NUREG-0706
Vol. I

Final Generic Environmental Impact Statement

on uranium milling

Project M-25

Summary and Text

September 1980

Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission

7. ENVIRONMENTAL EFFECTS OF ACCIDENTS

The environmental effects of accidents involving the release of radioactive materials or harmful chemicals that could occur at the model site are covered in this chapter. Accidents which might occur during mill operations have been conceptualized on a generic basis and the potential environmental impact of these postulated accidents are evaluated. The descriptions of the site and model mill considered in this analysis are contained in Chapters 4 and 5 of this report. Two situations are considered--(1) operation of a single mill and (2) operation of as many as 12 mills. Both the nominal consequences and corresponding probabilities are evaluated by use of realistic assumptions in regard to release and transport of radioactive materials. In cases of doubt or where information adequate for realistic evaluation was unavailable, very conservative assumptions were used to compute environmental impacts. Thus, the actual environmental effects from the accidents that are postulated would be, in most cases, significantly less than those predicted in this assessment.

7.1 SINGLE MODEL MILL

The radioactive materials handled at the model mill typically have low specific activities (LSA);* i.e., $\sim 10^{-9}$ Ci/g for the tailings, $\sim 10^{-9}$ Ci/g for the ore, and $\sim 6 \times 10^{-7}$ Ci/g for the refined yellowcake product. The quantities of materials handled, on the other hand, could be relatively large--as much as 580 MT (635 ST) of yellowcake per year, representing about 350 Ci of radioactivity.

The very low specific activities require the release of exceedingly large quantities of material in order to be of concern; driving forces for such releases are generally lacking at the model mill. For this assessment, postulated plant accidents involving radioactivity are considered in the following three categories:

1. Trivial incidents; i.e., those not resulting in a release to the environment,
2. Small releases to the environment (relative to the annual release from normal operations),
3. Large releases to the environment (relative to the annual release from normal operations).

Typical trivial incidents include spills, ruptures in tanks or plant piping containing solutions or slurries, failures of the centrifuge used for yellowcake dewatering, and rupture of a tailings disposal system pipe in which the tailings slurry is released into the tailings pond. Small releases include failure of the air-cleaning system serving the concentrate drying and packaging area, a fire or explosion in the solvent extraction circuit, and a gas explosion in the yellowcake dryer. Large releases include a major tornado strike and releases to the watercourse from the tailings pond or tailings distribution system.

In most cases for which a postulated accident results in a release to the environment, the estimated magnitude of the release, the corresponding maximum individual dose,** and the estimated annual probability of occurrence are presented below. The likelihoods are estimates based on a variety of sources, including incidents on record, chemical industry statistics, and failure prediction methodologies. The dispersion model was taken from NRC Regulatory Guide 1.4,[1] and the dose conversion factors are based upon the recommendations of the International Commission on Radiological Protection (Committee II),[2] updated by the lung model advocated by the Environmental Protection Agency.[3]

*In contrast to the relatively high specific activities of a number of prominent radionuclides; i.e., $\sim 10^{-1}$ Ci/g for Pu-239 and $\sim 10^{3}$ Ci/g for Co-60.

**To place the results of the accident analysis in perspective, the annual lung dose from natural background radiation to individuals living within an 80-km (50-mile) radius of the model mill is about 8.2×10^{3} man-rem. This dose was estimated using the annual dose from background radiation (Sec. 4.12) and population data for the region.

During the three decades of nuclear facility operation, the frequency and severity of accidents have been markedly lower than those in related industrial operations. The experience gained from the few accidents that have occurred has resulted in improved engineering safety features and operating procedures, and the probability that similar accidents might occur in the future is considered low. In light of past experience, it is believed that even if major accidents did occur radiation exposures would be too small to cause any observable deleterious effect on the health of the human population.

7.1.1 Trivial Incidents Involving Radioactivity

The following accidents at the model mill caused by human error or equipment failure would not result in the release of radioactive material to the environment.

7.1.1.1 Leaks or Rupture in Tanks or Piping

Uranium-bearing slurries and solutions are contained in several tanks comprising the acid leach, washing and clarification, and solvent extraction stages of the model mill circuit. Human error during the filling or emptying of tanks or the failure of valves or piping in the circuit would result in spills which might be expected to occur several times annually during operations. Large spills from tank failures or uncorrected human error might involve the release of several hundred pounds of uranium in the liquid phase to the room. However, the entire content of the tanks would be contained within the mill sumps and therefore would not reach the environment.

7.1.1.2 Centrifuge Failure

Prior to drying, the thickened yellowcake slurry is likely to be dewatered by the use of a centrifuge. The centrifuge may be located in the vicinity of a tank containing uranium in solution or as a slurry. If the centrifuge rotor were to fail, it could conceivably penetrate one of these tanks and release radionuclides to the room. However, the entire contents of a tank would be contained by dikes constructed around the tank and therefore would not reach the environment.

7.1.1.3 Rupture of a Pipe in the Tailings Disposal System

The throughput of the model mill is 1800 MT (2000 ST) of ore per day. At this rate, approximately 65 MT (70 ST) per hour of sand, silt, and clay-sized particles are transported to the tailings pond through the tailings disposal system piping. This material, usually transported as a slurry ($\sim$ 50% water), contains mill chemicals and radioactive materials. Ruptures in the piping would be expected to occur; however, the majority of the length of the piping would probably parallel the tailings pond, and the flow of the slurry released from the ruptures would be toward the tailings pond, where it would be contained along with the existing tailings material. Should a rupture occur in the length of piping between the mill and the tailings area, the slurry could conceivably reach the watercourse. This case is considered along with tailings pond releases in Section 7.1.3.

7.1.2 Small Releases Involving Radioactivity

The following accidents, caused by human error or equipment failure, would release small quantities of radioactive materials to the environment. The estimated releases, however, are expected to be small in comparison with the annual release from normal operations.

7.1.2.1 Failure in the Air Cleaning System Serving the Yellowcake Drying Area

The off-gases from the model mill drying operation, which contain entrained solid particles of yellowcake, typically pass through a wet scrubber which is expected to collect roughly 98% of the solid material, depending on particle size. The emission rate to the scrubber is assumed to be approximately 1400 g/hr (3.1 lb/hr) of uranium oxide. Should the scrubber fail, all of this material could be released to the environment. Although the stack is routinely monitored for uranium, the circuit also is usually checked every one-half hour as a part of the formal plant procedures. A drop in pressure would indicate failure of the scrubber, in which case operations would be terminated until the scrubber was repaired. If the failure occurred during daylight hours, the plume would be visible to an observer.

For purposes of analysis, it is assumed that the scrubber totally fails to function for eight hours during the night shift and that the pressure goes unchecked for the entire shift. This

would result in the release to the environment of approximately 11 kg (25 lb) of insoluble uranium oxide particles, assumed to be in the respirable size range. For this magnitude of release at the model mill, it is conservatively estimated that an individual at the closest permanent residence [2000 m (6500 ft)] would receive a 50-year dose commitment to the lung of approximately 86 mrem.

Although quantitative data are unavailable, catastrophic scrubber failure is highly unlikely. Progressive failure, in which case the plugging of vents causes back pressure, would be readily detectable during operational checks and would probably produce inefficiencies, rather than complete failure.

7.1.2.2 Fire or Explosion in the Solvent Extraction Circuit

The solvent extraction circuit is generally in a separate building and could contain as much as 1300 kg (2900 lb) of uranium. Major fires have occurred in solvent extraction circuits of uranium mills in recent history.[4] The tanks, containing about 380,000 L (100,000 gallons) of solvent (kerosene and amines), are typically fitted with sprinkler systems containing an extinguishing agent.

It is conservatively assumed from previous estimates[5,6] relating to both uranium and plutonium solutions that in the event of a major fire, as much as 1% of the uranium would be dispersed.* This would result in the ultimate release to the environment in the vicinity of the model mill of about 13 kg (29 lb) of soluble uranium and 0.65 kg (1.4 lbs) of thorium. The maximum individual 50-year dose commitments at the fence [500 m (1600 ft)] and nearest residence [2000 m (6500 ft)] resulting from this incident are estimated to be approximately 1.36 rem and 0.15 rem to the bone, respectively.

From chemical industry data, the probability of a major fire per plant-year is estimated to be 4×10^{-4}.[5] However, at least two major solvent extraction circuit fires are documented in the literature.[4] There have been over 570 plant-years of mill operation in the United States. Thus, from the historical incidents, the likelihood of a major solvent extraction fire is in the range of 0.4 to 1×10^{-2} plant-year. Using these two estimates to bracket the probability, the staff estimates the likelihood of a major solvent extraction fire at the model mill to fall in the range of 4×10^{-4} to 1×10^{-2} per year.

7.1.2.3 Gas Explosion in the Yellowcake Drying Operation

A propane- or natural-gas-fired furnace is generally used to remove the water remaining in the yellowcake slurry after the centrifuge operation. The furnace, which usually consists of several tiers of hearths enclosed within a large cylinder, is generally contained in an isolated enclosed area on a concrete slab. For the model mill, the inventory of yellowcake in the dryer is taken to be approximately 1500 kg (3300 lb). The off-gas from the dryer, as discussed earlier, is usually vented through a wet scrubber. An explosion in the dryer or the fuel piping, however, could blow off the duct work associated with the ventilation system and disperse yellowcake into the room.

The consequences of explosion accidents are limited by the concentration of heavy material that can be maintained in the air, estimated to be approximately 100 mg/m^3 (6.25×10^{-6} lb/ft^3).[5] For a room with a volume on the order of 10^4 m^3 (3.5×10^3), the quantity of yellowcake released to the room air is estimated to be approximately 1000 g (2.2 lb); this estimate is based on the conservative assumption that all of the material would be swept out into the environment when the room is ventilated. It is estimated that if 100% of the insoluble particles are in the respirable size rnage, individuals at the fence line [500 m (1600 ft)] and at the closest residence [200 m (6500 ft)] would receive 50-year dose commitments to the lung approximately 6.5×10^{-2} rem and 6.9×10^{-3} rem, respectively.

No quantitative data have been found relating either to propane or natural gas furnace explosions. Failure rates observed for piping used in the transmission of natural gas can be converted to equivalent failure rates per plant year.[7] The result of this analysis indicates approximately 5×10^{-3} failures per plant year. This is probably an upper limit of the likelihood of a gas explosion because it is based upon the conservative estimate of 52,000 m (170,000 ft) of piping per plant and does not take into account the probability of ignition given a failure.

*It is estimated that a smaller fraction of the uranium inventory would be released to the room, and subsequently to the environment, in the event of an explosion.

7.1.3 Large Releases Involving Radioactivity

For operations at the model mill, there are conceivable accidents which could release larger quantities of radioactive materials to the environment that would be released annually from normal operations. By virtue of complex and highly variable dispersion characteristics, however, the individual impacts will not necessarily be proportional to the total amount of radioactivity released to the environment.

7.1.3.1 Tornado

Thunderstorms, occasionally spawning tornadoes, are frequent in spring and summer. These tornadoes tend to be less destructive than tornadoes occurring further east. Dust devils are frequent in the area and may occasionally cause slight damage in their paths. The area is categorized as Region 3 in relative tornado intensity;[8-10] i.e., for a typical tornado, the wind speed is 110 m/s (240 mph), of which 85 m/s (190 mph) is rotational and 25 m/s (50 mph) is translational. Generally, the mill structures in the model region are not designed to withstand a tornado of this intensity.

The nature of the milling operation is such that little more could be done to secure the facility with advance warning than without it. Accordingly, a "no warning" tornado is postulated. Moreover, since it is not possible to predict accurately the total amount of material dispersed by the tornado, a highly conservative approach is adopted. It is assumed that (1) three days production of yellowcake is free and not packaged in containers, (2) the maximum inventory of 45 MT (50 ST) of yellowcake is onsite when the tornado strikes, and (3) 15% of the contained material is released. Thus, it is assumed that the tornado lifts about 11,400 kg (25,100 lb) of yellowcake (equivalent to the contents of twenty-six 55-gallon drums).

A conservative model, in which it is assumed that all of the yellowcake is in a respirable form, was used for the dispersion analysis.[11] It is assumed that all of the material is entrained as the vortex passes over the site. Upon reaching the site boundary, the vortex dissipates, leaving a volume source to be dispersed by the trailing winds through an arc of 45°. Because of the small particle sizes assumed, the settling velocity is considered to be negligible.

The model predicts a maximum exposure at a distance of approximately 4 km (2.5 miles) from the mill, where the 50-year dose commitment to the lungs of an individual is estimated to be 8.3×10^{-7} rem. For individuals at the fence line [500 m (1600 ft)] and at the closest residence [2000 m (6500 ft)], the 50-year dose commitments are estimated to be 2.2×10^{-7} rem and 4.8×10^{-7} rem, respectively.

7.1.3.2 Release of Tailings Slurry

The underflow from the washing and clarification step in the model mill is pumped to the tailings disposal pond. Approximately 1800 MT/day (2000 ST/day) of sand, silt, and clay-sized particles entrained in approximately an equal weight of solution constitutes the tailings slurry. Over the projected life of the milling operation, approximately 9.9×10^6 MT (10.9×10^6 ST) of barren tailings could be generated and retained in the disposal area, typically 1×10^6 m^2 (1.1×10^7 ft^2). Inadvertent release of the tailings slurry to the environment might result from an overflow of the tailings slurry, a rupture in the tailings distribution piping, or a failure of the tailings embankment plus washout. Failure of the tailings dam could be caused by a destructive earthquake, flood-water breaching, or structural failure.

For the expected rates of precipitation during the life of the model mill, the tailings pond could overflow only if the processing system were allowed to operate unattended for several weeks. A minimum of 1.5 m (5 ft) of freeboard is generally provided, which is approximately 8.0×10^8 L (2.2×10^8 gallons) of emergency storage. The predicted runoff, with diversion ditches installed, to the tailings pond from the postulated 100-year storm is 7.9×10^7 L (2.1×10^7 gallons). Moreover, it is assumed that if the diversion ditches fail and a 500-year return-period storm occurs, only 3.7×10^8 L (9.8×10^7 gallons) of water would be input to the tailings pond. The maximum monthly precipitation recorded in the model mill site area is 12.3 cm (4.8 inches). Assuming a maximum 24-hour precipitation event of 6.0 cm (2.4 inches), an inflow to the tailings pond of 2.1×10^8 L (5.6×10^7 gallons) is estimated. The sum of these inflows does not exceed the reserve capacity of the tailings pond. (It is concluded in an independent analysis that the Bear Creek tailings dam would not be overtopped by a 100-year return-period flood or by one-half of the probable maximum precipitation event.)[12]

In any event, if tailings are deposited above grade, current regulations require that the tailings dam be designed to withstand the probable maximum flood.

Failure of the tailings dam because of earthquake would be unlikely since the model site is postulated to be in a zone of low seismicity.[13,14] Within the model region, an earthquake of intensity MM VI might be expected to have occurred within recent history. (As indicated in the Supplement, this is the general situation in U.S. uranium resource regions.)

From the foregoing discussion it is clear that sufficient data are not available to estimate the small probability of the occurrence of a natural disaster with sufficient intensity to result in a release of tailings slurry to the environment. Even if the probability were known accurately, however, it would be difficult to predict the magnitude of the release. However, tailings slurry releases have occurred in the past, and the consequences associated with these events have been documented to varying levels of detail in reports to the NRC (AEC) and to Agreement States and will be used to estimate the nominal model mill release. Table 7.1 contains a summary of recorded incidents in the period 1959 through 1979.

Table 7.1. Summary of Accidental Tailings Slurry Releases, 1959-1979[a]

Cause	Solids Released, kg	Liquids Released, liters	Reached Watercourse
Flash flood	14×10^6	1.2×10^7[b]	Yes
Dam failure	9×10^5[b]	9.1×10^5	Yes
Dam failure	5×10^5	4×10^5[b]	No
Dam failure	2×10^5	2×10^5[b]	Yes
Pipeline failure	3×10^5	2×10^5	Yes
Flooding	1×10^8[b]	8.7×10^7	Yes
Pipeline failure	6.4×10^4[b]	6.1×10^4	Small amount
Pipeline failure	2×10^6[b]	1.7×10^6	Yes
Dam failure	$1\text{-}14 \times 10^6$[b]	$1\text{-}11 \times 10^6$	Yes
Pipeline failure	1×10^5[b]	1.3×10^5	Yes
Dam failure	9×10^3[b]	8×10^3	No
Pipeline failure	4.5×10^7	$8\text{-}30 \times 10^6$	No
Dam failure	8.2×10^6[b]	7.6×10^6	No
Pipeline failure	1.1×10^3	1.5×10^4	Yes
Dam failure	1.0×10^6	3.8×10^8	Yes
Pipeline failure/dam failure	No quantitative information		

[a]From "Environmental survey of the Uranium Fuel Cycle," WASH-1248, U.S. Atomic Energy Commission, Fuels and Materials, Directorate of Licensing, April 1974, and "Summary of Tailings Slurry Releases 1972-1977," prepared by Teknekron, 28 February 1978.

[b]This value is based on the assumption that equal weights of solids and liquids are released, and that the density of the liquids is approximately 1.6 g/cm³ (100 lb/ft³).

From these historical data, the average releases from tailings embankment failure or flooding were approximately 5.5×10^7 L (1.4×10^7 gallons) of liquids and 1.4×10^7 kg (3.2×10^7 lb) of solids. Six out of ten of the releases from embankment failure or flooding reached the watercourse. Thus, considering the 430-odd mill-years of operation in the period, the likelihood of release from the tailings pond to the watercourse is approximately 1 to 2×10^{-2} per plant year. Mills having dikes similar in construction to those that failed were required to strengthen the dikes, and for new mills the design of the embankment retention system is expected to conform to Regulatory Guide 3.11.[15]

As discussed in Section 7.1.1, most failures in the tailings distribution piping would result in release of the slurry to the tailings pond and not to the environment. However, if the failure were to occur in the length of piping between the mill and the tailings area, the slurry could conceivably reach the watercourse. Based on the historical data given in Table 7.1, the average releases to the watercourse from piping failure were approximately 3.5×10^6 L (9.1×10^5 gallons) of liquid and 8.2×10^6 kg (1.8×10^7 lb) of solids. Furthermore, on the same basis as

embankment failure estimates, the likelihood of tailings release from failure of the piping is less than 1×10^{-2} per plant-year. Since both the historical consequences and likelihood of piping failures are lower than those of embankment failure, only releases from embankment failures or flooding are considered in the discussion that follows relative to the impact of a tailings slurry release.

For the model mill the fractions of the uranium, thorium, and radium originally present in the ore that remain in the tailings are about 7%, 99.8%, and 100%, respectively. Generally, the solid tailings are coated with acid solutions and are estimated to have a radiological composition of approximately 20 μCi/MT each of U-238 and U-234, 280 μCi/MT of Th-230, and 280 μCi/MT of Ra-226. Because of losses due to seepage, evaporation from the disposal area, and entrapment in the tailings solids, the composition of the liquid phase is difficult to predict. In addition to dissolved minerals from the ore, the tailings solution contains trace quantities of the components of the organic phase of the solvent extraction step in the milling circuit. In Table 7.2 the composition of typical tailings solution from an acid leach mill is compared with standards.

Table 7.2. Typical Concentrations of Radionuclides and Chemicals in Tailings Solution

Radionuclide	Concentration, μCi/mL	Maximum Permissible Concentration in Unrestricted Areas,[a] μCi/mL
U-238	1.7×10^{-6}	4×10^{-5}
U-234	1.7×10^{-6}	3×10^{-5}
Th-230	9.0×10^{-5}	2×10^{-6}
Ra-226	2.5×10^{-7}	3×10^{-8}
Pb-210	2.5×10^{-7}	1×10^{-7}
Po-210	2.5×10^{-7}	7×10^{-7}
Bi-210	2.5×10^{-7}	4×10^{-5}
Chemical	**Concentration, mg/L**	**NAS Water Quality Standards for Livestock,[b] mg/L**
As	0.2	0.2
Na	200	--
Fe	1,000	--
Al	2,000	--
F	5	--
V	0.1	--
Ca	500	--
$SO_4^{=}$	30,000	250
Cl^-	300	3000
NH_3	500	--

[a] From Rules and Regulations, Title 10 - Chapter I, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, U.S. Nuclear Regulatory Commission.

[b] "Water Quality Criteria 1972," A report of the Committee on Water Quality Criteria, National Academy of Sciences, National Academy of Engineering, prepared for the U.S. Environmental Protection Agency, 1972.

The estimated 1.4 × 10^7 kg (3.2 × 10^7 lb) of solid tailings released from the impoundment area in the event of an overtopping or failure of the embankment would be expected to settle out below the embankment. The extent of the area covered would depend upon the specifics of the failure and is difficult to calculate. Scaling from previous estimates on the basis of the total mass of tailings released,[16] the material may be assumed to follow the tributary stream channel for a distance of approximately 2100 m (6800 ft), covering a width of approximately 130 m (425 ft), and forming a wedge 3 cm (1-1/4 inches) in average thickness.

The main radiological concern associated with the deposition of the tailings material is the small 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 may be prevented by removing the contaminated material from the environment. Accordingly, a measure of the impact associated with the release of the solid tailings from the pond is the estimated cost of excavating, removal of the tailings and contaminated soil, and transporting the material back to the tailings impoundment. Estimates of a similar operation have been made in connection with the Vitro mill.[17] Using the Vitro mill unit costs and assuming that (1) 15 cm (6 inches) of contaminated soil would require removal along with the tailings, and (2) the approximate travel distance back to the tailings impoundment is 3.5 km (2 miles), the staff estimated the total cost for excavation, removal of tailings and contaminated soil, and the truck transport of the material back to the tailings impoundment to be approximately $120,000.

The fate of the estimated 5.5 × 10^7 L (1.4 × 10^7 gallons) of tailings solution released with the tailings slurry resulting from embankment failure or flooding would depend upon the flow at the time in the tributary stream to Reservoir I. This is assumed to be an ephemeral stream that has maximum flow in June and July and is dry from September to February. The soil in the central area of the model site consists mainly of the Petula-Tomahawk association (see Ch. 4). A thin, approximately 100-m (325-ft) surficial deposit of terrace and pediment alluvium caps the Triassic siltstone, which is an alluvial soil of moderate to high permeability. The typical tailings pond effluents would tend to move downward through the soil profile; part of the acidity of the tailings would be neutralized by the calcareous nature of the soils, but there would still be substantial leaching of organic matter and cations from the surface horizons. If the tributary stream were not dry, much of the liquid could conceivably flow via the tributary stream to Reservoir I, approximately 10 km (6 miles) downstream from the tailings pond. The average volume is assumed to be 2.8 × 10^7 m^3 (7.4 × 10^9 gallons), with an average minimum of approximately 1.4 × 10^7 m^3 (3.7 × 10^9 gallons). If all of the tailings solution were to reach the reservoir, and if the reservoir volume was at the minimum value, the dilution provided by the reservoir would lower the concentration by a factor of approximately 250. The larger volume of water now containing the radionuclides could conceivably place a larger population at risk; but this effect is outweighed by the dilution.

Reservoir I may be used for the watering of livestock and for irrigation of crops. It is assumed that 100 head of cattle may be using the reservoir at any one time, and occasionally throughout the year the reservoir may be frequented by antelope and deer. If the estimated concentrations of chemicals in the tailings solution were as given in Table 7.2 and if the dilution provided by the reservoir was at the average minimum volume, the estimated concentrations of arsenic, sulfate, and chloride ions in the reservoir from the tailings solution would be well within water quality standards for livestock use.[18] Water quality standards for livestock have not been promulgated for the other chemicals.

Of the radioisotopes released to the reservoir in the event of a tailings slurry release from the model mill, Th-230 is of primary concern,* with typical concentrations in the tailings solutions approximately two orders of magnitude in excess of the maximum permissible concentration (MPC) for unrestricted areas, as specified in 10 CFR 20.[19] The actual concentration of thorium would be expected to be considerably lower than this value because of sorption onto the stream bed sediment and precipitation in the reservoir as the pH of the solution approaches neutrality. Nevertheless, an individual consuming meat derived exclusively from livestock watered from Reservoir I could conceivably receive significant bone exposure by virtue of the potentially high concentration factors in meat from ingestion of thorium. However, should a release of tailings slurry occur, the NRC or the Agreement State must be notified and informed of the approximate time of the accident and be furnished estimates of the quantities of liquids and solids that have been released from the tailings pond. If the tailings solution were to reach Reservoir I, the radioactivity of the water, including its thorium concentration, would be monitored prior to its use for the watering of cattle or for irrigation. Alternative sources of water would have to be provided for these uses if the concentrations of radionuclides were found to be excessive. In the extreme case of irreversible contamination of the Reservoir I stream bed the top 15 cm (6 inches) of sediment from Reservoir I could be excavated and hauled to the tail-

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*The estimated concentration of Ra-226 in the reservoir is less than the EPA drinking water standard of 5 pCi/L.

ings pond [approximately 4.4 × 10^5 MT (4.8 × 10^5 ST)]. Using the unit costs estimated for the Vitro Mill,[17] the staff estimates that for the model mill the cost of excavation and transportation would be $470,000 and $480,000, respectively. The total costs then would be $950,000.

7.1.4 Accidents Not Involving Radioactivity

The potential for environmental effects from accidents involving nonradiological materials at the model mill is expected to be small. Failure of the boiler that supplies process steam to the acid leach stage of the mill circuit could release low pressure steam to the room, possibly causing minor injuries to workers, but neither chemicals nor radiological materials would be released to the environment. Typically, forced-air ventilation systems will be provided in the acid leach and solvent extraction stages of the process to dilute the chemical vapors emitted and protect the workers from the hazardous fumes. Failure of these ventilation systems might result in the interim collection of these vapors in the building air. Since the vapors would ultimately be discharged to the atmosphere in either case, such a failure would have no incremental effect on the environment.

A number of chemical reagents used in the process are expected to be stored in relatively large quantities at the model mill site. Specifically, storage tanks are provided for 1.4 × 10^6 L (3.6 × 10^5 gallons) of sulfuric acid, 2.5 × 10^4 kg (5.6 × 10^4 lb) of sodium chlorate, 8.2 × 10^3 kg (1.8 × 10^4 lb) of kerosene, and 6.0 × 10^4 L (1.6 × 10^4 gallons) of ammonia. Each of the tanks containing a liquid reagent is surrounded by a dike of sufficient capacity to contain the entire contents of the tank. Also, even if an overflow of a dike were to occur, drainage of the liquid at the model site would generally be toward the tailings pond.

The only chemical which might seriously impact the environment is ammonia. The anhydrous ammonia storage tank is generally located in proximity to the mill. A break in the tank's external piping would result in only a minor release, since an internal safety valve automatically closes when pressure drops, thus preventing further escape of ammonia. Department of Transportation (DOT) regulation 10 CFR Part 178.377 requires the use of this safety valve.[20] It is possible that the line carrying ammonia to the storage tank from the tank truck could be ruptured, in which case the release rate is assumed to be limited to 100 g/s (0.2 lb/s) of vapor. The resulting concentration of ammonia at the closest residence [2000 m (6500 ft)] is conservatively estimated to average approximately 35,000 μg/m^3 over the entire period of release. This concentration is less than the 40,000 μg/m^3 minimum concentration which produces a detectable odor, and the 69,000 μg/m^3 recommended limit for prolonged human exposure,[21] but greater than 600 μg/m^3 short-term air quality standard derived from typical state regulations (at 1/30 threshold limit values). Thus, the ammonia would pose no substantial health risk.

7.1.5 Transportation Accidents

Transportation of materials to and from the model mill can be classified into three categories--(1) shipments of refined yellowcake from the mill to the uranium hexafluoride conversion facility, (2) shipments of ore from the mine pit to the mill, and (3) shipments of process chemicals from suppliers to the mill. An accident in each of these categories has been conceptualized and analyzed, and the results are given below.

7.1.5.1 Shipments of Yellowcake

At the model mill, the refined yellowcake product is generally packed in 55-gallon, 18-gauge drums holding an average of 430 kg(950 lb) and classified by the Department of Transportation as Type A packaging (49 CFR Parts 171-189 and 10 CFR Part 71). The yellowcake is shipped by truck an average of 2400 km (1500 miles) to a conversion plant, which transforms the yellowcake to uranium hexafluoride for the enrichment step of the light water-cooled reactor fuel cycle. An average truck shipment contains approximately 40 drums, or 17 MT (19 ST) of yellowcake. Based upon the projected annual yellowcake yield of 580 MT (635 ST), approximately 34 such shipments will be required annually.

Based on published accident statistics the probability of a truck accident is in the range of 1.0 to 1.6 × 10^{-6}/km (1.6 to 2.6 × 10^{-6}/mile).[22-24] Truck accident statistics include three categories of events: collisions, noncollisions, and other events. "Collisions" are between the transport vehicle and other objects, whether moving vehicles or fixed objects. "Noncollisions" are accidents involving only the one vehicle, such as when it leaves the road and rolls over. Accidents classified as "other events" include personal injuries suffered on the vehicle, persons falling from or being thrown against a standing vehicle, cases of stolen vehicles, and fires occurring on a standing vehicle. The likelihood of a truck shipment of yellowcake from the mill being involved in an accident of any type during a one-year period is approximately 11%. This probability was obtained by multiplying the probability of accident per vehicle-km (1.3 × 10^{-6}/km) by the number of shipments per year (34) and the distance per shipment (2400 km).

A generalized evaluation of accident risks by NRC classifies accidents into eight categories, depending upon the combined stresses of impact, puncture, crush, and fire. On the basis of this classification scheme, conditional probabilities (i.e., given an accident, the probability that

the accident is of a certain magnitude) of the occurrence of the eight accident severities were developed. These fractional probabilities of occurrence for truck accidents are given in Column 2 of Table 7.3.[24]

Table 7.3. Fractional Probabilities of Occurrence and Corresponding Package Release Fractions for Each of the Release Models for Low Specific Activity (LSA) and Type A Containers Involved in Truck Accidents[a]

Accident Severity Category	Fractional Occurrence of Accident	Release Fractions	
		Model I LSA & Type A	Model II LSA & Type A
I	0.55	0	0
II	0.36	1.0	0.01
III	0.07	1.0	0.1
IV	0.016	1.0	1.0
V	0.0028	1.0	1.0
VI	0.0011	1.0	1.0
VII	8.5×10^{-5}	1.0	1.0
VIII	1.5×10^{-5}	1.0	1.0

[a]From "Final Environmental Report on the Transportation of Radioactive Materials by Air and Other Modes," U.S. Nuclear Regulatory Commission, NUREG-0170, 1977.

In order to assess the risk of a transportation accident, it is necessary to know the fraction of radioactive material that is released when an accident of a given severity occurs. For this analysis, two accident models are considered: Model I assumes complete loss of drum contents, and Model II, based upon actual tests,[24] assumes partial loss of drum contents. The packages are assumed to be Type A drums containing low specific activity (LSA) material. The fractional releases to the environment for each model are shown in Columns 3 and 4 of Table 7.3.[24] Integrating the fractional occurrence and the release fractions (loss) for Model I and Model II, the expected fractional release in any given accident is approximately 0.45 for Model I and 0.03 for Model II. The quantity of yellowcake released from the containers in the event of a truck accident is estimated to be about 7700 kg (17,000 lb) for Model I and 530 kg (1200 lb) for Model II. Most of the yellowcake released from the container would be deposited directly on the ground in the immediate vicinity of the accident. Some fraction of the released material, however, would be dispersed to the atmosphere. Expressions for calculation of the dispersal of plutonium oxide to the environment have been developed at Battelle Northwest Laboratories on the basis of actual laboratory and field measurements over several years.[23] The following empirical expression was derived for the dispersal of plutonium oxide via the air following an accident involving a release from the container:

$$f = 0.001 + 4.6 \times 10^{-4} (1-e^{-0.15ut})\, u^{1.78} ,$$

where: f = the fractional airborne release,

u = the wind speed at 15.2 m (50 ft) expressed in m/s, and

t = the duration of the release, in hours.

In this expression, the first term represents the initial "puff" immediately airborne when the container fails in an accident. If the above expression is also valid for U_3O_8 dispersal, if the wind speed is 5 m/s (10 mph), and if 24 hours are available for the release, it is estimated that the environmental release fraction would be 9×10^{-3}. For insoluble uranium, all particles of which are in the respirable size range, a 5° sector, and a population density of 2.9 persons/km^2 (7.5 persons/mi^2) characteristic of the model region (see Ch. 4), the consequences of a truck accident involving a shipment of yellowcake from the mill would be 50-year

dose commitments of approximately 9 and 0.7 man-rem to the lungs of the general public for Models I and II, respectively. It is equally likely that this accident could occur in the more densely populated regions of the country where the uranium conversion plants are located. Using the population density [61 persons/km^2 (160 persons/mi^2 (160 persons/mi^2)] of the Eastern United States, it is found that the 50-year dose commitments to the lungs of the general public would be about 200 man-rem and 14 man-rem for Models I and II, respectively.* It is possible that the postulated accident could occur on a bridge, such that the containers could be knocked into the water. No actual data are available from which to estimate the probability of such an event; however, it is possible to use indirect data to arrive at an estimate. In a recent study by Sandia Corporation,[25] it was conservatively estimated that there are a total of 160 km (100 miles) of bridges and that most of the bridges are on Federal highways. A value of 240,000 km (150,000 miles) of roads under Federal control was used.[26] This leads to a conditional probability of 6.7×10^{-4} that if an accident occurs, it takes place on a bridge. Moreover, many of the accidents are relatively minor, and most deepwater bridges are heavily protected, such that the occurrence of an accident on a bridge would probably not result in immersion of the containers in the water. For purposes of this analysis, however, it is conservatively postulated that the truck and all of the containers involved in the accident would be immersed and that 45% of the containers would be ruptured and would release their contents to the river. If the accident rate for trucks of 1.3×10^{-6}/vehicle-km (2×10^{-6}/vehicle-mile) is combined with the conditional probability of an accident occurring on a bridge, the probability of the yellowcake becoming immersed is about 8.7×10^{-10}/vehicle-km (1.4×10^{-10}/vehicle-mile).

The yellowcake will be transported east from the model region to the conversion facility. The first major river to be crossed other than dry drainage ditches and ephemeral streams would be the Tributary River. Additional rivers would be crossed during the assumed 2400-km (1500-mile) trip to the conversion facility. In the unlikely event of a transportation accident on a bridge, two situations are postulated. In the first, the drums rupture and spill their contents on the bridge or partially on the bridge and on the riverbank below, but not in the river. For this situation, the accident probabilities and consequences are the same as previously described for the Model I and II releases. For the other, the truck crashes through the guardrail and breaks up on impact with the water. For this situation, it is assumed that 45% of the containers rupture and release their contents of yellowcake concentrate to the river.

Under the first situation described above, the yellowcake should be cleaned up as rapidly as possible to prevent spread of the contamination. The cleanup should be directed by qualified personnel from the state radiological emergency assistance team. Should the accident be judged by the state personnel to be beyond their capability, the Nuclear Regulatory Commission would be requested to provide assistance. The NRC regional office would assist by dispatching a radiological emergency assistance team to the scene of the accident to: identify and assess the hazard, advise on emergency operations to protect the health and safety of the public, provide or prescribe procedures which will minimize injury or deleterious effects on the surrounding environment, and generally provide assistance as may be necessary.

Under the second situation, where the containers are immersed in water, it is estimated that 7.7×10^3 kg (1.7×10^4 lb) of yellowcake containing approximately 4.3×10^3 μCi of radioactivity would be released to the river. If the Tributary River is typical of the rivers on route, the flow rate would vary from a minimum of 5 m^3/s (1400 gps) to a maximum of 80 m^3/s (23,000 gps). For a minimum flow rate, the concentrations of radioisotopes would be diluted to maximum permissible concentrations in a matter of a few minutes. Even in the highly unlikely event that water for a public water supply system were being withdrawn immediately below the point of accidental release, an individual would only receive a small fraction of the Radiation Protection Guide (RPG) of 500 mrem per year. In order to be exposed to this dose, an individual would have to drink the water at the MPC level for one year. It is expected that the yellowcake concentrate released by the accident would pass down the river as a slug and during its transit would be further diluted until it was not detectable above the background radiation level of the river. It is not possible in this generic analysis to estimate the time and distance for the material to reach background levels.

In a recent accident (September 1977) a commercial carrier with 50 drums of uranium concentrate overturned and spilled an estimated 3200 kg (7000 lb) of concentrate on the ground and in the truck trailer. Approximately three hours after the accident, the material was covered with plastic sheeting to prevent further release to the atmosphere. Using the formula given earlier for the three-hour duration of release, approximately 24 kg (53 lb) of U_3O_8 are estimated to have been released to the atmosphere. The consequence for the area in which the accident actually occurred, where the population density is about 1.0 person/km^2 (2.5 persons/mi^2), is estimated to be 1.2 man-rem.**

*A population density of 900 persons/km^2 out to 5 km from the point of the accident in East City, and 2.9 persons/km^2 from 5 to 80 km was assumed. A 5° sector was used.

**5° angle of dispersion, 80-distance.

Inhalation of yellowcake dust might produce some health effects due to the chemical toxicity of uranium. In the case of the September 1977 accident, no clinical effects were observed among the individuals who were involved with the spill and subsequent cleanup.[27] Also, uranium bioassays of 27 persons who were in the vicinity of the spill (including the law enforcement and rescue personnel) indicated that chemically toxic levels of uranium intake did not occur.

It is possible that in the future yellowcake will be transported as a slurry to the conversion facility. One milling company has applied to the NRC for a permit to transport yellowcake in such a form and is designing tank cars which would be subject to Department of Transportation approval. If the yellowcake were transported as a slurry, the consequence of an accidental release of the material on land or in the water probably would be less than for the dry concentrate. It is expected that the slurry would be transported from the model mill in specially designed 9.9×10^3-L (2.6×10^3-gallon) stainless steel tanks with 1/4-inch-thick walls. The slurry in such a tank would contain an average of 6 to 7 curies of radioactivity.* It is expected that the tank truck would be able to withstand the impact of most collisions, or under the most severe conditions, an accident would result in a rupture of the tank and release of only a portion of the slurry. To prevent the spread of contamination, the slurry would need to be cleaned up as rapidly as possible under the direction of a state radiological emergency assistance team. It is expected that eventually there would be some drying out of the slurry and release of yellowcake to the atmosphere in the immediate vicinity of the accident, depending upon how long it took to clean up the material. Although sufficient data are not available for a quantitative analysis of such an accident, it is expected that the consequences would be considerably lower than those estimated for the shipment of dry concentrate.

7.1.5.2 Shipments of Ore to the Mill

For the model mill, the uranium ore is usually shipped to the ore stockpiles adjacent to the mill in 23-MT (25-ST) batches. The average distance from the initial uranium mine pit to the mill stockpile is approximately 50 km (32 miles). Based upon the mill capacity of 1800 MT (2000 ST) of ore daily, approximately 29,000 trips per year will be required. Although the ore will be hauled on private roads, it is assumed that the probability of a truck accident is in the range cited in the previous section; therefore, the estimated likelihood of an ore truck being involved in an accident during a one-year period is about 0.4. However, because of the low specific activity of the material and the ease with which the contamination can be removed, the radiological impact in the model region site is not considered significant.

As it comes from the mine, the ore contains a significant fraction of moisture and has a lower percentage of fines than ore that has been crushed. For the purpose of this analysis, it is conservatively assumed that the ore contains 1.0% respirable dust by weight, and that in an accident all of this dust would be released from the truck and be available for dispersal. Furthermore, the environmental release factor of 9×10^{-3} derived in the previous section from the Battelle formula is assumed valid. Based on the foregoing assumptions, the quantity of dispersible ore released to the atmosphere in the event of a truck accident is estimated to be about 2.1 kg (4.6 lb). If all of the dust is in the respirable range, the consequence of a truck accident involving a shipment of ore from the mine to the mill would be a maximum individual 50-year lung dose commitment of 0.13 rem at 500 m (1600 ft) and 0.014 rem at 2000 m (6500 ft) from the accident scene.

7.1.5.3 Shipments of Chemicals to the Mill

Truck shipments of anhydrous ammonia to the mill, if involved in a severe accident, could result in a significant environmental impact. Approximately 39 shipments of anhydrous ammonia are made annually in 19,000-L (5000-gallon) tank trucks from the nearest supplier. It is assumed that the supplier is about 400 km (250 miles) from the mill.

The annual United States production of anhydrous ammonia which is shipped in that form is approximately 6.9×10^6 MT (7.6×10^6 ST). It is estimated that about 26% of the shipments are made by truck (with the remainder by rail, pipeline, and barge). Based on the assumption that the average truck shipment is about 19 MT (21 tons), approximately 93,000 truck shipments of anhydrous ammonia are made annually. Based on accident data collected by DOT,[28] there are about 140 accidents per year involving truck shipments of anhydrous ammonia.** For an estimated average shipping distance of 560 km (350 miles), the resulting accident frequency is roughly 2.7×10^{-6}/km (4.3×10^{-6}/mile). The DOT data also reveal that a release of ammonia [770 kg

*J. Deuel, Consultant, Kerr-McGee, private communication.

**The DOT accident statistics are extrapolated from the number of shippers reporting, estimated to constitute approximately 10% of the total number of shippers.

(1700 lb) on the average] resulted from approximately 80% of the reported incidents, and that a member of the general public was injured in about 15% of the reported incidents involving a release. (Most of the injuries were sustained by the driver.)

On the basis of these data, the probability of an injury to a member of the general public resulting from an average shipment of anhydrous ammonia is about 3×10^{-7}/km (4.8×10^{-7}/mile). This would be expected to be an overestimate for shipments in the vicinity of the model mill because of the relatively low population density. Nevertheless, on the basis of this estimate, the likelihood of an injury to a member of the general public resulting from shipments of ammonia to the mill is predicted to be about 5×10^{-3} per year.

7.1.6 Regional Variations

Potential accidents at a model mill located in each of the six physiographic regions described in the Supplement are examined to determine the regional variations in the potential environmental effects.

7.1.6.1 Trivial Incidents Involving Radioactivity

Trivial accidents involving leaks or ruptures in tanks or piping, centrifuge failure, or rupture in the tailings disposal system are not expected to result in releases of radioactive material to the environment at the model site. Similarly, no factors can be identified that could lead to such releases in any of the six regions.

7.1.6.2 Small Releases Involving Radioactivity

Short-term atmospheric dispersion is expected to be similar in all regions; thus, the estimated short-term dispersion factor used in the model site analyses of failure in the air-cleaning system serving the yellowcake drying area, fire in the solvent extraction circuit, and gas explosion in the yellowcake drying operation would also apply to the analysis of these accidents in the six regions. Consequently, the estimated 50-year dose commitments to individuals located at a fence line 500 m (1600 ft) away and at the closest residence, 2000 m (6500 ft), would be the same in each of the six regions as that for the model mill. It is expected that the only regional variation in the consequences of these accidents would be in the 50-year population dose commitments, which are a function of population density. The population densities corresponding to the subregions of the physiographic regions, as shown in the Supplement, were selected for this analysis because it is assumed that uranium mills would be located close to known uranium deposits. The predicted 50-year population dose commitments for each of the six regions are compared to that of the model region in Table 7.4.

Table 7.4. Comparison of the Predicted 50-Year Population Dose Commitments in Each of the Six Regions with that at the Model Region for Selected Accidents

Region	Failure in the Air Cleaning System, man-rem to lung	Fire in the Solvent Extraction Circuit, man-rem to bone	Gas Explosion Yellowcake Drying Area, man-rem to lung
Model Region	1.5	2.5	0.12
Northern Rocky Mountains	1.4	2.4	0.11
Western Great Plains	1.1	1.8	0.09
Wyoming Basin	0.72	1.2	0.07
Southern Rocky Mountains	0.68	1.1	0.06
Colorado Plateau	1.3	2.2	0.1
Texas Coastal Plains	3.1	5.2	0.24

7.1.6.3 Large Releases Involving Radioactivity

7.1.6.3.1 Tornado

The annual frequency and probability of occurrence of a tornado in the model region are approximately 0.15 and 1.1×10^{-4}, respectively. Using the method described by Thom,[9] the mean annual frequency and probability of occurrence of tornadoes for the six regions are compared with those for the model region in Table 7.5. The relative tornado intensity, as described in the NRC Regulatory Guide 1.76,[8] is included in this table. The Western Great Plains and Texas Coastal Plains are in Category I of relative tornado intensity, whereas the Northern Rocky Mountains, Wyoming Basin, Colorado Plateau, and Southern Rocky Mountains are in Category III, as is the model region. For a typical tornado in Category I, the wind speed is 160 m/s (360 mph), of which 134 m/s (300 mph) is rotational and 26 m/s (60 mph) is translational. Generally, the mill structures are not designed to withstand tornadoes in either Category I or III.

Table 7.5. Comparison of Tornado Probabilities in Each of the Six Regions with that in the Model Region

Region	Mean Annual Frequency	Annual Probability	Tornado Intensite Category
Model Region	0.15	1.1×10^{-4}	III
Northern Rocky Mountains (Spokane, WA)	0.1	8.8×10^{-5}	III
Western Great Plains (Rapid City, SD)	0.6	4.8×10^{-4}	I
Wyoming Basin (Casper, WY)	0.4	3.2×10^{-4}	III
Southern Rocky Mountains (Denver, CO)	0.6	4.5×10^{-4}	III
Colorado Plateau (Grand Junction, CO)	None reported	---	III
Texas Coastal Plains (Beeville, TX)	1.6	1.1×10^{-3}	I

The conservative dispersion model[11] and the assumed value of 11,400 kg (25,100 lb) of yellowcake lifted by a tornado (used in Sec. 7.1.3.1 are also applied to the evaluation of population exposures in the six NURE regions. The model predicts a maximum exposure at a distance of 4 km (2.5 miles) from a mill located in any region, such that the 50-year dose commitment to the lungs of an individual is estimated to be 8.3×10^{-7} rem. The 50-year population dose commitments for people living in a 45° sector within 80 km (50 miles) of the mill in each region are given in Table 7.6.

The Western Great Plains and Texas Coastal Plains are in Category I of relative tornado intensity. It is conservatively estimated that in the event of a tornado strike at a mill in these regions, the 50-year population dose commitments would be 6.9×10^{-4} and 2.0×10^{-3} man-rem, respectively.

7.1.6.3.2 Release of Tailings Slurry

Historical tailings slurry release data were used in predicting the nominal quantities of solids and liquids released to the environment in the event of a tailings embankment failure at the model site. It is not possible from these sparse historical data to identify regional trends that influenced either the quantities released or the probabilities of release. Consequently, the quantities of tailings slurry released to the environment from pipeline breaks or from failure of the tailings embankment in each of the six regions are assumed to be roughly the same

as those assumed at the model site. However, since flooding has been the initiating event for tailings releases at a number of mills, it is reasonable to assume that the probability of release is higher in those regions that have high rates of precipitation than those with relatively low rates, although it is not possible to relate the probability of release to the precipitation rate. The annual rates of rainfall and snowfall are given in Table 7.7 for each of the six regions.

Table 7.6. Comparison of Predicted 50-Year Population Dose Commitments in the Six Regions with the Model Region from a Tornado Accident

Region	Population Density,[a] people/km^2	Population in 45° Sector within 80 km	50-Year Population Dose Commitment, man-rem
Model Region	2.9	7,200	9.6×10^{-4}
Northern Rocky Mountains	2.7	6,700	8.9×10^{-4}
Western Great Plains	2.1	5,200	6.9×10^{-4}
Wyoming Basin	1.4	3,500	4.6×10^{-4}
Southern Rocky Mountains	1.3	3,200	4.3×10^{-4}
Colorado Plateau	2.5	6,200	8.3×10^{-4}
Texas Coastal Plains	6.0	15,000	2.0×10^{-4}

[a]From subregion (mill environs) data, Table 12.2 of the Supplement.

Table 7.7. Annual Rates of Rainfall and Snowfall in the Six Regions

Region	Precipitation		Average Annual Snowfall, cm	Monthly Max. Precipitation, cm	Evaporation Potential, cm (exceeds precipitation)
	Average Annual, cm	Time of Year			
Northern Rocky Mountains (Spokane, WA)	30-50	November-February, May	October-May 17-58	May 14.5	100-160
Western Great Plains (Rapid City, SD)	40-60	April-September	September June 10-42	May 18.7	100-150
Wyoming Basin (Casper, WY)	30-40	April-September	September-June 18-54	April 14.6	100-180
Colorado Plateau (Grand Junction, CO)	20-40	April-September	September-May 8-33	August 8.8	150-200
Southern Rocky Mountains (Denver, CO)	25-80	April-October	September-June 14-16	May 18.6	100-150
Texas Coastal Plains (Beeville, TX)	35-115	January-December	0.3-2.9	September 51.6	165-215

The highest monthly precipitation at the model site is 12.3 cm (4.8 inches), whereas in the NURE regions the maximum monthly precipitation varies from a low of 8.8 cm (3.5 inches) for the Colorado Plateau to a high of 51.6 cm (20.3 inches) for the Texas Coastal Plains. This value is representative of the area assumed for the model site. Although the maximum monthly precipitation for a region would be taken into consideration in the design of a tailings impoundment for a mill located in that region, flooding of the tailings impoundment possibly still could occur. The fate of tailings solution released with the tailings slurry during an embankment failure or flooding would vary from region to region, depending upon the location of the tailings impoundment and the flow in the rivers or stream below. The typical rivers in each region have a maximum flow that varies 9 to 60 times that of the Tributary River in the model region. Although the exact location of the uranium mills in each region is not specified, it is assumed that they are located in the central subregions designated in the Supplement to this document and at a considerable distance from the typical river. During the months of April through September in the Northern Rocky Mountains, Wyoming Basin, Western Great Plains, Colorado Plateau, and Southern Rocky Mountains regions, and throughout the year in the Texas Coastal Plains, the monthly rainfall and snowmelt make it possible for flooding to occur. In the event of flooding of the impoundment and breaching of the embankment during these months, the tailings solution would most likely flow to the major river, where it is expected that the high flow rates would dilute the approximately 5.5×10^7 L (1.4×10^7 gallons) of tailings solutions by several orders of magnitude, depending on the flow rate at the time of flooding. For mills located in the Northern Rocky Mountains, Wyoming Basin, Western Great Plains, Colorado Plateau, and Southern Rocky Mountains region, it is likely that the streams would be dry most of the period November through March. Thus, during these months of the year, it is expected that the tailings solutions released in the event of a tailings embankment failure would tend to move downward through the soil profile and the environmental impact would be similar to that described in Section 7.1.3 for the model site.

In each of the six regions there are most likely to be local problems that reflect the presence of municipal water treatment centers, irrigation uses, or areas of industrial concentrations that need to be evaluated on a case-by-case basis. Furthermore, for the Northern Rocky Mountains, Colorado Plateau, and the Southern Rocky Mountains regions, the radioactive material could be carried by the river to a reservoir where it would be further diluted. Of the isotopes in the tailings slurry, Th-230 would be of primary concern and should be monitored prior to use of the receiving water as a municipal water supply or irrigation water source. It is expected that the NRC or the Agreement State would be notified should a release of tailings slurry occur, and the assessment of the consequences of the accident would be made by the state's radiological emergency assistance team. If a state were unable to respond, the NRC could be requested to provide assistance.

Most of the regions where uranium is milled are in areas of low or moderate seismic risk. When the tailings disposal area is designed, the geologic and seismologic investigations needed would be determined on a site-specific basis in accordance with the provisions of revised Regulatory Guide 3.11.[15] The dynamic stability analysis to be carried out is stipulated in that Guide, which requires that the embankment be designed to withstand an earthquake of greater magnitude than would reasonably be expected to occur in that area.

7.1.6.4 Accidents Not Involving Radioactivity

As discussed in Section 7.1.4, ammonia is the only chemical which might seriously impact the environment in the event of an accident. The consequences of an ammonia release in any of the six regions would not be expected to be significantly different than those for the model site, since the short-term dispersion factors are comparable (see Sec. 7.2.3). Moreover, no factors can be identified that would lead to an increase in the probability of such a release.

7.1.6.5 Transportation Accidents

Transportation of materials to and from mills within each region involves shipment of refined yellowcake to the uranium hexafluoride facility, shipments of ore from the mine pit to the mill, and shipments of process chemicals from suppliers to the mill.

7.1.6.5.1 Shipments of Yellowcake

For the uranium mills in each region, it is assumed that the yellowcake will be packaged and shipped by truck in the same quantities as for the model mill discussed in Section 7.1.5. The probabilities of an accident occurring during shipment of yellowcake to the UF_6 facility from mills located in each of the six regions are given in Table 7.8. The values indicate that for each region the probability of a transportation accident during yellowcake shipments is comparable to that for shipments from the model mill, and varies with the distance of the mill from the UF_6 facility. In the event that the postulated accident occurs on the highway in an area of

low population density or on a highway bridge, the consequences most likely would be the same as those estimated in Section 7.1.5 for the model region. It is possible, however, for such an accident to occur in or close to a city along the route to the UF_6 facility. If the accident were to occur in the largest city on the truck route from the regions in the West to the locations of the two existing UF_6 facilities, and for the worst case (Model I) release fraction, a 50-year population dose commitment of 840 man-rem is computed.

Table 7.8. Accident Probabilities for Shipments of Yellowcake

Region	Distance to Conversion Facility		Probability of Accident	
	Metropolis, IL	Gore, OK	Metropolis, IL	Gore, OK
Model Region	2400 km	1400 km	0.11	0.06
Northern Rocky Mountains	3240 km	2920 km	0.14	0.13
Western Great Plains	1860 km	1600 km	0.08	0.07
Wyoming Basin	2000 km	1630 km	0.09	0.07
Southern Rocky Mountains	1680 km	1180 km	0.07	0.05
Colorado Plateau	2050 km	1575 km	0.09	0.07
Texas Coastal Plains	1420 km	760 km	0.06	0.03

7.1.6.5.2 Shipment of Ore to the Mill

For the model region, it was assumed that the average distance from the uranium mine pit to the mill is about 50 km (32 miles) and that about 29,000 trips per year would be required. In the absence of specific data on the location of the uranium mines and mills in the six NURE regions, it is assumed that the transportation distance is about the same as that for the model mill. Thus, the probability of an ore shipment accident is assumed to be roughly the same as that described for the model site, also, there are no specific environmental factors that could be identified in any of the six regions that would change the estimated consequences discussed in Section 7.1.5.

7.1.6.5.3 Shipments of Chemicals to the Mill

As discussed in Section 7.1.5, if a shipment of anhydrous ammonia to the mill were involved in a severe accident, a significant environmental impact could result. The typical shipping distance to the mills located in each of the six NURE regions is comparable to that assumed for the model site [approximately 400 km (250 miles)]. Therefore, the probability of an ammonia shipment accident in the six NURE regions is not expected to be significantly different than that for the model regions. Moreover, since the short-term dispersion factors in the six NURE regions are comparable to that at the model region (see Sec. 7.3.2), the consequences of an ammonia shipment accident should be similar for all regions and comparable to that in the model region.

7.2 MULTIPLE-MILL SITE

7.2.1 Trivial Accidents Involving Radioactivity

None of the trivial accidents discussed in Section 7.1.1 in connection with the one-mill site are expected to result in the release of radioactivity to the environment. Although more of these incidents might be expected to occur if there were 12 mills, there are no circumstances which can be foreseen that would result in an environmental impact.

7.2.2 Small Releases Involving Radioactivity

The probability of an accident involving small releases of radioactivity from one mill is independent of the likelihood of an accident at any other mill within the region, since the mills would be well separated and the initiating events for the accidents postulated in this category are independent. Therefore, the probability of any of these accidents occurring at the 12-mill site is 12 times larger than the probability of occurrence at a site containing a single mill. The consequences from these small releases are described in the following sections.

7.2.2.1 Failure in the Air Cleaning System Serving the Yellowcake Drying Area

The estimated quantity of yellowcake released to the atmosphere in the event of a catastrophic failure of the scrubber is the same for any one of the 12 model mills on the site. However, the 50-year dose commitment to the lungs of individuals in the nearest residence [2 km to 20 km (1.3 miles to 13 miles)] would range from .09 rem to 0.003 rem, depending upon which mill experienced the failure. The dose commitment to individuals at the fence line and the population dose commitment would be the same as for the one-mill site, regardless of which mill experienced the failure.

7.2.2.2 Fire or Explosion in the Solvent Extraction Circuit

The estimated quantity of uranium released to the atmosphere in the event of a fire or explosion in the solvent extraction circuit is the same for any of the 12 mills on the site. The dose commitment to an individual at the fence line and the population dose commitment would be the same as for the one mill, regardless of which mill experienced the failure. However, the 50-year dose commitment for an individual at the nearest residence [2 to 20 km (1.3 to 13 miles)] would range from 0.15 rem to 0.006 rem to the bone.

7.2.2.3 Gas Explosion in the Yellowcake Drying Operation

The estimated quantity of yellowcake released to the atmosphere in the event of a gas explosion in the yellowcake drying operation is the same for any of the 12 model mills on the site. The dose commitment to an individual and the population dose commitment would be the same as for the single model mill, regardless of which mill experienced the failure. However, the 50-year lung dose commitment for an individual at the nearest residence [2 to 20 km (1.3 to 13 miles)] would range from 6.9×10^{-3} to 2.8×10^{-4} rem.

7.2.3 Large Releases Involving Radioactivity

7.2.3.1 Tornado

It is conceivable that a tornado could pass through the model region and damage from one to five of the 12 operating mills, depending upon the direction of its passage through the region. Sufficient data are not available to estimate the probability of a tornado impacting five mills during a single pass through the region; however, such an event is considered to have a very low probability. Even if this unlikely common mode event were to occur, and the tornado were to lift the same quantity of yellowcake from each mill, the population dose to the lungs of the general population out to a distance of 80 km (50 miles) is estimated to be only 4.8×10^{-3} man-rem.

7.2.3.2 Releases of Tailings Slurry

It is conceivable that a common initiating event, such as a severe flood or a high intensity earthquake, could breach or overtop each of the 12 tailings ponds in the model region, releasing all of the solution contained in the ponds. The quantity of tailings slurry released from each of the 12 mills is assumed to be the same as that postulated for the single model mill, as considered in Section 7.1.3. Although difficult to evaluate quantitatively, the probability of an event occurring of sufficient magnitude to release tailings solution from all 12 ponds is significantly lower than the probability of a single pond release estimated in the previous section.

Middle Reservoir, having a capacity of 1.8×10^7 m^3 (4.7×10^9 gallons) and located about 50 km (32 miles) downstream from the mills, would be the most likely destination of any tailings solution which does not seep into the ground from uranium mills 1-6 and 10-12. West Reservoir, having a capacity of 1.0×10^7 m^3 (2.6×10^9 gallons) and located about 60 km (38 miles) downstream from the mills, would be the most likely destination of any tailings solution from uranium

mills 7, 8 and 9. Under the 100-year flood condition, the flow in Tributary River could reach 100 m^3/s (3500 ft^3/s).

Based on these values, the dilution factors for Middle Reservoir and West Reservoir are 0.017 and 0.018, respectively. The isotopes released would result in a 50-year dose commitment of 0.1 mrem to the maximally exposed individual drinking from the reservoirs in West City. This 50-year dose commitment is not significantly greater than that from drinking water with only background radioactivity present.

7.2.4 Accidents Not Involving Radioactivity

The probability of an accident involving the steam boiler, ventilation system, or tanks of toxic chemicals at the one mill site is independent of the likelihood of an accident at any other mill within the region. The mills are well separated and the initiating events are independent. The potential for environmental effects at the 12-mill site is expected to be small. The consequences described in Section 7.1.4 for a release of anhydrous ammonia would be the same for each mill in the 12-mill site.

7.2.5 Transportation Accidents

Transportation of materials to and from a one-mill site have been conceptualized and analyzed in Section 7.1.5. A postulated transportation accident at one mill is not related to an accident at any other mill within the region, since the mills are well separated and the initiating events are independent.

7.2.5.1 Shipments of Yellowcake

The likelihood of an accident at the one-mill site is 0.11 per year, or 1.3 per year for 12 mills. The consequences are the same as those described in Section 7.1.5.

7.2.5.2 Shipment of Ore to the Mill

The likelihood of an accident at the one-mill site is 0.4 per year, or 5 per year for 12 mills. A collision between two ore trucks on the site can be postulated because of the large number of shipments (approximately 350,000 annually). The consequences of such an event would be twice that of a single truck accident, or approximately 0.05 man-rem to the lungs of the population in the vicinity of the model mill.

7.2.5.3 Shipments of Chemicals to the Mill

The likelihood of an injury to the general public from the shipment of anhydrous ammonia to the one-mill site is estimated to be roughly 5×10^{-3} per year. Consequently, the estimated likelihood is increased to approximately 6×10^{-2} per year for the 12-mill site.

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