dose rates were used because the worker is exposed from the front while operating the forklift.

Table A3.3 Effective Dose to Forklift Driver (Scenario 2)

Effective Dose Rate (mSv/hr), Antero-posterior geometry (with build-up)	1.89E-03
Hours Spent Moving Drums per Delivery	5
Total Effective Dose Rate per Delivery[a] (mSv/delivery)	4.72E-03
Deliveries per year	15
Total Effective Dose Rate per Year (mSv/yr)	0.07

Note: the values in the table were rounded.
a) The effective dose was calculated by multiplying the antero-posterior effective dose rate (with build-up) by the number of hours the worker, and a shielding factor of 0.5 (i.e., the transmission of radiation through and around shielding provided by the forklift[3]).

1.3 Truck Driver – Dump Truck with Uranium Ore

During the transport of uranium ore containing 0.23% U_3O_8, the worker is exposed while driving the trailer.

Source Geometry

For the MicroShield run, the source geometry used was a rectangular volume. The dimensions of the dump box and pup (i.e., source) were calculated based on the mass of the ore in the dump box (15 tons) and pup (12 tons) and assumed bulk density of the ore (1.9 g/cm^3) and are:

For dump box:

Length = 350 cm
Width = 200 cm
Height = 105 cm

For pup

Length = 280 cm
Width = 200 cm
Height = 105 cm

Other source geometry assumptions included:

3 Mascanzoni (1989) measured the transmission of photons from ground-level sources to the operator's seat in a conventional tractor. The result showed that the tractor shield more than 60% of the radiation. Considering the differences in geometry between a tractor and a forklift, and source geometry, a lower shielding factor of 50% was credited for the calculations.

- The walls of the trailer are 1/4th inch (0.6 cm) thick steel; and,
- The wall of the cab was assumed to provide an equivalent of 1/8th inch (0.3 cm) thick steel.

Source Material

For the MicroShield calculations, SiO_2 was used as a surrogate for the bulk ore.

Source Density

The bulk density of the ore is 1.9 g/cm^3.

Source Radionuclides

The ore was assumed to have U-238 and all its decay products in equilibrium. The U-238 concentration in ore (45.755 BqU-238 per cm^3) was calculated as shown in equation 2. (The concentrations of the U-238 decay products were generated in MicroShield by doubling the calculated U-238 concentration and decaying U-238 for one half-life (4.47 x 10^9 y)).

$$C_{U\text{-}238}\left(\frac{\text{Bq U-238}}{\text{cm}^3}\right)=1.2347\times10^4\left(\frac{\text{Bq U-238}}{\text{gU}}\right)\times\text{Ore grade}\left(\frac{\text{gU}_3\text{O}_8}{\text{g ore}}\right)\times\text{Fraction of U in U}_3\text{O}_8\left(\frac{\text{gU}}{\text{gU}_3\text{O}_8}\right)\times\rho_{ore}\left(\frac{\text{g ore}}{\text{cm}^3}\right) \quad (2)$$

where:

1.2347×10^4	=	Specific activity of U-238
Ore grade	=	0.0023
Fraction of U in U_3O_8	=	0.848
ρ_{ore}	=	1.9 g/cm^3

Dose Points

During the time spent driving, the worker is located in the cab of the truck and is exposed from behind (i.e., driver's back towards the width of the source). The driver's cabin was assumed to be 150 cm from the trailer. However, it should be noted that the actual distance from the source is 170.6 m when the thicknesses of the steel wall of the trailer (0.3 cm), wall of the cab (0.3 cm), the space between the driver and the back wall of the cab (20 cm). In addition, for conservative purposes the worker was assumed to be located at the centre point of the shorter side (width) of the trailer (i.e., half-width and half-height of the source).

Build-up

The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration

The integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were changed increased until the effective dose converged.

<u>Results</u>

The effective doses to the worker while driving the truck are provided in Table A3.4. The postero-anterior effective dose rate was used because the worker is exposed from behind while driving and the antero-posterior dose rate was used for the worker exposure while inspecting the truck to be conservative.

Table A3.4 Effective Dose to Truck Driver (Scenario 3)

Effective Dose Rate (mSv/hr), Postero-anterior geometry (with build-up)	7.99e-4
Hours per day	3
Total Effective Dose Rate per delivery (mSv/delivery)	2.40E-3
Delivery days per year	200
Total Effective Dose Rate per year[a] (mSv/yr)	0.48

Note: the values in the table were rounded.
a) Total per delivery x Deliveries per year.

2.0 Summary

The annual effective doses for Scenarios 1 and 2 are provided in Table A3.5.

Table A3.5 Annual Effective Dose

Receptor	Effective Dose, mSv/y (mrem/yr)
Truck Driver - Trailer with Drums Containing Yellowcake	0.394 (39.4)
Forklift Driver - Moving Drums Containing Yellowcake	0.07 (7)
Truck Driver - Dump Truck with Uranium Ore	0.48 (48)

3.0 References

Grove Engineering 2009. *MicroShield Version 8.02*

Mascanzoni, D. 1989. *Structure Shielding of a Tractor against Ground-Deposited Radioactive Fall-out.* J. Radiol. Prot., Vol. 9, pages 237-240.

S. Cohen and Associates 2005. *Report to the Advisory Board on Radiation and Worker Health*. Document No. SCA-TR-TASK-CNPIID. February

APL Limited 2009. *http://www.apl.com/equipment/html/equipment_specs_standard.html#48HC*.

Appendix A4 Dilution Factor for Air Dispersion Modeling (Based on unit emission)

```
 ***  SCREEN3 MODEL RUN  ***
 *** VERSION DATED 96043 ***

SIMPLE TERRAIN INPUTS:
   SOURCE TYPE               =        AREA



   EMISSION RATE (g/s                  =     0.100000E+01
   SOURCE HEIGHT (M)          =       6.0000
   LENGTH OF LARGER SIDE (M)   =      10.0000
   LENGTH OF SMALLER SIDE (M)  =      10.0000
   RECEPTOR HEIGHT (M)        =       0.0000
   URBAN/RURAL OPTION         =       RURAL
THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.

   MODEL ESTIMATES DIRECTION TO MAX CONCENTRATION


BUOY. FLUX =    0.000 M**4/S**3;  MOM. FLUX =    0.000 M**4/S**2.

*** STABILITY CLASS  F ONLY ***
*** ANEMOMETER HEIGHT WIND SPEED OF   1.00 M/S ONLY ***

*********************************
*** SCREEN AUTOMATED DISTANCES ***
*********************************

*** TERRAIN HEIGHT OF      0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST     CONC           U10M   USTK  MIX HT   PLUME  MAX DIR
   (M)   (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   (DEG)
-------  ----------  ----  -----  -----  ------  ------  -------
  1000.   611.1       6     1.0    1.0 10000.0    6.00     34.
  1100.   533.2       6     1.0    1.0 10000.0    6.00     31.
  1200.   470.3       6     1.0    1.0 10000.0    6.00     37.
  1300.   418.7       6     1.0    1.0 10000.0    6.00     33.
```

1400.	375.8	6	1.0	1.0	10000.0	6.00	31.
1500.	339.6	6	1.0	1.0	10000.0	6.00	33.
1600.	308.9	6	1.0	1.0	10000.0	6.00	31.
1700.	282.4	6	1.0	1.0	10000.0	6.00	33.
1800.	259.5	6	1.0	1.0	10000.0	6.00	33.
1900.	239.5	6	1.0	1.0	10000.0	6.00	33.
2000.	221.9	6	1.0	1.0	10000.0	6.00	33.
2100.	207.1	6	1.0	1.0	10000.0	6.00	39.
2200.	194.0	6	1.0	1.0	10000.0	6.00	34.
2300.	182.1	6	1.0	1.0	10000.0	6.00	34.
2400.	171.5	6	1.0	1.0	10000.0	6.00	39.
2500.	161.8	6	1.0	1.0	10000.0	6.00	39.
2600.	153.1	6	1.0	1.0	10000.0	6.00	39.
2700.	145.1	6	1.0	1.0	10000.0	6.00	34.
2800.	137.8	6	1.0	1.0	10000.0	6.00	34.
2900.	131.1	6	1.0	1.0	10000.0	6.00	39.
3000.	124.9	6	1.0	1.0	10000.0	6.00	39.
3500.	101.5	6	1.0	1.0	10000.0	6.00	39.
4000.	84.80	6	1.0	1.0	10000.0	6.00	39.
4500.	72.35	6	1.0	1.0	10000.0	6.00	39.
5000.	62.76	6	1.0	1.0	10000.0	6.00	39.
5500.	55.19	6	1.0	1.0	10000.0	6.00	39.
6000.	49.07	6	1.0	1.0	10000.0	6.00	39.
6500.	44.05	6	1.0	1.0	10000.0	6.00	39.
7000.	39.86	6	1.0	1.0	10000.0	6.00	36.
7500.	36.43	6	1.0	1.0	10000.0	6.00	39.
8000.	33.50	6	1.0	1.0	10000.0	6.00	35.
8500.	30.96	6	1.0	1.0	10000.0	6.00	33.
9000.	28.74	6	1.0	1.0	10000.0	6.00	33.
9500.	26.79	6	1.0	1.0	10000.0	6.00	33.
10000.	25.06	6	1.0	1.0	10000.0	6.00	33.
15000.	14.81	6	1.0	1.0	10000.0	6.00	39.
20000.	10.46	6	1.0	1.0	10000.0	6.00	38.
25000.	7.998	6	1.0	1.0	10000.0	6.00	38.
30000.	6.426	6	1.0	1.0	10000.0	6.00	38.

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 1000. M:

1000.	611.1	6	1.0	1.0	10000.0	6.00	34.

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)

SIMPLE TERRAIN 611.1 1000. 0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

Appendix A5 Probability Assessment of Traffic Accident

1.0 Traffic Accident and Release

Three credible accident scenarios were assessed in this study. They are:

- Scenario 1: Collision of two vehicles (Crash)
- Scenario 2: Roll over into a ditch or down an embankment
- Scenario 3: Roll over directly into a river (considered the most extreme environmental accident)

To assess the probabilities and potential consequences associated with these scenarios, it was considered that a spill into a river is the most serious environmental event. As such, the impact assessment examined a release of materials into the water at a river crossing.

2.0 Accident Scenarios

Accident statistics are presented and used to derive estimates of probability of events occurring that could result in spills to the environment. As yellowcake is transported in DOT-approved sealed drums, there are a number of events that must occur for a spill to occur. Much of the discussion that follows therefore applies to the assessment of the probability of a spill of the yellowcake.

In simple terms, several events need to occur at the same time for a release of yellowcake to occur. The probability and severity of damage to a drum in an accident is a function of the severity of the accident, the form and amount of force applied to the drum and the ability of the drum to withstand these forces. The potential for a release and the corresponding size of a release can then be described symbolically as the product of conditional probabilities:

> *Frequency of a release = [Frequency of an accident] x*
> *[conditional probability of damage to the container] x [conditional probability that container ruptures]*

The spill to a river, with the potential transport downstream of spilled material, represents the worst case accident scenario from an environmental perspective. While the roll-over and head-on collision represent more likely accident scenarios, releases from these accidents could be easily contained unless the accident occurred in or near a water body or during an extreme rainfall event.

Accident statistics reported for the United States were reviewed in selecting appropriate statistics to use in the current assessment. The U.S. DOT (2007) statistical data for hazardous material transportation in 2007 showed that the frequency of accidents involving hazardous material transport on all roads and rural roads were 0.136 and 0.051 accidents per million ton-miles, respectively. The same statistics indicate that the frequency of rollovers and truck crashes during transportation of hazardous materials were 6.7×10^{-4} and 8.1×10^{-4} accidents per million ton-miles, respectively.

The yellowcake will be transported from the mill to Metropolis, Illinios though Highway 50 (1357 miles). Using these data combined with the accident statistics, the truck transportation frequency, and transportation distance, the frequency of rollover and truck crashes along the haul route for yellowcake were estimated to equal 3.6×10^{-4} and 4.3×10^{-4} per year, respectively, as determined by the calculations below:

The ore will be transported from the mine sites to the mill (<60 miles). Using these data combined with the accident statistics, the truck transportation frequency, and transportation distance, the frequency of rollover and truck crashes along the haul route were estimated to equal 7.6×10^{-3} and 9.2×10^{-3} per year, respectively, as determined by the calculations below:

- Ton-miles / year = Trucks per year * length of route (miles) * Truck load (tons)
- For yellowcake:
  Ton-mile/year = 15 trips per year *1357miles *26 ton
  = 5.3×10^{5} ton-mile/yr
- For ore:
  Ton-mile/year = 7300 trips per year *60 miles *26 ton
  = 1.1×10^{7} ton-mile/yr

- For yellowcake:
  Frequency of rollover = $6.7\times10^{-4} * 5.3\times10^{5}$ / 1,000,000 = 3.6×10^{-4} per year
  Frequency of crash = $8.1\times10^{-4} * 5.3\times10^{5}$ / 1,000,000 = 4.3×10^{-4} per year

- For ore:
  Frequency of rollover = $6.7\times10^{-4} * 1.1\times10^{7}$ / 1,000,000 = 7.6×10^{-3} per year
  Frequency of crash = $8.1\times10^{-4} * 1.1\times10^{7}$ / 1,000,000 = 9.2×10^{-3} per year

The U.S. DOT reported that in 2007 only 8 out of 17,000 hazardous material transportation accidents involved radioactive material. It should be noted that the statistics presented above do not address specific issues related to an accident occurring at stream or river crossings or adjacent to nearby lakes. Factors that affect accidents at bridge crossings include:

- Low visibility in foggy conditions increases the risk of an accident at bridge crossings, as they are normally narrower than other parts of the road. Bridges do not have shoulders and typically the clearance of trucks from the side of the bridge is low.
- Accidents on bridges normally involve a fall with higher probability of damage compared with accidents that occur along other parts of the road.
- Presence of structural materials such as steel structures, rebar and other reinforcement steels can puncture containers during an accident.

Thus, additional safety measures may be warranted at bridge crossings to reduce the probability of accident events occurring. Such measures include adequate lighting, signs, reduced speed limits, and appropriate guard rails.

3.0 Length of Roadway Exposed to Water

Accidents close to water bodies were considered critical events due to their potential to release contaminants to the aquatic environment. The probability of an accident occurring close to a water body is a function of the proximity of water along the roadway and the overall travel distance. The methodology used to calculate the length of haul road in proximity to water, referred to as the Effective Exposed Length, is described in this section.

It was estimated that if a vehicle were to leave the roadway, the forward momentum would carry it a distance equivalent to the braking distance on a normal road surface (i.e., rocks, trees and topography would serve to decelerate the vehicle). For an A-train truck, this is assumed to be equivalent to approximately 262 ft. It was assumed that any streams with a width greater than 7 ft would be sufficient to stop the forward momentum of an out-of-control vehicle. Thus, if a vehicle were to leave the roadway within 262 ft of a stream crossing wider than 7 ft, the vehicle would come to a complete stop in the stream. Therefore, for streams that are greater than 7 ft wide, the Effective Exposed Length of the roadway would be the stream's width plus an additional 262 ft.

For streams narrower than 7 ft, it was assumed that a vehicle would have sufficient momentum to "jump" the stream. In such a case, a stream's Effective Exposed Length would be equivalent to the width of the stream. For the purposes of this investigation, an additional 16.5 ft was added to each side of the stream to account for the "flood-plain" of the streams. For example, if a stream is 3 ft wide, it was assumed that a spill within 16.5 ft of either side of the stream would end up entering the stream. In this particular case, the Effective Exposed Length of the roadway would be 36 ft. Table A5.1 summarizes the Effective Exposed Lengths of all ecologically significant stream crossings.

Table A5.1 Effective Exposed Length for Stream Crossings – Yellowcake Shipments to Metropolis, Illinois

Width of Crossing (ft)	Number of Crossings	Additional Width per Crossing (ft)	Effective Exposed Length for all Crossings (ft)
7	92	33	3621
16	9	262	2509
33	3	262	886
66	13	262	4264
98	15	262	5412
131	4	262	1574
164	6	262	2558
197	4	262	1837
230	1	262	492
328	2	262	1181
492	1	262	754
656	3	262	2755
1312	1	262	1574
1640	1	262	1902
Total Effective Exposed Stream Crossings			31,321 ft

To calculate the risk of a spill occurring in water, the possibility of a vehicle going off the road and travelling perpendicular to the roadway was also considered. It was assumed that in the event of an accident, a vehicle would travel in a perpendicular direction one-half of the distance travelled parallel to the roadway before coming to a stop. In the case of an accident involving a train carrying yellowcake, the spill would have to occur directly into the stream, as the material is handled in a dry state. The Effective Exposed Length for the yellowcake assessment therefore was adjusted to reflect the portion of the transportation route where there is a risk of release to a water body without consideration of the flood plain of the streams. As indicated in Table A5.1, the overall width of crossings for all stream crossings is 31321 ft, of which 1600 ft is the width of the Rend Lake crossing. The road also has two major crossings with branches of the Missouri River with one crossing width of about 1300 ft and two crossing widths of about 660 ft each. Another major crossing is at Kansas River with an approximate width of 660 ft.

Therefore, the total Effective Exposed Length attributed to stream crossings and bodies of water located adjacent to the roads is 36100 ft (6.8 mile). These distances were used in the analysis of the frequency of a truck rollover and crash that could result in a spill of yellowcake into one of the water bodies along the haul road between Piñon Ridge and the Metropolis conversion facility.

Total rollover and crash frequency = $3.6x10^{-4} + 4.3x10^{-4} = 7.9x10^{-4}$ per year
Adjusting for the exposed length = $7.9x10^{-4}$ x 6.8/1357 = 4 x 10^{-6} per year

Assuming the same fraction of the haul road is exposed to water bodies, the frequency of rollover and crash for hauling the ore can be calculated as follows:

Total rollover and crash frequency = $7.6x10^{-3} + 9.2x10^{-3} = 1.7x10^{-2}$ per year
Adjusting for the exposed length = $1.7x10^{-2}$ x 6.8/1357 = 8.4 x 10^{-5} per year