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EXTRACTION AND BENEFICIATION OF ORES AND MINERALS

VOLUME 5

URANIUM

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DISCLAIMER AND ACKNOWLEDGEMENTS

This document was prepared by the U.S. Environmental Protection Agency (EPA). The mention of company or product names is not to be considered an endorsement by the U.S. Government or the EPA.

This Technical Resource Document was distributed for review to the U.S. Department of the Interior's Bureau of Mines, the Western Governors Association, the Interstate Mining Compact Commission, the American Mining Congress, and Public Interest Groups. EPA is grateful to all individuals who took the time to review sections of this Technical Resource Document.

Since this document was prepared, and prior to publication, EPA issued final regulations to correct and prevent contamination of groundwater beneath and in the vicinity of inactive uranium processing sites by uranium tailings (60 *Federal Register* 2854, January 11, 1995). These regulations have been included in Appendix C of this document.

The use of the terms "extraction," "beneficiation," and "mineral processing" in the Profile section of this document is not intended to classify any waste streams for the purposes of regulatory interpretation or application. Rather, these terms are used in the context of common industry terminology.

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1.0 MINING INDUSTRY PROFILE: URANIUM

1.1 INTRODUCTION

This Industry Profile presents the results of U.S. Environmental Protection Agency (EPA) research into the domestic uranium mining industry and is one of a series of profiles of major mining industry sectors. Additional profiles describe other industry sectors, including gold, lead/zinc, copper, iron, and several industrial minerals. EPA prepared these profiles to enhance and update its understanding of the mining industry and to support mining program development by states. EPA believes the profiles represent current environmental management practices as described in the literature.

Each profile addresses extraction and beneficiation of ores. The scope of the Resource Conservation and Recovery Act (RCRA) as it applies to mining waste was amended in 1980 when Congress passed the Bevill Amendment, Section 3001(b)(3)(A). The Bevill Amendment states that "solid waste from the extraction, beneficiation, and processing of ores and minerals" is excluded from the definition of hazardous waste under Subtitle C of RCRA (40 CFR 261.4(b)(7)). The exemption was conditional upon EPA's completion of studies required by RCRA Section 8002(f) and (p) on the environmental and health consequences of the disposal and use of these wastes. EPA segregated extraction and beneficiation wastes from processing wastes. EPA submitted the initial results of these studies in the 1985 *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden From Uranium Mining, and Oil Shale* (U.S. EPA 1985). In July 1986, EPA made a regulatory determination that regulation of extraction and beneficiation wastes under Subtitle C was not warranted (51 FR 24496; July 3, 1986). EPA concluded that Subtitle C controls were not appropriate and found that a number of existing Federal and State programs already addressed many of the risks posed by extraction and beneficiation wastes. Instead of regulating extraction and beneficiation wastes as hazardous wastes under Subtitle C, EPA indicated that these wastes should be controlled under Subtitle D of RCRA.

EPA reported their initial findings on mineral processing wastes from studies required by the Bevill Amendment in the 1990 *Report to Congress: Special Wastes From Mineral Processing* (U.S. EPA 1990). This report covered 20 specific mineral processing wastes; none involved uranium processing wastes. In June 1991, EPA issued a regulatory determination (56 FR 27300) stating that regulation of these 20 mineral processing wastes as hazardous wastes under RCRA Subtitle C is inappropriate or infeasible. These 20 wastes are subject to applicable state requirements. Any mineral processing wastes not specifically included in this list of 20 wastes no longer qualifies for the exclusion (54 FR 36592).

In addition to preparing profiles, EPA has undertaken a variety of activities to support state mine waste programs. These activities include visits to a number of mine sites; compilation of data from State regulatory agencies on waste characteristics, releases, and environmental effects; preparing summaries of mining-related sites on the Superfund National Priorities List (NPL); and an examination of specific waste management

practices and technologies. EPA has also conducted studies of State mining-related regulatory programs and their implementation.

The purpose of this report is to provide additional information on the domestic uranium mining industry. It should be noted that the uranium industry has been depressed since the early 1980s and that the extent of current operations is limited. The report describes current uranium extraction and beneficiation operations with specific reference to the wastes associated with these operations. It also refers to activities and impacts documented when the uranium mining industry was more active. The report is based on reviews of literature and a limited number of State documents. This report complements, but was developed independently of, other EPA activities, including those described above. Uranium processing wastes are not addressed in this profile.

This report briefly characterizes the geology of uranium ores and the economics of the industry. Following this discussion is a review of uranium extraction and beneficiation methods; this section provides the context for descriptions of wastes and materials managed by the industry, as well as a discussion of the potential environmental effects that may result from uranium extraction and beneficiation. The report concludes with a description of regulatory programs that apply to the uranium mining industry as implemented by EPA, Federal land management agencies, and selected states.

1.2 ECONOMIC CHARACTERIZATION OF THE URANIUM INDUSTRY

The primary demand for uranium is by commercial power generating facilities for use in fuel rods. Prior to 1942, its primary uses were as a coloring agent in glass manufacturing and in the production of certain copper, nickel and steel alloys. After the start of World War II, the U.S. began stockpiling uranium principally for the development of atomic weapons (EIA/DOE, 1991).

In 1946, the Atomic Energy Act (AEA) established the Atomic Energy Commission (AEC) as the sole purchasing agent for domestically produced uranium. The AEA also set fixed prices for uranium ore and provided incentives including access roads, haulage allowances, and buying stations in an effort to bolster development within the domestic uranium mining industry. The AEC acted as the sole purchasing agent for uranium from 1948 through 1970. Since the end of the Federal buying program in 1970, private entities have handled sales of uranium between producers and consumers.

The industry slowed in the late 1960s as a result of the a slowdown of the Federal procurement program which terminated in 1970. Uranium production in the early 1970s remained steady as commercial markets began to emerge. The industry was revitalized shortly thereafter by the prospect of supplying fuel to the developing commercial nuclear power industry. Production and prices peaked in the early 1980s, the same time period when planning and construction of new commercial nuclear power plants came to a halt (EIA/DOE, 1992). Domestic raw ore production figures since 1950 are presented in Figure 1

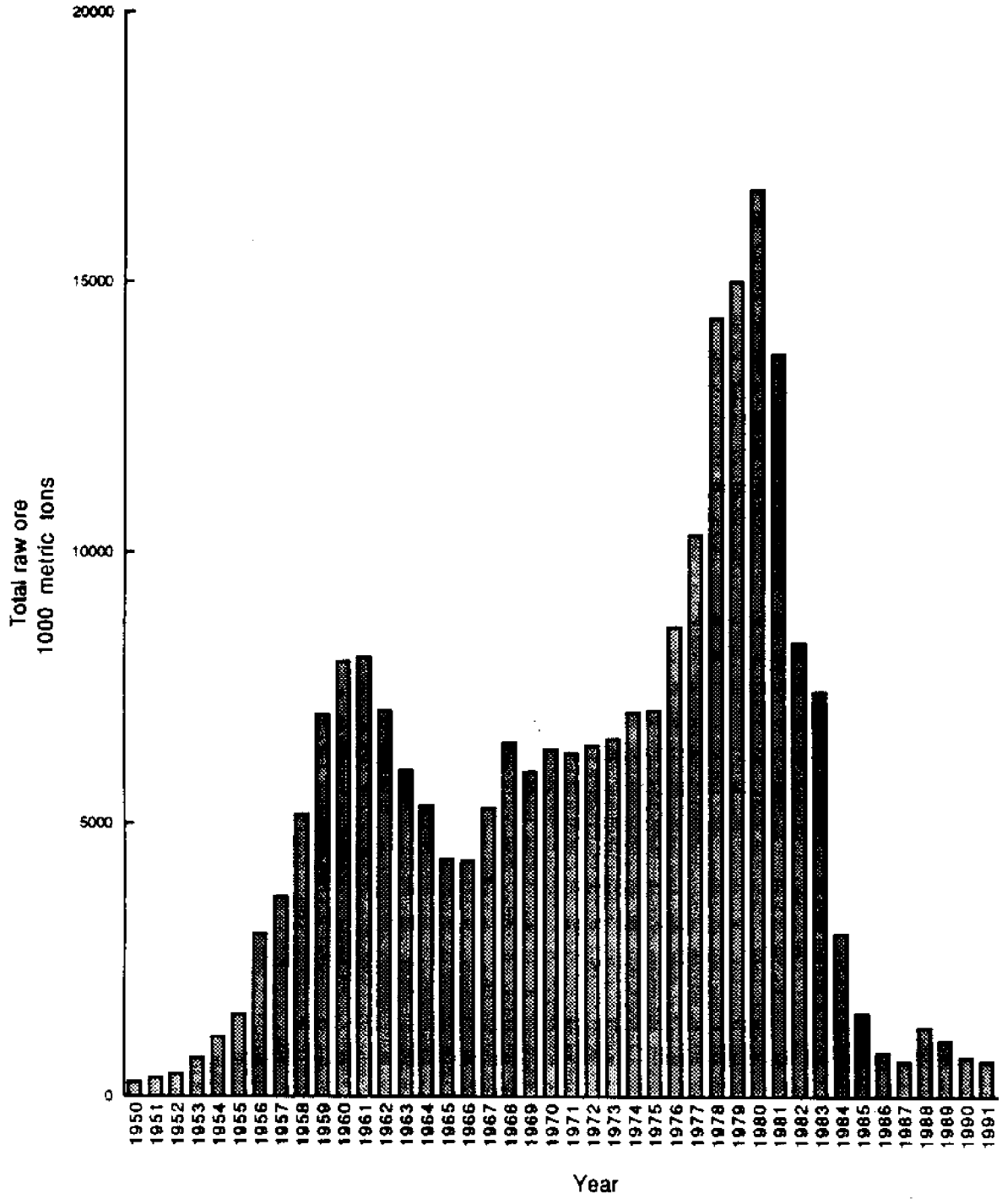

Figure 1-1. Domestic Raw Ore Production–1950 through 1991

(Source: DOE/EIA, 1992)

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In the uranium market, references to ore, intermediate, and some final products, are in terms of percent of uranium oxide or uranium oxide equivalent. Uranium oxide is a generic term for a number of common chemical forms of uranium, the most common being U_3O_8. Yellowcake is another generic term, used to describe the yellow powder generated as the end product of uranium beneficiation. The purity of yellowcake typically ranges from 60 to 75 percent U_3O_8 (Merritt, 1971). A discussion of the different chemical forms of yellowcake is provided in the Extraction and Beneficiation section of this document.

Uranium is sold to commercial utilities in the U.S. by both domestic and foreign suppliers. Government stockpiles supply at least a portion of the uranium required by the defense industry. Suppliers derive their sources from operational mines, natural grade uranium stockpiles (as opposed to the processed, enriched form used as the component of fuel rods) and foreign sources. Domestic suppliers delivered 11,125 metric tons of U_3O_8 equivalent to domestic utilities in 1991; commercial mills in the U.S. provided 3,600 metric tons while suppliers imported almost 2,600 metric tons. Most of the remaining 4,900 metric tons of U_3O_8 equivalent supplied to domestic utilities came from commercial stockpiles. Domestic utilities directly imported an additional 6,400 metric tons of U_3O_8 equivalent in 1991 (EIA/DOE, 1992).

Commercial inventories of U_3O_8 equivalent held in the United States at the end of 1991 stood at over 55,500 metric tons. The Federal government held approximately 21,250 metric tons while the remainder was held by utilities and domestic suppliers (DOE/EIA, 1992).

Uranium mines within the United States produced 522 metric tons (1.4 million pounds) of U_3O_8 equivalent in 1992. Production figures from 1992 indicate a drop of over 70 percent from 1991 levels and the lowest level of production since 1951 (see Figure 1). Uranium prices as well as production are down. In 1992, the average price per pound of uranium oxide equivalent was $8.70, down from an average of $13.66 in 1991 (DOE/EIA, 1993).

In 1981, the United States produced nearly 14,800 metric tons of U_3O_8 equivalent at an average price of over $34 per pound. At the time, the uranium industry reported an employment figure of 13,676 person-years. U_3O_8 equivalent production in 1991 was approximately 3,600 metric tons sold at an average price of $13.66 per pound. The 1992 employment figure of 682 person-years reflects the current trend in production and prices. The EIA reports that in 1992, 51 person-years were expended in exploration, 219 in mining activities, 129 in milling operations and 283 in processing facilities. (DOE/EIA, 1992, 1993).

Uranium has primarily been mined in the western United States; Arizona, Colorado, New Mexico, South Dakota, Texas, Utah, Washington and Wyoming. A total of 17 uranium mines were operational in 1992; five conventional mines (both underground and open pits), four *in situ*, and eight reported as "other" (heap leach, mine water, mill tailings, or low-grade stockpiles). Uranium was also produced to a limited extent as a byproduct of phosphoric acid production at four sites (DOE/EIA, 1993). Figure 2

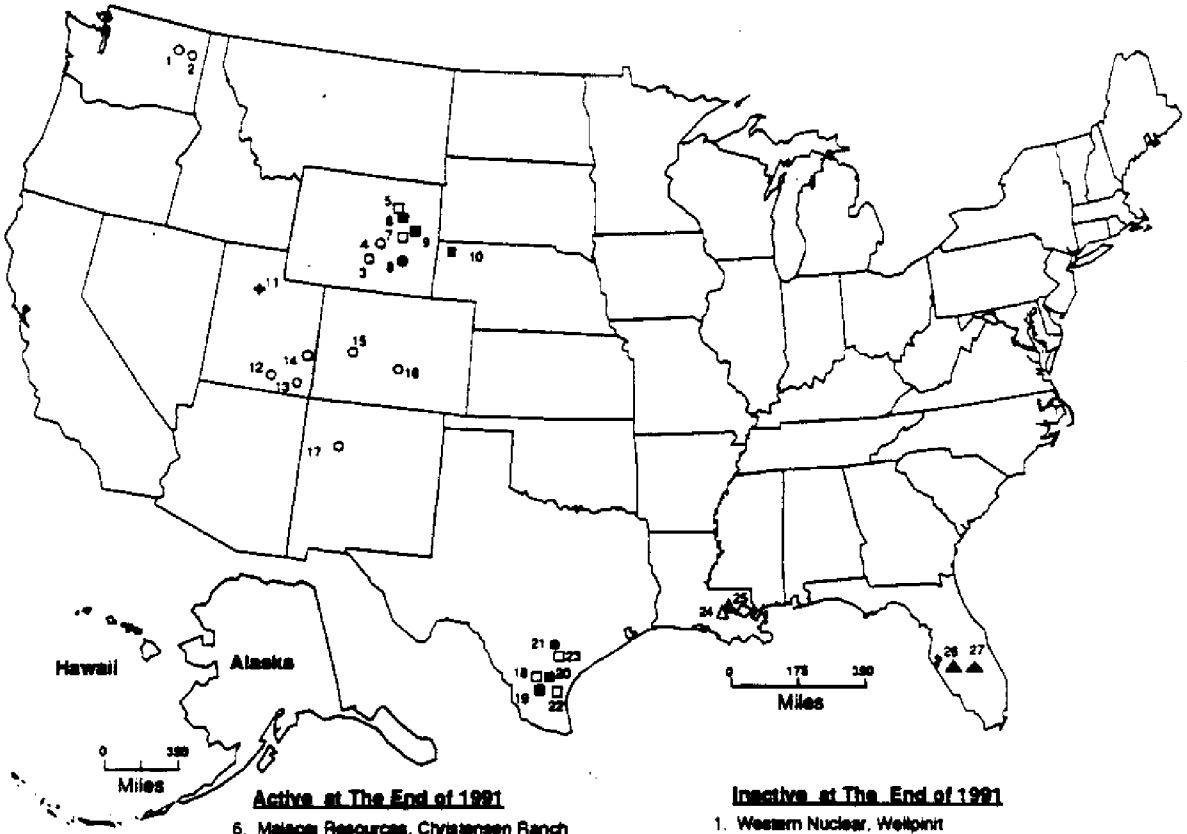


Figure 1-2. Location of Active and Inactive Milling Operations in the U.S. as of 1991

(Source: DOE, 1991)

illustrates the location of operational (operational in this case includes active and inactive mines and mills but not decommissioned mills nor closed (reclaimed) mines) mines and mills in the U.S. in 1991. (DOE/EIA, 1992)

Total milling capacity for active and inactive conventional mills in 1991 was 14,550 tons per day (tpd) of ore (the type of tons was not defined). As of 1991, the two active mills (Hobson, Texas and Shirley Basin, Wyoming) had the capacity to handle a total of 4,800 tpd yet, the total daily feed averaged 1,920 tpd. The average grade of ores processed in 1991 was 0.198 percent uranium oxide (USGS, 1990; DOE/EIA, 1991; DOE/EIA, 1992). These two active mills closed during 1992 and are currently being dismantled.

The percentage of U_3O_8 equivalent produced by conventional and other mills by State is difficult to determine. Texas was the largest producer of U_3O_8 equivalent in 1991 producing 1,063 metric tons of yellowcake. Wyoming, the second largest domestic producer, produced 1,017 metric tons. Production of U_3O_8 equivalent from Arizona, Florida, Louisiana, Nebraska, New Mexico, South Dakota, and Washington combined totalled nearly 2,850 metric tons in 1991 (DOE/EIA, 1992).

As part of the annual viability assessment of the domestic uranium mining and milling industry required by 10 CFR 761, the Secretary of Energy has declared the uranium mining and milling industry nonviable annually from 1984 through 1991 (DOE/EIA, 1992a). (A definition of viability was not provided in the report nor 10 CFR 761). A 1992 summary of various mineral markets published in the Engineering and Mining Journal (E&MJ) noted that the industry remained depressed with large inventories and low prices. The report also indicated that the Cigar Lake project in Canada, with ore reserves capable of supplying most of the uranium needs in the Western Hemisphere, was scheduled to begin production in the near future (Grisafe, 1992). (The ore grade at Cigar Lake is approximately eight percent uranium oxide.)

Projections of spot-market demand versus production (under 1992 conditions) indicate the continuation of a depressed market with demand and production near current levels through the year 2000 (DOE/EIA, 1993).

1.3 ORE CHARACTERIZATION

In order to understand the operations used to mine and concentrate uranium, it is necessary to discuss the chemical and physical make-up of uranium ores. Understanding the characteristics of uranium ore and their host rocks also provides insight into the type of waste products that may be produced as a result of specific mining or beneficiation techniques. This section presents a brief description of the geochemistry of uranium minerals and the genesis and physical characteristics of different types of uranium ore bodies found in the United States.

1.3.1 Chemical Characterization

The element uranium is generally found in naturally occurring minerals in one of two ionic states: U^{6+} (the uranyl "oxidized" ion) and U^{4+} (the uranous "reduced" ion). Minerals containing the uranyl ion tend to be brightly colored (red, yellow, orange and green) and occur in oxidized portions of uranium ore deposits. Common uranyl minerals include tyuyamunite ($Ca(UO_2)_2V_2O_8 \cdot 8H_2O$), autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$), torbernite ($Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$) and uranophane ($(H_3O)_2Ca(UO_2)_2(SiO_4)_2 \cdot 3H_2O$) (Smith, 1984; Hutchinson and Blackwell, 1984). Minerals containing the uranous ion are more subdued in color, typically brown or black, and occur in reducing environments. Common uranous minerals include uraninite (UO_2), pitchblende (a crystalline variant of uraninite) and coffinite ($USiO_4$) (Smith, 1984; Hutchinson and Blackwell, 1984). Uranium occurs in the minerals as one of three isotopes: U-234, U-235 and the most abundant of the isotopes, U-238 (Tatsch, 1976).

1.3.2 Types of Uranium Deposits

Economically recoverable uranium deposits in the United States generally fit into one of four types of deposits: stratabound, solution breccia pipes, vein, and phosphatic. Figure 3

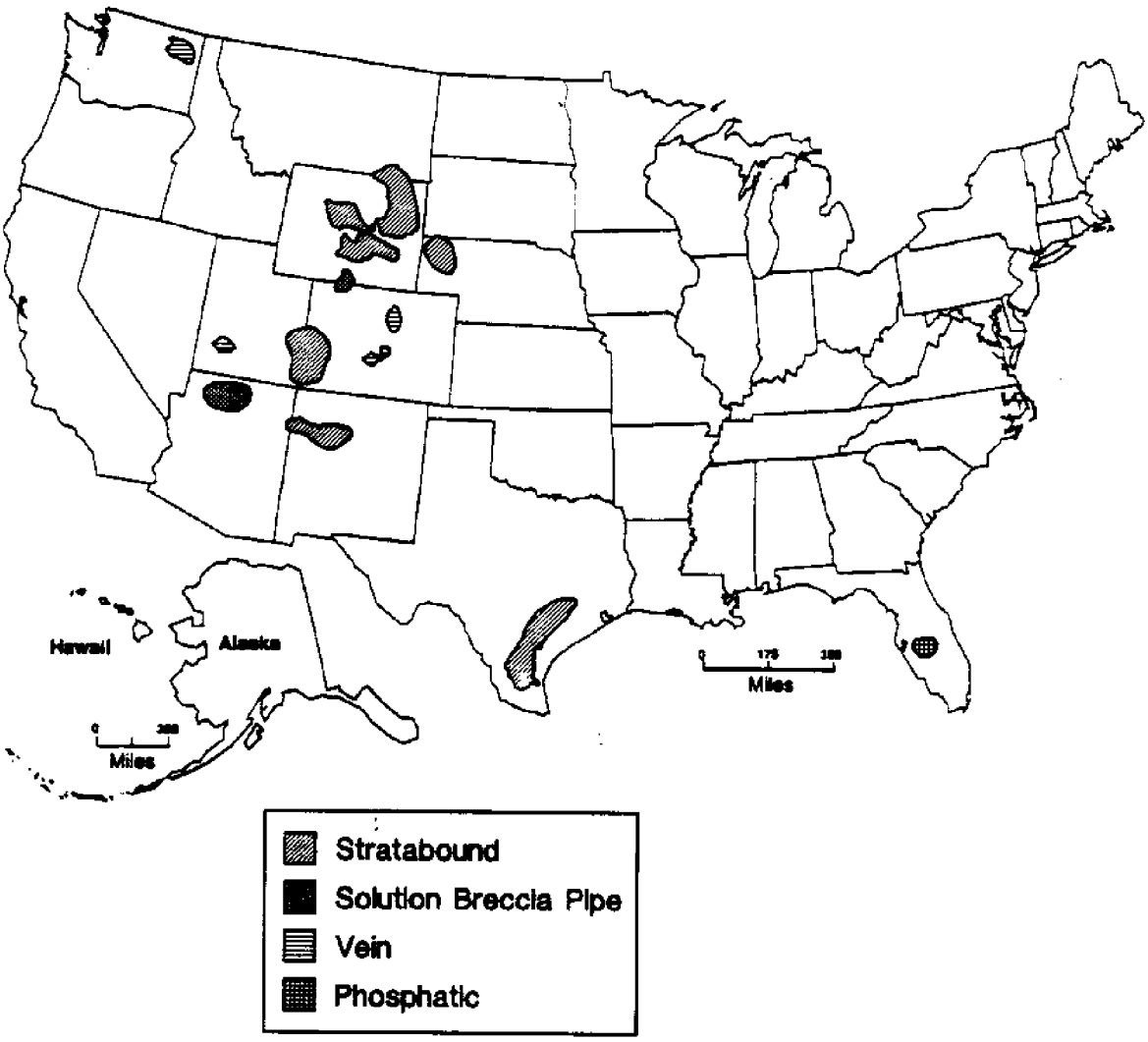


Figure 1-3. Location of the Four Types of Uranium Deposits Found in the U.S.

(Source: DOE, 1991)

depicts the general geographic location of these four types of uranium deposits within the United States. Forty percent of the world's uranium reserves occur in the stratabound uranium deposits in the western United States. These reserves account for more than ninety percent of the U.S. production of uranium and vanadium (an element that is often present in uranium minerals as well as in accessory minerals) (Guilbert and Park, 1985).

1.3.2.1 Stratabound

Stratabound is a term used to describe ore deposits that are contained within a single layer of sedimentary rock. In the United States, stratabound uranium ores are found in three major geographic areas: the Wyoming Basin, south Texas, and the Colorado Plateau. Grades of ore mined from these deposits range from 0.15 to 0.30 percent U_3O_8.

The ore is found in bodies ranging in size from two tons to more than 10 million tons. Several of these bodies may make up one uranium deposit (Tatsch, 1976).

The current theory on the genesis of stratabound uranium orebodies proposes that they formed through the transport of uranium (and associated elements) by oxidizing groundwater. Groundwater flowed through uranium-containing rocks or sediments, leaching uranium from the rock through the oxidation of U^{4+} to U^{6+}. The U^{6+} ion is soluble in groundwater as one of many different uranyl complex ions. These uranium ions remained in solution until they encountered and moved through a reducing environment. There the uranyl ions were reduced and a uranous mineral, such as uraninite, was precipitated.

The uranium deposits of the Wyoming Basin and south Texas are known as "roll-front" deposits, a uranium ore-body deposited at the interface of oxidizing and reducing groundwaters. These deposits are found in permeable sandstone beds that are generally interbedded with silty claystones or shales. Tongues of oxidizing groundwater containing uranium (vanadium, molybdenum, selenium, and sulfur may also be present) in solution flowed through the sandstone beds until reducing groundwater was reached. Precipitation of the uraninite and accessory minerals occurred at the interface of the oxidized fluids and the reducing environment. A zonation of mineralization is typically noted in these deposits; pyrite and calcite are found at the leading edge of the interface, pyrite and uraninite in the ore-zone and siderite ($FeCO_3$), goethite ($FeO{\cdot}OH$) and hematite (Fe_2O_3) on the trailing edge. The deposits display a crescent shape in plan view, resulting from the configuration of the interface between the tongues of oxidizing groundwater and reducing groundwater. As the interface of the oxidizing and reducing environments migrated, the uranous minerals were deposited over a laterally extended area. The roll-front ore bodies may only be a few meters in height, but may extend over a hundred meters in length. These deposits are particularly well suited for *in situ* solution mining techniques (see Beneficiation section) due to the high permeability of the host sandstones and their generally shallow depths (Guilbert and Park, 1985; Texas Department of Water Resources, 1984).

The Salt Wash uranium-vanadium deposits of the Colorado Plateau (includes the Uravan Mineral Belt in Colorado and Utah) were formed when uranium- and vanadium-enriched groundwater flowed through zones

of high permeability containing solids (organic matter), gases (hydrogen sulfide), or liquids capable of reducing the uranyl ion. The uranium and vanadium minerals were deposited in the areas where these substances created reducing environments. The deposits are generally tabular shaped and are found in sandstones, limestones, siltstones and conglomerates scattered throughout western Colorado, eastern Utah, northeastern Arizona and northwestern New Mexico. Grades of these deposits range from 0.16 percent to 0.25 percent U_3O_8. Significant vanadium is also associated with these deposits, which grades about one percent V_2O_5. Other metals associated with these deposits are copper, silver, selenium, molybdenum, chromium, lead, zinc, arsenic, cobalt and nickel. Although the primary ore minerals associated with these deposits are the reduced minerals pitchblende and coffinite, the brightly colored weathering products of these two minerals are also present, the oxidized uranium and vanadium minerals tyuyamunite, carnotite, and montroseite (Guilbert and Park, 1985).

The humate uranium deposits of the Colorado Plateau (located in northwestern New Mexico and known as the Grants Mineral Belt) have provided over 50 percent of the total U.S. uranium production. These deposits occur in sandstones, arkoses and siltstones of the Morrison Formation. The uranium is found associated with tabular layers of organic matter (humates) averaging 0.5 to two meters thick and up to hundreds of meters across. The uranium ore contains the minerals uraninite and coffinite and an organo-uraniferous mineraloid. These compounds coat sand grains, and fill pore spaces and fractures. Locally, some younger oxidizing "roll fronts" have advanced through the uraniferous humate deposits and redistributed the uranium into the characteristic roll-front deposit (Guilbert and Parker, 1985).

1.3.2.2 Solution Breccia Pipes

Solution breccia pipe uranium deposits occur in the Arizona Strip, an area of northern Arizona known for high grade uranium deposits. Between 1980 and 1992, seven mines in the Arizona Strip produced in excess of 19 million pounds of uranium ore averaging 0.64 percent U-238. (Pillmore, 1992). No production figures were available for uranium ores mined prior to 1980.

These solution breccia pipes (not to be confused with breccia pipes of volcanic origin) were created by the flow of groundwater through limestones. The neutral to acidic groundwater began to dissolve the limestone along areas of weakness in the rock. As the dissolution progressed, large cavities formed in the limestone units. The overlying units, no longer supported by the underlying limestone, progressively collapsed into the cavities. This progressive collapse of the overlying units resulted in cylindrical columns of broken rock (commonly referred to as solution breccia pipes). Many of these structures extend a vertical distance of more than 2,000 feet and may reach 250 feet in width (Verbeek, Grout and Gosen, 1988; Pillmore, 1992).

The solution breccia pipes became preferential pathways for fluids as a result of their increased permeability. Sometime after pipe formation, hydrothermal fluids circulated in the pipes and in fractures surrounding the pipes, depositing uranous minerals in the presence of reducing solids (ferrous iron, sulfides or organic matter) or liquids. The source of these hydrothermal solutions and the uranium contained in them is currently open to debate.

Uraninite or pitchblende coats quartz grains and fills small cavities (vugs) in many of the pipes. A variety of copper, iron, zinc and lead sulfides are also found in what appears to be deposition contemporaneous with the uraninite. Following the hydrothermal phase, many of the ore minerals deposited in the pipes were chemically altered as the geological environment changed. Oxidizing, low temperature groundwater migrated thorough the pipes and oxidized the primary uranium ores to tyuyamunite, uranophane, torbernite and other uranyl uranium minerals. Copper and zinc sulfides were altered to carbonate, sulfate and hydrous silicate compounds. In some pipes, this alteration is nearly complete, eliminating all traces of the primary mineral assemblages. Many of these deposits

have been exploited through underground mining methods (Verbeek, Grout, Van Gosen, 1988 and Rich, Holland and Peterson, 1977).

1.3.2.3 Vein Deposits

Uranium vein deposits are formed by the migration of hydrothermal solutions through faults and fractures at moderate temperatures (100 to 300°C) and pressures. As geochemical changes occur in the solutions, pitchblende and other uranium minerals are precipitated in the veins. In addition to the uranium minerals, the vein may also contain many different types of minerals. These accessory minerals may contain any number of metals, including copper, lead, iron and zinc.

Vein deposits of uranium ore may be found in any type of host rock: sedimentary, metamorphic or igneous. Most uranium vein deposits in the U.S. have been relatively unimportant in U.S. production (Rick, Holland and Petersen, 1977). Exceptions to this are the Schwartzwalder mine in Colorado, the Marysvale District in Utah and the Midnite mine in Washington. A current accounting of the total U.S. uranium production originating from vein deposits was not available.

1.3.2.4 Phosphatic

Uranium was extracted to a limited extent, from the phosphate ores of central Florida until recently. In these ores, uranium is a trace constituent of apatite ($Ca_5(PO_4)$), the primary mineral in phosphate deposits. The uranous ion ($U^{4+)}$ substitutes for calcium in the crystalline structure of apatite and a small amount of U^{6+} may be adsorbed onto the mineral surface. (USGS, 1990)

The central Florida phosphate deposits contain uranium concentrations ranging from 90 ppm to 150 ppm in phosphate pellets, the main form of phosphate ore. The uranium was deposited at the same time as the apatite and not as a secondary replacement of the calcium. Secondary enrichment of uranium has occurred in some areas of the phosphate district as a result of leaching by acidic groundwater. As acidic water percolates through the phosphate rock, uranium and apatite are dissolved and transported to a geochemical environment favorable for precipitation. This process secondarily concentrates uranium (up to 1,000 ppm) and apatite (USGS, 1990). Uranium was recovered from the apatite during the manufacture of phosphoric acid. In 1988, two phosphoric acid manufacturing plants recovered about two million pounds of U_3O_8 (21 percent of U.S. production for 1988) from the phosphate rock mined in Florida (USGS, 1990). These operations are now closed.

1.4 URANIUM MINING PRACTICES

The major operational steps in producing commercial uranium products fall into three broad categories: extraction, beneficiation and processing. Extraction involves the removal of ore from a deposit and includes all steps prior to beneficiation. Beneficiation includes the crushing, grinding, leaching of the ore; it also includes concentration and subsequent precipitation of the uraniferous compounds. During the last stage of beneficiation the precipitated yellowcake is washed, dried and packaged for shipment. Typically, yellowcake is shipped to a Federal facility for processing. In the processing step, uranium fluoride (UF_6) is produced from yellowcake. The uranium fluoride is then enriched, an operation that concentrates the U-235 from a concentration of 0.7 percent to approximately two to three percent. The enriched uranium fluoride is further refined to ultimately produce the fuel rods used in nuclear reactors. The terms extraction and beneficiation, for the purposes of this report, are used in the broadest sense and discussions herein should not be construed for regulatory purposes for any specific waste. Extraction and beneficiation methods are discussed further in this section; uranium processing is beyond the scope of the report. A discussion of the wastes generated during each phase of mining and beneficiation is presented in the next chapter.

1.4.1 Extraction

Uranium is typically mined using one of three techniques: surface (open pit), underground, or solution mining. (Solution mining is discussed below in the Beneficiation section). The method of extraction is dependent on the grade, size, location, and geology of the deposit and is based on maximizing ore recovery within economic constraints. A low-grade cutoff point is established on a site-specific basis and depends on recovery costs at the site, the market price of the ore, and feed requirements at the mill. A survey conducted in 1986 indicated that low-grade cutoff values ranged from 0.01 to 0.3 percent U_3O_8 (USEPA, 1986).

Unlike operations in many other mineral sectors, uranium ore production levels from open pit and underground mines were approximately equal for the period of 1978 through 1985 (see Figure 4

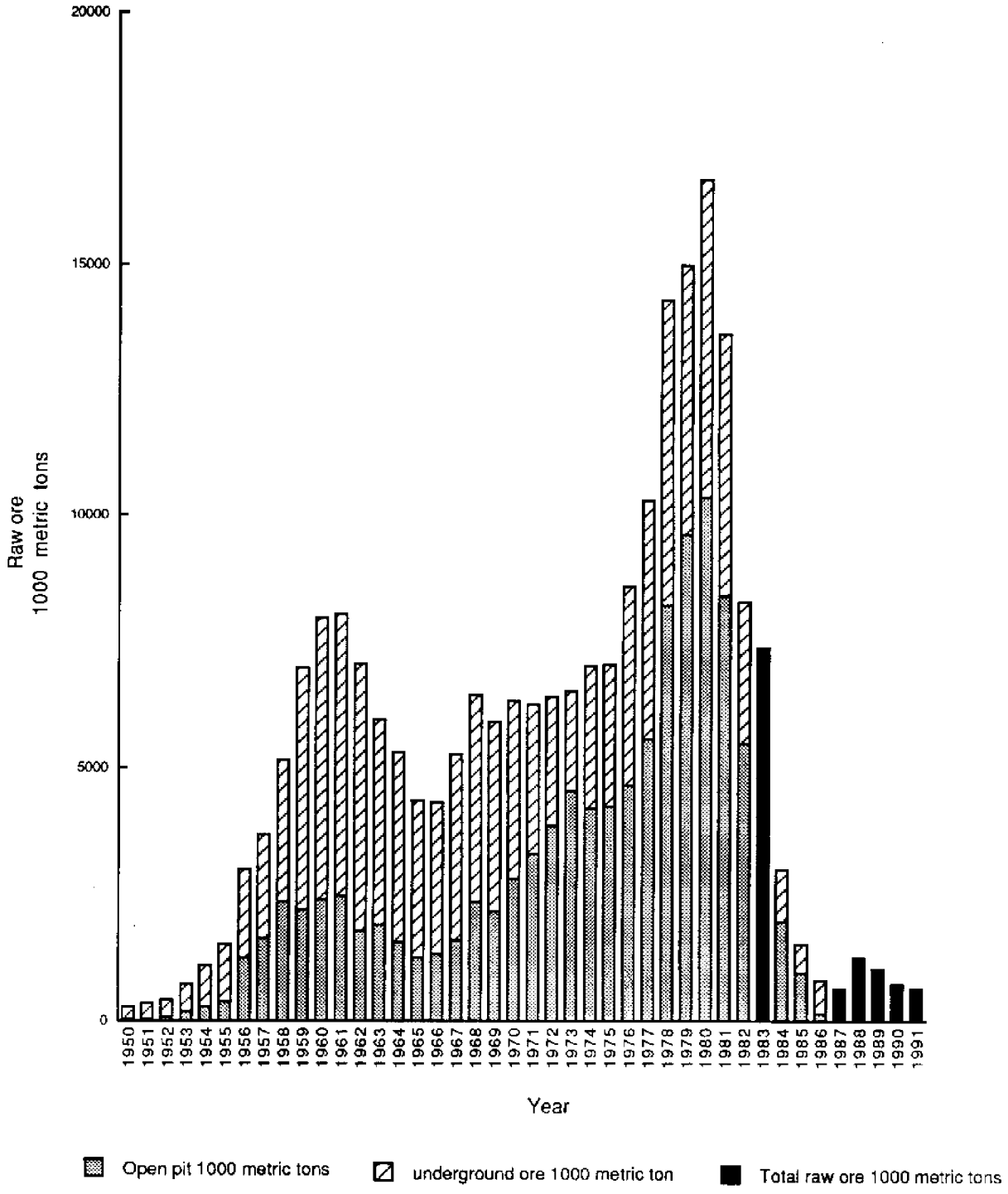


Figure 1-4. Raw Ore Production from Open Pit and Underground Uranium Mines–1950 to 1991

(Source: DOE/EIA, 1992)

Production figures since 1985 have been withheld as proprietary information, so, more recent comparisons between the two methods were not possible (EIA/DOE, 1991). It is likely that as the price of uranium declines, more costly methods of mining, such as underground, have become less economically feasible.

1.4.1.1 Open Pit Mining

Open pit mining techniques are employed to exploit ore deposits relatively close to the surface of the earth. Topsoil is typically removed separately and stockpiled. Overburden, the material overlying the deposit is removed using scrapers or with trucks and loaders or mechanical shovels.

Depending on the extent of consolidation, the overburden may be ripped with bulldozers or blasted prior to removal. Overburden may be stockpiled outside the pit or placed in mined out portions of the pit once pit development has progressed to an acceptable point. Mining economics typically require that overburden haulage be minimized. Once the ore body is exposed, it is ripped, loaded into trucks, and trucked to an onsite stockpile. The ore can then be moved from the stockpile to the mill site as required.

The depth to which an ore body is mined depends on the ore grade, nature of the overburden, and the stripping ratio. Stripping ratios describe the amount of overburden that must be removed to extract one unit of ore. One report indicates that stripping ratios for open pit uranium mines range from 10:1 to 80:1 with an average of around 30:1 (USEPA, 1983b Vol 2). Stripping ratios at open pit mines currently in operation were not available. The primary advantage of surface mining is the ability to move large amounts of material at a relatively low cost, in comparison with underground operations.

1.4.1.2 Underground Mining

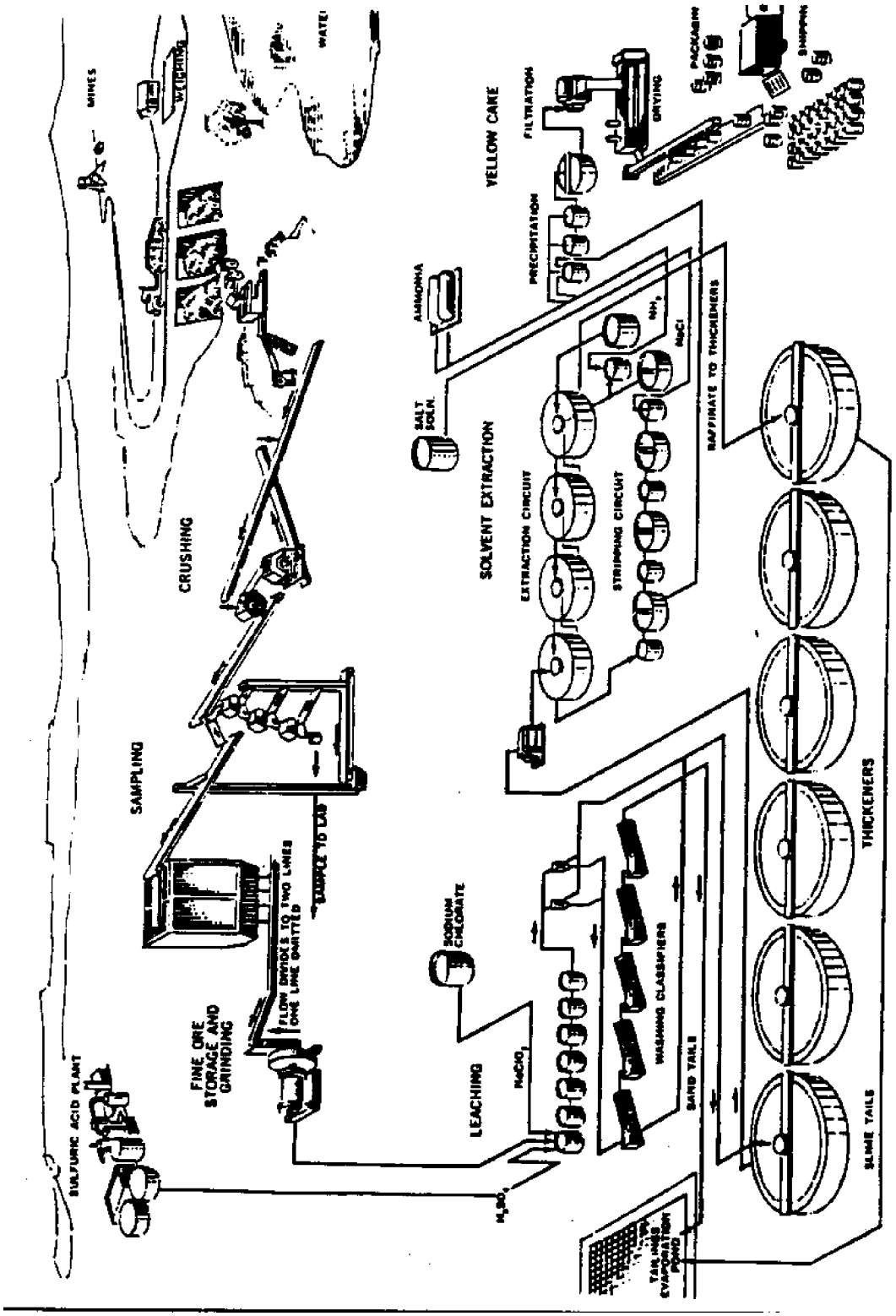
A variety of techniques are employed in underground operations depending on the distribution and orientation of the ore deposit. In general, underground mining involves sinking a shaft (or driving an adit) near the ore body to be mined and extending levels from the main shaft at various depths to the ore. Shafts, adits, drifts and cross-cuts, are developed to access and remove the ore body. Levels and adits often slope slightly upward away from the main shaft to encourage positive drainage of any water seeping into the mine. Ore and development rock, the non-ore bearing material generated during mining, may be removed either through shaft conveyances or chutes, and hoisted in skips (elevators) to the surface or used to backfill mined out areas. Ore is placed in stockpiles while development rock brought to the surface is placed in waste rock. As underground mining techniques are able to leave much of the non-ore bearing material in place, the ratio of waste (development) rock to ore is much lower than stripping ratios in open pit mines. Ratios of waste rock to ore range from 1:1.5 to 1:16 (USEPA, 1983b Vol 2). In shallow underground mines, ore and waste rock may be brought to the surfaced by train or conveyor belt. Often, mining progresses from the edge of the ore deposit or property line toward the main shaft (USDOI, 1980).

As with surface mining operations, ores and sub-grade ores may be stockpiled on the surface. These materials may be beneficiated as market conditions allow or left with mine development rock in waste rock piles.

1.4.2 Beneficiation

Beneficiation of ores and minerals is referenced in 40 CFR 261.4(b)(7) as being the following: crushing; grinding; washing; dissolution; crystallization; filtration; sorting; sizing; drying; sintering; pelletizing; briquetting, calcining to remove water and/or carbon dioxide; roasting; autoclaving, and/or chlorination in preparation for leaching (except where the roasting (and/or autoclaving and/or chlorination)/leaching sequence produces a final or intermediate product that does not undergo further beneficiation or processing); gravity concentration; magnetic separation; electrostatic separation; flotation; ion exchange; solvent extraction; electrowinning; precipitation; amalgamation; and heap, dump, tank, and *in situ* leaching. Beneficiation of conventionally mined ores in the uranium industry involves crushing and grinding the extracted ores followed by a leaching circuit. *In situ* operations bypass the extraction step and perform the leaching step using a leach solution to dissolve desirable metals from deposits in-place. The uranium, in this case, is brought to the surface in solution. Uranium in either case is removed from pregnant leach liquor and concentrated using solvent extraction or ion exchange techniques and precipitated to form yellowcake. Prior to 1980, approximately 90 percent of yellowcake production came from conventional mills; as of 1991, yellowcake production from conventional mills and *in situ* operations is close to equal (USDOI, 1980; DOE/EIA, 1992).

Uranium mills have typically been associated with specific mines or functioned as custom mills, serving a number of mines. The two mills that operated in 1991 closed in 1992 and are in the process of being decommissioned (Stephenson, 1993). The specific circuits employed by those mills for beneficiation, prior to their closure, were not determined. Most available information on milling operations were written when a dozen or more were operational, therefore the following discussions may not precisely describe milling activities being conducted at present. Figure 5


MINES
WATER
CRUSHING
SAMPLING
FINE ORE STORAGE AND GRINDING
SULFURIC ACID PLANT
LEACHING
SODIUM CHLORATE
SOLVENT EXTRACTION
EXTRACTION CIRCUIT
STRIPPING CIRCUIT
AMMONIA
SALT SOLN.
PRECIPITATION
FILTRATION
DRYING
YELLOW CAKE
RAFFINATE TO THICKENERS
WASHING CLASSIFIERS
SAND TAILS
SLIME TAILS
THICKENERS

illustrates operations at a typical conventional mill.

The chemical nature of the ore determines the type of leach circuit required and, in turn, the extent of grinding. Most ores are ground to approximately 28 mesh and acid-leached. Ores containing greater than 12 percent limestone require finer grinding (200 mesh) and are leached with an alkaline solution. Mills may use one type of circuit or the other although in the past, some mills maintained both acid and alkaline leach circuits. Solvent extraction or ion exchange circuits can be used to concentrate the uraniferous compounds from either of the leach circuits (USEPA, 1983a; USDOI, 1980).

The literature indicates that solvent exchange was employed more frequently in conventional milling operations than ion exchange. Where ion exchange was employed by conventional mills, it appears to have been conducted as a resin-in-pulp operation rather than using columns. *In situ* operations usually employ ion exchange columns for concentration of the uraniferous compounds.

Some limitations of ion exchange columns are the inability to treat solutions with solids and the finite life of the fixed resins. Ion exchange is effective for *in situ* operations because of the relative ease with which resin columns can be transported from satellite areas to a centralized uranium stripping/precipitation facility.

Conventional Milling

Crushing and Grinding

The initial step in conventional milling involves crushing, grinding, and wet and/or dry classification of the crude ore to produce uniformly sized particles. A primary crusher, such as a jaw type, is used to reduce ore into particles less than 150 millimeters (about 6 inches) in diameter. Generally, crushing continues using a cone crusher and an internal sizing screen until the ore has a diameter less than 19 mm (3/4 inch). Crushing in jaw and cone crushers is a dry process, with water spray applied only to control dust. Ore feeds from the cone crusher to the grinding circuit where ball and/or rod mills, and/or autogenous or semiautogenous grinding, continue to reduce the size of the ore. Water or leach liquor is added to the system in the grinding circuit to facilitate the movement of the solids, for dust control, and (if leach liquor is added) to initiate leaching (USDOI, 1980).

Classifiers, thickeners, cyclones or screens are used to size the finely ground ore, returning coarse materials for additional grinding. The slurry generated in the grinding circuit contains 50 to 65 percent solids. Fugitive dust generated during crushing and grinding is usually controlled by water sprays or, if collected by air pollution control devices, recirculated into the beneficiation circuit. Water is typically recirculated through the milling circuit to reduce consumption (USEPA, 1983a).

Leaching

After grinding, the slurry is pumped to a series of tanks for leaching. Leaching is defined as dissolving metals or minerals out of ore (USDOI, 1968). Two types of leaching have been employed by uranium mills, acid and alkaline. Acid leaching had been the predominant leaching process employed by conventional mills although the methods in use at the two mills operating in 1991 were not determined. Figure 6

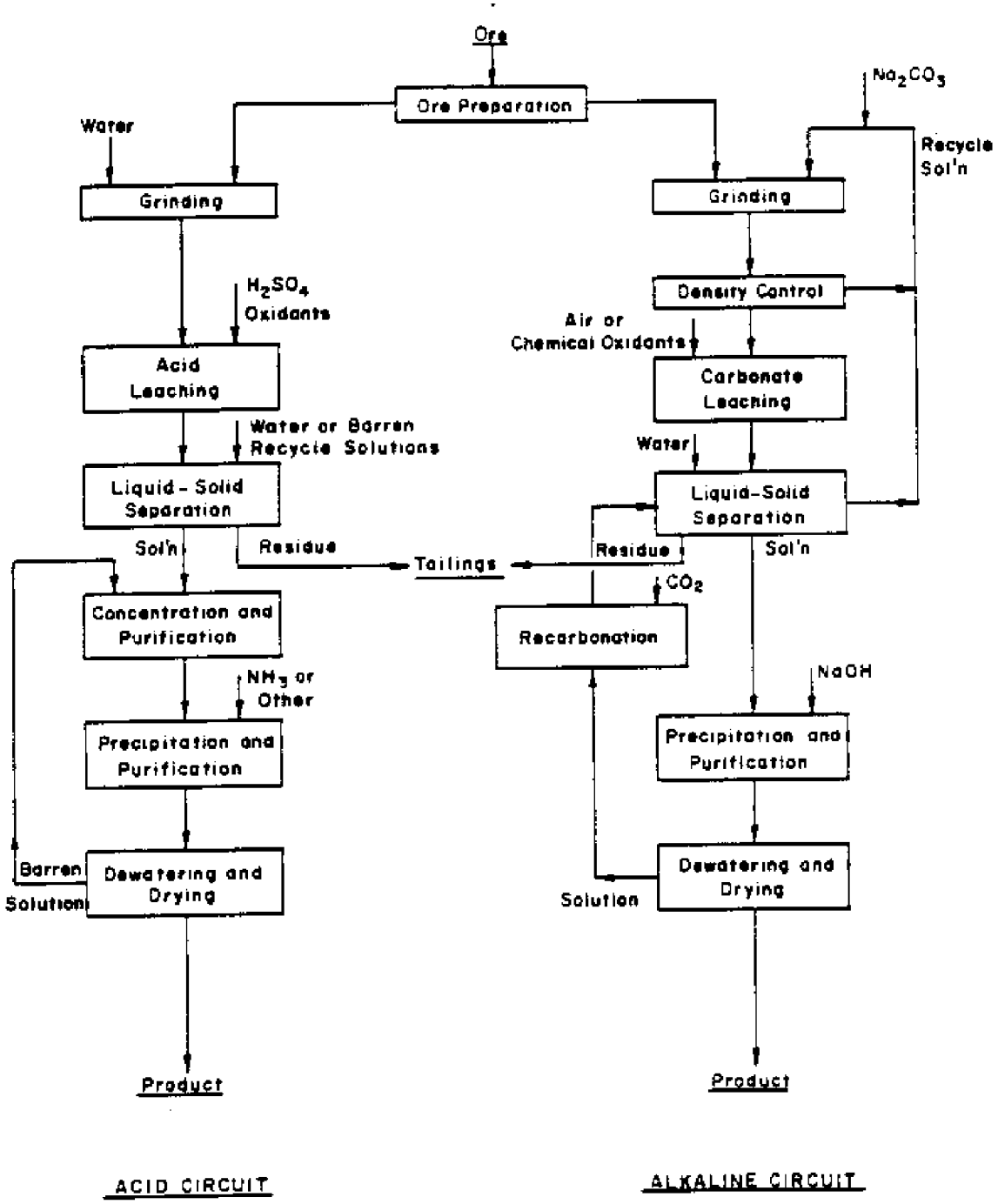


Figure 1-6. Comparison of Acid and Alkaline Leaching Circuits

(Source: Merritt, 1971)

illustrates process flow diagrams for acid and alkaline leaching. In the discussions that follow, an overview of leaching is provided followed by a more detailed description of both acid and alkaline leaches. Generally, leaching is a simple operation. A solvent (lixiviant) is brought into contact with the crushed ore slurry (or, in the case of *in situ*, with the ore in the ground). The desired constituent (uranyl ions) is then dissolved by the lixiviant. The pregnant lixiviant is separated from the residual solids (tails); typically the solids are washed with fresh lixiviant until the desired level of recovery is attained.

The uranyl ions are recovered (stripped) from the pregnant lixiviant. The final steps consist of precipitation to produce yellowcake, followed by drying and packaging (Pehlke, 1973). The stripped lixiviant may be replenished and recycled for use within the leaching circuit or as the liquid component in the crushing/grinding operation. Ultimately, the solids may be washed with water prior to being pumped to the tailings pond; this wash serves to recover any remaining lixiviant and reduce the quantity of chemicals being placed in the tailings impoundment. Wash water may be recycled to the lixiviant or to the crushing and grinding circuits.

The first step in any uranium leaching operation is oxidation of the uranium constituents. Uranium is found as uranium dioxide (UO_2, U^{+4} oxidation state) in many deposits (pitchblende and uraninite). Uranium dioxide is insoluble; to create a soluble form, UO_2 is oxidized from the U^{+4} to the U^{+6} oxidation state. Iron present within the ore, and oxygen, are used to perform oxidation via the following reactions:

(1) alkaline $UO_2 + ½O_2 \rightleftarrows UO_3$
(2) acid $UO_2 + 2Fe^{+3} \rightleftarrows UO_2^{+2} + 2Fe^{+2}$.

(Source: Twidwell *et al*., 1983)

(Note: iron can be readily reoxidized by the addition of O_2, sodium chlorate ($NaClO_3$), or manganese oxide (MnO_2) to the lixiviant.)

The second step in leaching is the stabilization of the uraniferous ions in solution. The uraniferous ions form stable, soluble complexes with sulfate (SO_4^{-2}) or carbonate (CO_3^{-2}). Sulfuric acid is added as the source for sulfate ions; sodium bicarbonate, sodium carbonate, or carbon dioxide are added to alkaline leach circuits to provide a carbonate source. Uraniferous complexes are formed through the following reactions:

(1) alkaline $UO_3 + CO_3^{-2} + 2HCO_3^{-} \rightleftarrows UO_2(CO_3)_3^{-4} + H_2O$
(2) acid $UO_2^{+2} + 6SO_4^{-2} \rightleftarrows UO_2(SO_4)_6^{-4}$.

(Source: Twidwell *et al*., 1983)

In a typical acid leaching operation, sulfuric acid is added to the crushed ore slurry to maintain the pH between 0.5 and 2.0. Twenty to 60 kilograms of sulfuric acid per metric ton of ore are normally required to reach the target pH. $NaClO_3$ or MnO_2 is added to maintain the oxidation by iron. Because iron is normally found in uranium deposits, the ore body itself supplies the iron in the leach step (Twidwell *et al*., 1983; USEPA, 1983a).

Alkaline leaching is not as effective as acid leaching for uranium recovery and is not used except in cases of high lime-content ores. Typically, ore bodies containing greater than 12 percent carbonates will be alkaline leached. Alkaline leaching is primarily employed in *in situ* mining operations, although a few conventional mills maintained alkaline leach circuits (Merritt, 1971). Alkaline leaching requires the use of a strong oxidant and long retention times to oxidize the uraniferous minerals (Twidwell *et al*., 1983). As stated previously, oxygen and a carbonate source are added to water to make up the lixiviant. The carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) concentrations are typically 40-50 g/L and 10-20 g/L respectively (Merritt, 1971). For its leaching process, the Highland *in situ* project injects O_2(g) and CO_2(g) into the lixiviant prior to underground injection. The dissolution of CO_2 in the lixiviant produces both CO_3^{-2} and HCO_3^- ions (Hunter, 1991).

Leaching may be performed in tanks, heaps or *in situ*. *In situ* leaching is practiced on low grade ores; (after crushing and grinding) high grade ores are typically leached in tanks. Heap leaching is also applicable to low grade ores; however, the available literature indicates that the application of this technique to uranium ores is limited and consequently it will not be discussed in detail. Depending on the grade of the ore, grain size (amount of grinding), and the method used, the leach times vary. Leaching in tanks may take from four to 24 hours while heap leaching may be measured in days or weeks (Twidwell *et al*., 1983).

Once the uraniferous compounds have been leached from the ore, the pregnant leach solution is separated from the solids using classifiers, hydrocyclones and thickeners. Sand-sized particles are removed first and washed with clean water or raffinate (raffinate is another term used to refer to barren lixiviant). Continued treatment removes the slimes, which are also washed. Depending on the settling time allowed by beneficiation operations, flocculants may be added to the process to encourage settling of suspended solids. After final washing, the solids (sands and slimes) are pumped as a slurry to a tailings pond for further settling. The pregnant leach solution then enters a solvent extraction or ion exchange circuit. Wash solution is recycled to reduce consumption of leach chemicals, solute, and water (USDOI, 1980; USEPA, 1983a).

Solvent Extraction

Solvent extraction is an operation that concentrates specific ions. Generally, solvent extraction uses the immiscible properties of two solvents (the pregnant leach solution and a solvent) and the solubility properties of a solute (uraniferous ions) in the two solvents. Solvent extraction is typically employed by conventional milling operations since solvent extraction can be used in the presence of fine solids (slimes). The pregnant leach solution is mixed in tanks with the solvent. Selection of a solvent in which the target solute (uraniferous ions) is preferentially soluble allows the solute to migrate to the solvent the pregnant leach solution while other dissolved compounds remain in the leach solution. Normally, the solvents are organic compounds that can combine with either solute cations or solute anions. As uranyl-carbonates or sulfates are commonly generated in the leaching step, anionic solvent extraction solutions are typically employed; cationic solvent extraction solutions may be employed depending on unique characteristics of the ores or leaching solutions.

Some anionic SX solutions include:

- Secondary amines with aliphatic side chains
- High molecular weight tri-alkyl tertiary amines
- Quaternary ammonium compounds.

Some cationic SX solutions include:

- Monododecyl phosphoric acid (DDPA)
- Di-2-ethylhexyl phosphoric acid (EHPA)
- Heptadecyl phosphoric acid (HDPA)
- Dialkyl pyrophosphoric acid (OPPA).

(Source: Twidwell *et al*., 1983).

Typically, the solvent extraction solution is diluted in a low cost carrier such as kerosene with a tributyl phosphate modifier or a long chain alcohol (Twidwell *et al*., 1983). The uraniferous ions preferentially move from the aqueous pregnant leach solution into the organic solvent as the two are mixed and agitated (USDOI, 1980). After the uraniferous compounds are thus extracted from the pregnant leach solution, the barren lixiviant (raffinate) is typically recycled to the leaching circuit.

After the solute exchange has taken place, the pregnant solvent extraction liquor must be stripped. The uraniferous solute is typically in an anionic state, and accordingly many solvent extraction solutions are anionic-based. Amine solvent extraction solutions can be stripped by many different agents such as nitrates, chlorides, sulfates, carbonates, hydroxides, and acids. Chlorides are used most frequently due to their cost-effectiveness (Twidwell *et al*., 1983).

The pregnant stripping liquor is then pumped to the precipitation step while the stripped organic solvent is recycled to the beginning of the solvent extraction circuit. Solvent exchange can be done as a batch or continuous process (Twidwell *et al*., 1983).

Ion Exchange

Like solvent extraction, ion exchange operations make use of organic compounds to perform solute concentration. Generally, fixed organic resins contained within a column are used to remove uraniferous compounds from the pregnant leach solution by exchange. After adsorption, the uraniferous compounds attached to the resins are released (eluted) by a stripping solution and sent to precipitation. Ion exchange is used by most if not all *in situ* operations and was employed by some conventional mills. It was not determined if the currently operational mills employ ion exchange circuits within their operations.

Resins are constructed with anionic or cationic functional groups (typically anionic for uranium compounds) that have an affinity for the target compound and specifically bind the compound to the resin. Resins are synthetic polymers in which hydrocarbon groups make up a three-dimensional network that hold stable, reactive functional groups (e.g., strong acid-SO_3H; weak acid-COOH; strong base-NR_3Cl; weak base-

NH_2RCl). Resins containing acid groups are called cation exchangers while resins containing basic groups are termed anion exchangers (Twidwell et al., 1983). Chloride ions can exchange with the anionic component of all the functional groups, thus providing an inexpensive stripping solution (i.e., any chloride salt solution) for any of the resins.

As the pregnant leach solution passes through the ion exchange resins, the uraniferous compounds bind to the resins. The barren leach solution is recycled back to the leaching circuit. As the resins' binding ports are filled by the uranyl ions, the uranyl ion concentration at the outlet of the ion exchange column increases. Once the uranyl ions at the outlet reach a predetermined concentration, the column is considered to be loaded and ready for elution. Typically, the pregnant leach stream is then directed to a fresh vessel of resins. A concentrated chloride salt solution is then directed through the loaded resins, eluting off the uraniferous complexes. The pregnant elute liquor can then be directed to the precipitation circuit. The pregnant elute solution may be acidified slightly to prevent the premature precipitation of uraniferous compounds (Twidwell *et al*., 1983).

Yellowcake Production

Once the uraniferous ions have been concentrated by solvent extraction or ion exchange, they are precipitated out of solution to produce yellowcake. The precipitate is then washed, filtered, dried and drummed. The chloride stripping solution is recycled back to the stripping circuit. The type of ion concentration solution (e.g., acid or alkaline solution) governs the precipitation method employed. With acid pregnant stripping liquors or pregnant elute liquors, neutralization to a pH of 6.5 to 8 using ammonia hydroxide, sodium hydroxide or lime results in the precipitation of ammonium or sodium diuranate (Merritt, 1971). Hydrogen peroxide may also be added to an acid pregnant stripping liquor or pregnant elute liquor to precipitate uranium peroxide (Yan, 1990). All forms of the uraniferous precipitate are known as yellowcake.

Alkaline pregnant stripping liquors or pregnant elute liquors typically contain uranyl carbonates. Prior to precipitation of the uranyl ions, the carbonate ions must be destroyed. An acid (usually hydrochloric acid) is added to the carbonate concentrate solution to break down the carbonates to carbon dioxide; the carbon dioxide is vented off. Once the carbonates have been destroyed, the acidified solution is neutralized with an alkali or treated with hydrogen peroxide to precipitate the uraniferous compounds. Precipitation operations based on neutralization of acid solutions are favored because of the higher purity of the yellowcake product; sodium, carbonate, and, in some cases, vanadium, are impurities that may be present in yellowcake produced from an alkaline neutralization (Merritt, 1971).

The yellowcake is separated from the precipitation solution by filtration. Thickeners may be used in conjunction with filtration units. The filtered yellowcake can then be dried and packaged for shipping (USBOM, 1978). The supernatant generated from precipitation and dewatering circuits can be recycled to the respective solvent extraction or ion exchange stripping solution.

1.4.2.1 Solution Mining

Solution mining is a general term used in the uranium industry to describe operations in which a leach solution, referred to as the lixiviant, is employed to extract uranium from subsurface ore deposits. The chemical reactions involved in *in situ* leaching are the same as those described in the Leaching section above. A number of solution mining techniques have been explored since the 1960s, including *in situ* leaching, stope leaching, borehole mining, and minewater treatment.

Other than *in situ*, the application of solution mining techniques has been limited. Stope leaching involves the injection of lixiviant into mined-out areas or those sections of underground mines that had been backfilled with low grade ore. The lixiviant can be recovered from a sump or well drilled to the bottom of the mine workings. Like other solution mining techniques, this method allows the recovery of uranium from ores not economically minable using conventional methods. Stope leaching was used to a limited extent in Wyoming (Smith Ranch) and in New Mexico (Quivira) (Michel, 1977; Ingle, 1993; Parker, 1990).

Mine water treatment involves recovery of uranium from mine effluent and was used at one point at the inactive Schwarzwalder Mine in Colorado. Available information indicates that uranium was recovered using ion exchange techniques (see above) although the recovered uranium was sent to the Cotter Mill for storage (Cray, 1990).

Borehole mining (or water-jet mining) is a technique the U.S. Bureau of Mines demonstrated on uranium deposits in the late 1970s. Borehole mining combines conventional and *in situ* mining techniques and involves removal of uranium-containing sandstone from underground deposits using a high-pressure water jet. The jet, inserted down one borehole, is used to fragment the sandstone, creating a slurry which is moved to the surface via an adjacent recovery well (USDOI, 1980). No information on the use of borehole techniques in actual production was obtained.

In situ leaching is the most commonly employed solution technique and continues to be employed at present by at least two mines in Wyoming. Nebraska's Department of Environmental Control permitted an *in situ* operation in 1990; it is currently operable (NDEC, 1990). Texas has 17 mines that are permitted for *in situ* operations and only two of these are currently being mined. The rest have groundwater restoration activities underway (Kohler, 1993). Deposits amenable to *in situ* leaching are usually (if not always) within an aquifer. Water quality within a mineral deposit may vary depending on the presence of and boundary between oxidizing and reducing groundwaters. Ore body characteristics, including chemical constituents, grade, and permeability, are key considerations in the development of production methods (selection of lixiviants, arrangement of well patterns). Ideally, the deposit should be confined by impermeable strata above and below the deposit to prevent contamination of adjacent aquifers by excursions (solution leaks from the ore zone). *In situ* production operations consist of three phases: removal of minerals from the deposit, concentration of uraniferous minerals, and generation of yellowcake. In addition to the production operations, water treatment and, in some cases, deep well injection facilities, are employed.

In *in situ* mining, barren lixiviant is pumped down injection wells into the ore body; production wells then bring the pregnant leach solution to the surface for further beneficiation. Numerous well patterns have been investigated since the early 1960s when *in situ* mining techniques were first employed. Five spot well patterns, which consist of four injection wells forming the corners of a square, and a production well in the center, are common in the industry. Alternating injection and production wells are used in narrow deposits (see Figure 7). The spacing between injection and production wells can range from 20 to 200 feet. The number of well patterns in a well field varies, and a specific range of numbers was not obtained. Mining units are portions of the deposit to be mined at one operation, often following "pods" of ore deposited along a roll front.

Mining units may be mined in sequence or simultaneously. Pumping rates at one *in situ* operation in Wyoming ranged from two gallons per minute (gpm) to 30 gpm for injection wells and five gpm to 40 gpm

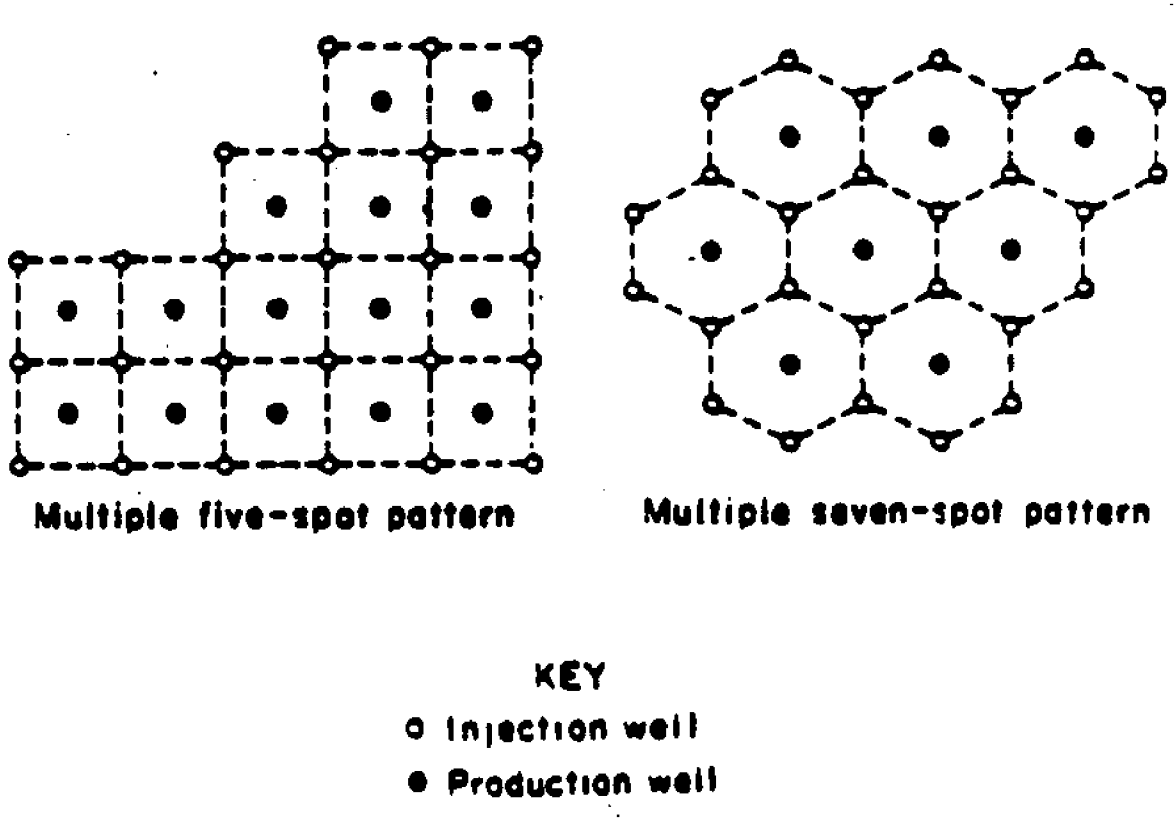


Figure 1-7. Well-Field Patterns

(U.S. BOM, 1978)

for production wells. Approximately one percent of the fluid drawn from the well field is removed as a bleed to generate a cone of depression within the "production zone." Pumping rates can be varied at each well individually in order to compensate for differences in permeability of the deposit and the gradient being generated by the production operation.

Lixiviant is introduced to the deposit through injection wells to initiate the operation. The lixiviant consists of two parts, an oxidizing agent, which acts to solubilize the target minerals, and a complexing agent, which binds to the target minerals, keeping them in solution. In the developmental stages of *in situ* mining, lixiviants were selected based solely on their ability to dissolve and mobilize the target minerals. Sulfuric acid, nitric acid, ammonium carbonate/bicarbonate and sodium carbonate were among the first lixiviants used. Sulfuric acid lacked effectiveness in carbonaceous deposits and, while nitric acid was more effective on carbonaceous ores, the nitrogen component made aquifer restoration difficult. Ammonium carbonate/bicarbonate leach solutions also presented problems in the restoration phase. Sodium-based lixiviants allowed for relatively easy aquifer restoration; however, in some cases, the sodium fraction reacted with clays in the deposits, reducing permeability of the aquifer (in the immediate vicinity of the injection wells) (USBOM, 1981b). According to permit documents, Wyoming *in situ* operations recover uraniferous minerals using oxygen gas as the oxidizer and carbon dioxide, which ultimately forms complexes with uranium to form uranyl carbonates, as the complexing agent (WDEQ, 1991).

The constituents of the lixiviant used at the Highland Uranium Project *in situ* operation in Wyoming are as follows:

Na	50-200 mg/l
Cl	50-900 mg/l
SO_4	100-400 mg/l
TDS	500-1850 mg/l
pH	6.2-6.5
HCO_3	200-1200
O_2	10-600 mg/l

Source: WDEQ, 1991.

Operational steps in *in situ* mining are straightforward. The barren lixiviant is charged with carbon dioxide as the solution leaves the ion exchange facility (discussed in more detail later in this chapter). Oxygen is injected to the solution in the wellfields, immediately before the lixiviant moves into the injection wells. As the solution moves through the deposit, uraniferous minerals are oxidized and move into solution. (A discussion of the oxidation and complexing is provided in the Leaching section above.) Carbon dioxide in the lixiviant reacts with water, forming carbonic acid, which in turn complexes with the solubilized uraniferous ions, forming uranyl carbonates. The uranyl carbonates and gangue minerals solubilized in the operation remain in solution as the pregnant solution is pumped to the surface through production (recovery) wells.

Pregnant lixiviant is pumped from the production wellheads through sand filters to remove any large particulates; the lixiviant is then transferred to the ion exchange units. Depending on the facility, the ion exchange resins may be placed in trailer-mounted tanks or moved via tanker truck from satellite plants to a central processing facility. Ultimately, the uraniferous compounds are stripped from the resins and precipitated to form yellowcake. The ion exchange and precipitation steps are discussed respectively in

sections above. The lixiviant is recharged with carbon dioxide and oxygen following the ion exchange circuit and injected back into the ore body.

Uranium recovery rates at *in situ* operations are highest within the first year of operation; economically viable recovery within a wellfield usually lasts one to three years under recent (1990s) market conditions. The efficiency of recovery is variable; the Highland Uranium Project in Wyoming reportedly recovers 80 percent of the estimated uranium reserve at the end of the production cycle (Hunter, 1991).

When uranium recovery drops below a previously determined point, lixiviant injection is terminated and the restoration phase is established in the wellfield. Aquifer restoration is required under State regulatory programs (see the Current Regulatory Framework chapter below). Normally, an aquifer must be restored to its previous water use classification although not all water quality parameters are necessarily returned to baseline values.

Restoration

Restoration of the aquifer can be conducted using one (or more) of the following techniques: groundwater sweep, forward recirculation, reverse recirculation, and directional groundwater sweeping. In some cases, a reducing agent may be injected prior to any restoration to reverse the oxidizing environment created by the mining process. A reducing agent may also be injected during later stages of restoration if difficulties arise in stabilizing the aquifer (Lucht, 1990).

A groundwater sweep involves the selective operation of production wells to induce the flow of uncontaminated groundwater into the mined zone while the withdrawn water continues to be treated through the ion exchange circuit. Contaminated water withdrawn from the aquifer can be disposed of in lined evaporation ponds or treated and discharged. Groundwater sweeps are most effective in aquifers with "leaky" confining layers, since uncontaminated groundwater can be induced to flow into the mined areas. Typically, two or more pore volumes are required to improve water quality parameters. The disadvantage to groundwater sweeping is its consumptive use of groundwater (Osiensky and Williams, 1990).

Forward recirculation involves the withdrawal and reinjection of groundwater through the same injection and production wells that were used during the mining operation. Groundwater withdrawn from the mined aquifer is treated using ion exchange or reverse osmosis with the clean water being reinjected and recirculated through the system. The water being reinjected is treated to the extent that it meets or exceeds the water quality required at the endpoint of restoration. The method does not allow the removal of any lixiviant or mobilized ions that may have escaped from the mined aquifer. For this reason, forward recirculation is most effective in restoring the portions of the aquifer associated with the interior of the well field (Osiensky and Williams, 1990).

Reverse circulation techniques can also be employed in which the function of production and recovery wells is reversed. Again, "clean" water is injected, this time through the recovery wells, while the injection wells are

employed to withdraw groundwater from the aquifer. This method is also more effective in restoring the aquifer in the interior of the well field than along the perimeter (Osiensky and Williams, 1990).

Directional groundwater sweeping techniques involve the pumping of contaminated groundwater from specific wells while treated water (at or surpassing baseline quality) is injected into the aquifer beyond the mined sections of the aquifer. The clean water is then drawn into the contaminated portions of the aquifer, removing the mobilized ions. Clean water injection can progress across a wellfield as the contaminants are progressively withdrawn (Osiensky and Williams, 1990).

Uranium can be recovered during the early stages of the restoration process as the water from the production wells passes through the ion exchange system. Eventually, uranium recovery is abandoned while restoration continues. A rinse of multiple aquifer pore volumes is typically required to reach a satisfactory level of restoration. The number of pore volumes required depends on ease with which the aquifer returns to baseline conditions and the permit requirements established in State permits (Osiensky and Williams, 1990; BOM, 1979).

Demonstration of successful restoration is accomplished through extended monitoring. The state of Wyoming, for example, requires that selected wells be monitored for stability for a period of at least six months following the return of monitoring parameters to baseline level (WDEQ, 1990).

Monitoring

In situ operations maintain monitor wells and a monitoring plan to detect any migration of the lixiviant from the production zone. Such movement of the lixiviant or any of its constituents from the mined portion of the aquifer into adjacent or overlying aquifers is termed an excursion. Excursions may be either vertical or horizontal. Horizontal excursions typically occur when pumping rates from production wells do not create a large enough cone of depression to maintain the lixiviant within the production zone. These excursions are brought under control by adjusting the pumping rates within the injection and production wells. Vertical excursions occur when lixiviant constituents are detected in an aquifer (typically) above the production zone. Vertical excursions may develop as a result of a leaky confining layer, improper construction of injection or production wells, or, more commonly, from wells previously drilled into the aquifer that were not adequately plugged before mining operations commenced. Vertical excursions are more difficult to remedy and may require extensive

testing to identify the source of the 'leak'. Wells may need to be sealed and new wells installed, depending on the source and severity of the vertical excursion. The number of excursions occurring at *in situ* operations has decreased with the growth in understanding of the causes of excursions and methods to avoid them. This technology developed with expansion of the industry through the 1980s (NRC, 1986).

As part of the monitoring program, upper control limits (UCLs) are established during baseline data collection. UCLs consist of groundwater parameters that would be expected to rise in the event of an excursion (NRC, 1986). Total dissolved solids, chloride, sulfate, bicarbonate and sodium have been used as UCLs by uranium *in situ* operations (WDEQ, 1990). Since horizontal and vertical excursions may occur, monitoring wells are established both above and below the production zone as well as around it. Monitoring for the purpose of detecting excursions is conducted on a regular basis usually established in the operating permit.

1.5 EXTRACTION AND BENEFICIATION WASTES AND MATERIALS ASSOCIATED WITH URANIUM MINING OPERATIONS

This section describes several of the wastes and materials that are generated and/or managed at uranium extraction and beneficiation operations and the means by which they are managed. A variety of wastes and other materials are generated and managed by uranium mining operations.

Some, such as waste rock and tailings, are generally considered to be wastes and are managed as such, typically in on-site management units. Even these materials, however, may be used for various purposes (either on- or off-site) in lieu of disposal. Some quantities of waste rock and tailings, for example, may be used as construction or foundation materials at times during a mine's life. Many other materials that are generated and/or used at mine sites may only occasionally or periodically be managed as wastes. These include mine water removed from underground workings or open pits, which usually is recirculated for on-site use but at times can be discharged to surface waters. Some materials are not considered wastes at all until a particular time in their life cycles.

The issue of whether a particular material is a waste clearly depends on the specific circumstances surrounding its generation and management at the time. In addition, some materials that are wastes within the plain meaning of the word are not "solid wastes" as defined under RCRA and thus are not subject to regulation under RCRA. These include, for example, mine water or process wastewater that is discharged pursuant to an NPDES permit. It is emphasized that any questions as to whether a particular material is a waste at a given time should be directed to the appropriate EPA Regional office.

Wastes and materials generated by uranium mining operations include waste rock, tailings, spent extraction/leaching solutions, and refuse. Mining method (conventional versus solution) has a bearing on the types of wastes and materials produced. Operational mills function independently of specific mines and generate materials that are, in most cases, unique from those generated at the site of extraction. Under the Uranium Mill Tailings Remediation Control Act (UMTRCA, see Regulatory section below), source handling licenses place specific requirements on the disposal of radioactive wastes; the design and construction of tailings impoundments typically address Nuclear Regulatory Commission (NRC) requirements for permanent storage of these wastes. Radionuclide-containing wastes generated by *in situ* operations are typically shipped to tailings impoundments at mill sites.

The greatest volume of waste generated by conventional mineral extraction (open pit and underground mines) is waste rock, which is typically disposed of in waste rock piles. Some waste rock is used for onsite construction (roads, foundations). The generation of acid mine drainage is one of the principal concerns surrounding waste rock in other mineral sectors; the potential for generation of acid drainage from uranium waste rock has not specifically been addressed in the references reviewed for this profile. However, pyrite is typically a constituent of uranium-containing ores, and may present the potential to great acid mine drainage in sufficient concentrations. Other materials generated by open pit and underground mining operations, including low-grade ore and mine water, are typically managed on-site during the active life of the facility.

Low-grade ores that are not beneficiated ultimately become waste rock. If a mill is co-located with a mine, mine water can be used as makeup water in the beneficiation operation. If a mill is not nearby, mine water may be treated and discharged (effluent standards are set forth in 40 CFR 440), or used for dust suppression.

The principal waste generated by conventional beneficiation operations are tailings; *in situ* operations, and to a more limited extent conventional mills, generate waste leaching solutions. Disposal of these wastes is dependent on the type of operation; beneficiation wastes generated by *in situ* operations are disposed of by one of four management methods: evaporation ponds, land application, deep well disposal, or shipment to NRC-licensed waste disposal facilities. Most beneficiation wastes generated at conventional mills are disposed of in tailings impoundments.

Waste constituents of concern include radionuclides (radium, radon, thorium, and to a lesser extent lead), arsenic, copper, selenium, vanadium, molybdenum, other heavy metals, and dissolved solids. Brines, spent ion exchange resins, and chemicals used in beneficiation operations are also constituents of wastes generated during beneficiation.

The first subsection below describes several of the more important wastes (as defined under RCRA or otherwise) and nonwastes alike, since either can have important implications for environmental performance of a facility. The next subsection describes the major types of waste units and mine structures that are of most environmental concern during and after the active life of an operation.

1.5.1 Extraction and Beneficiation Wastes and Materials

1.5.1.1 Waste Rock or Overburden

According to the 1985 *Report to Congress: Wastes From the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale*, the greatest quantity of waste generated as a result of the mining and beneficiation of uranium ore is in the form of overburden and waste rock. Generally, these materials are deposited in waste rock piles or dumps. Surface mining operations generate more waste per unit of crude ore extracted than underground operations. During the late 1970s, the largest open pit uranium mines produced an average of 40,000,000 metric tons of overburden annually. Underground mines produced an average of 2,000 metric tons of waste rock during the same time period. Characteristics of the waste rock were not specifically determined although limited data indicated that waste rock contained higher levels of arsenic, selenium, and vanadium than background levels (USEPA, 1983b Vol.2).

1.5.1.2 Mine Water

Mine water is generated when water collects in mine workings, both surface and underground, as a result of inflow from rain or surface water and of groundwater seepage. Surface water is generally controlled using engineering techniques to prevent water from flowing into the mine. During the life of the mine, water is

pumped out of the mine as necessary to keep the mine dry and allow access to the ore body for extraction. This water may be pumped from sumps within the mine pit or underground workings or may be withdrawn from the vicinity of mining activity through interceptor wells. Interceptor wells are used to remove groundwater, creating a cone of depression in the water table surrounding the mine; the result is dewatering of the mine. Mine water may be treated and discharged (subject to 40 CFR 440 Subpart C), or, if a mill is operating on-site, mine water can be pumped to the beneficiation circuit or to tailings impoundments.

The quantity and chemical composition of mine water generated at mines vary by site. The chemistry of mine water is dependent on the geochemistry of the ore body and surrounding area. The two principal concerns surrounding mine water associated with uranium mining are the potential for acid mine drainage and the presence of radionuclides.

Information on the potential for generation of acid mine drainage from uranium mine workings and waste rock was not available. While pyrite (an acid-forming mineral) is present in some uranium ore deposits, many uranium mines are located in arid climates. Low precipitation rates and the resultant lack of water may reduce the potential for generation of acid drainage (at least in the short term) from waste rock in both the Colorado Plateau and the Shirley Basin of Wyoming.

The presence of radionuclides in mine effluent has been documented and, in at least one case, uranium was recovered using ion exchange on effluent seeping from an inactive underground mine. The presence of elevated levels of radionuclides in alluvial aquifers in the Grants Mineral Belt, New Mexico, were attributed to authorized discharges from mines (discussed in the Environmental Effects section of this report) (Eadie and Kaufmann, 1977).

1.5.1.3 Tailings

Most wastes generated by conventional mills are disposed of in tailings impoundments.
Wastes are primarily disposed of in the form of a slurry composed of tailings, gangue (including dissolved base metals), spent beneficiation solutions, and process water bearing carbonate complexes (alkaline leaching) and sulfuric acid (acid leaching), sodium, manganese, and iron. The characteristics of this waste vary greatly, depending on the ore, the beneficiation procedure, and the source of the water (fresh or recycled). The liquid component is usually decanted and recirculated to the crushing/grinding or leaching circuit.

Tailings typically consist of two fractions, sands and slimes. The sand and slimes may be combined and deposited directly in the impoundment or may be distributed through a cyclone such that the sand fraction is directed toward the dam while the slimes are directed to the interior of the pond (Merritt, 1971).

The fate of radionuclides is of special interest in uranium mill tailings. Radium-226 and thorium-230 are the principal constituents of concern and are associated with the slime fraction of the tailings. Radon-222 (gas) is also a tailings constituent. The concentrations of radionuclides in the tails will vary depending on the leach

method used (thorium is more soluble in acid than alkaline leaches); typically, tailings will contain between 50 and 86 percent of the original radioactivity of the ores depending on the proportion of radon lost during the operation (Merritt, 1971). Other tailings constituents (including metals, sulfates, carbonates, nitrates, and organic solvents) would also be present in the tailings impoundment depending on the type of ore, beneficiation methods, and waste management techniques. (For updated information on specific hazardous constituents, see 60 *Federal Register* 2854, January 11, 1995, which is attached in Appendix C).

1.5.1.4 Bleed Solution

Bleed solutions are generated in both the extraction and restoration phases of *in situ* mining. There are three pathways that lead to the solution bleeds. During the extraction phase, a one percent bleed is typically maintained to develop the cone of depression within the mined aquifer (i.e., one percent less barren lixiviant is injected than the amount of pregnant solution withdrawn). The bleed is drawn from the circuit following the ion exchange columns and prior to the lixiviant being recharged for reinjection. Aalso, in the early phases of restoration, lixiviant injection is terminated; however, the solution removed by recovery wells is also sent through ion exchange to recover uranium remaining solubilized in the deposit. A bleed is maintained through this operation, again following the ion exchange step. In addition, as recovery of uraniferous components drops and ion exchange becomes uneconomical, solution (water) withdrawn from the mined aquifer through recovery wells is treated with reverse osmosis prior to being reinjected to the aquifer (see the discussion of Restoration above). A bleed is maintained through this point to insure that clean water is drawn into the aquifer being restored.

In each of the above cases, the bleed is usually pumped from the extraction/restoration circuit to lined settling ponds where barium chloride is added. Barium chloride reacts with radium to form a barium-radium-sulfate precipitate which is allowed to settle out of solution. When the radium levels reach acceptable levels (typically less than 30 mg/l), the water may be pumped to a holding (surge) pond, discharged to surface water through an NPDES-permitted outfall, land applied, or, may be stored in a storage pond for injection during the restoration phase.

1.5.1.5 Evaporation Pond Sludges

In situ bleed solutions and lixiviant leaching solutions constitute the major source of wastes directed to lined evaporation ponds. These solutions consist of barren lixiviant and usually have elevated levels of radium; other contaminants (metals, salts) are limited to what may have been solubilized by the lixiviant or contaminants in solutions used for beneficiation. Barium chloride is added to the evaporation ponds which, in the presence of radium, forms a barium-radium-sulfate precipitate. This precipitate forms the majority of the sludges in the settling/evaporation ponds at *in situ* mining operations. Alkali chlorides and carbonates are other likely constituents (USEPA, 1983b Vol. 2). These sludges are collected at the completion of mining (unless required sooner) and disposed of at an NRC-licensed disposal facility. The Agency does not have information regarding the specific chemical composition or radioactive level of these precipitants.

Evaporation pond sludges at conventional mills may also contain barium-radium-sulfate precipitates in addition to chemical wastes from the leaching and stripping circuits. These sludges may contain metals, sulfates, chlorides, lime, and amines depending on the leaching methods and waste disposal practices (Merritt, 1971).

1.5.1.6 Drilling Wastes

The number of wells involved in an *in situ* mining operation indicates that there may be significant quantities of wastes associated with drilling operations (drilling muds, cuttings, water). Drilling wastes (muds, cuttings, produced water) are typically directed into unlined pits adjacent to the wells. Following well completion, the pits and their contents are typically closed in-place. The majority of the cuttings generated in drilling operations are non-ore bearing and therefore contain little in the way of radioactive minerals (USEPA, 1983b Vol. 2).

1.5.1.7 Waste Ion Exchange Resins

Ion exchange resins have a limited life span and must occasionally be replaced. Resins consist of two portions, an organic structural component and (cationic or anionic) functional groups attached to the organic framework. The chemical composition of functional groups varies from strong acid groups to strong base groups. *In situ* operations typically dispose of spent resins with other so-called "contaminated waste" in labelled containers prior to disposal at an NRC-licensed disposal facility. Conventional mills would typically dispose of spent ion exchange resins in the tailings impoundment. The volume of spent ion exchange resins generated on an annual basis was not determined. At conventional mills, however, the contribution of spent resins to the volume of a tailings impoundment would be minimal compared to the volumes of tailings.

1.5.1.8 Reverse Osmosis Brines

The reverse osmosis process is used by *in situ* operations to treat effluent prior to final discharge and to treat groundwater during the restoration phase. Reverse osmosis wastes are typically high in salts (total dissolved solids) and may have concentrations of radionuclides that exceed NPDES discharge limits. These wastes are typically injected into deep disposal wells permitted under the UIC program (UIC permit requirements are discussed in the Current Regulatory Framework section of this report) (USEPA, 1983b Vol. 2). The quantities generated and more detailed characteristic data were not obtained.

1.5.1.9 Acid/Alkaline Leaching, Solvent Extraction, Stripping and Precipitation Circuit Wastes and Materials

Under normal operating procedures, solutions are recycled to the greatest extent possible to conserve water, chemicals, and uranium. Detailed discussions on the longevity and management of beneficiation solutions were not obtained. All wastes and materials generated during the beneficiation operation are likely to contain radionuclides in at least trace quantities as well as other metals dissolved from the ore.

In addition to radionuclides, solvent extraction solutions include phosphoric acids (cationic ion exchange), amines and ammonium salts (anionic ion exchange), and organic carriers such as kerosene or alcohol. Stripping solution could contain nitrates, chlorides, sulfates hydroxides or acids. Wastes from the ion exchange solution are dependant on the type of resins employed, however, chloride solutions are commonly used for elution. Constituents that could accumulate in the precipitation circuit are primarily anions - sulfates, chlorides and possibly, carbonates (Merritt, 1971; Twidwell et al., 1983). Again, information on quantities and characteristics were not obtained.

1.5.2 Waste and Materials Management

Wastes and nonwaste materials generated as a result of extraction and beneficiation of uranium ore are managed (treated, stored, or disposed) in discrete units. For the purposes of this report, these units are divided into six groups: (1) mine structures such as pits and underground workings; (2) overburden, waste rock, and ore; (3) tailings impoundments; (4) settling/evaporation ponds; (5) land application areas; and (6) deep disposal wells.

1.5.2.1 Overburden, Waste Rock, and Ore

Overburden and waste rock removed from the mine are stored or disposed of in unlined piles on site. Often constructed without liners, these waste dumps are generally unsaturated in the arid regions where most uranium mining occurs. Such dumps could possibly generate acid drainage if pyrites or other sulfide minerals and moisture are present in sufficient concentrations. Concentrations of radionuclides are likely to be similar to those in adjacent, undisturbed deposits although radon (gas) levels may be higher as a result of higher diffusion rates through unconsolidated piles as opposed to undisturbed bedrock. Topsoil may be segregated from overburden and waste rock and stored for later use in reclamation and revegetation.

Some operations store extracted ore in stockpiles until they are beneficiated as directed by the operator's mining, operating, or production plan. These piles may be located in or outside the pit. In some cases, low-grade ore may never be beneficiated and become waste at closure. Ore and sub-ore piles are typically unlined. States may or may not have required run-on/runoff controls for these piles; however, they are not required. Constituents of concern for waste rock and ore piles include low concentrations of radionuclides as well as sulfur-bearing minerals that, under certain conditions, may generate acid and, thus, leach metals.

1.5.2.2 Mine Pits and Underground Workings

In addition to wastes generated during active operations, when the mines close or stop production, pits and underground workings may be allowed to fill with water, since the need for dewatering is gone. (Mine water generated during the active life of a mine is usually not considered to be a waste; however, it is generally considered waste after mine closure.) Radionuclide concentrations are likely to be elevated in mine water (collected in abandoned pits or underground workings, and in discharges) and acid generation may be a problem, depending on local geochemistry. Abandoned underground mines and mine shafts may be

unprotected, and the surface above the mine may, with time, subside, though this is mostly a problem with historical mines. Deficiencies in mine shaft protection may be caused by the use of unsuitable materials, such as inadequate shaft cappings, or by unexpected occurrences that break capping seals, such as water surges in flooded mines (US DOI, Bureau of Mines 1983a).

1.5.2.3 Tailings Impoundments

The requirements for tailings impoundments at operational active mills changed with Title II of UMTRCA. Among other things, UMTRCA banned the use of mill tailings for off-site construction, the most significant pathway for human exposure to radionuclides (USEPA, 1983b Vol 2). Through UMTRCA, the NRC requirements for tailings ponds at active mills include impermeable liners to control the migration of liquids and soluble constituents, and adequate closure at the termination of milling operations. Prior to UMTRCA, impoundments were frequently unlined and reclamation (closure) requirements would have been dependant on State requirements. (For updated information, see 60 *Federal Register* 2854, January 11, 1995, which is attached in Appendix C).

Two general classifications of structures may be used to describe a tailings impoundment: water/slurry retention dams and raised embankments. The choice of impounding structure is influenced by the characteristics of the mill tailings, beneficiation effluents, and area geology and topography. The size of tailings impoundments varies between operations and may range up to hundreds of acres. No information was obtained on the number or sizes of evaporation ponds or on closure/reclamation practices.

1.5.2.4 Evaporation Ponds

Evaporation ponds are used by conventional milling operations to dispose of process water or other solutions that are unsuitable for discharge or undesirable for addition to the tailings impoundment. Wastes directed to evaporation ponds include barren leach, solvent exchange and ion exchange solutions. Bentonite or synthetic liners are typically installed to prevent the migration of fluids from the pond. Sludges removed from evaporation ponds are deposited in the tailings impoundment. No information was obtained on the number or sizes of evaporation ponds or on closure/reclamation practices.

1.5.2.5 Settling Ponds

Settling ponds are employed at *in situ* mining operations to remove radium from the bleed solution prior to discharge. Waste process water may also be directed to settling ponds after passing through an ion exchange or reverse osmosis circuit to remove the majority of contaminants. Barium chloride is added to the bleed solution to precipitate the radium, bringing the effluent within NPDES standards. The effluent can then be discharged via an NPDES permitted outfall or land applied. During restoration, settling pond effluent may be pumped to a storage reservoir and ultimately reinjected. Sludges removed from the settling ponds are containerized and shipped to NRC-licensed disposal facilities.

1.5.2.6 Land Application Areas

Land application is used as a method of eliminating the volume of water generated in the bleed solution during extraction and restoration phases of *in situ* mining. Land application discharges are permitted (in Wyoming) as a form of wastewater treatment and are required to meet NPDES discharge standards. The effluent is typically discharged to native grasslands used for grazing or hay production. Volumes of discharges were not determined.

1.5.2.7 Deep Disposal Wells

Since *in situ* mining operations usually do not operate a tailings impoundment, an alternative source for disposal of wastes is necessary. Deep disposal wells are often used to dispose of wastes that cannot be recycled, treated, and/or discharged. Brines generated by reverse osmosis treatment, laboratory wastes and other wastes are typically injected. Operation of these wells is regulated under the UIC program described in the Current Regulatory Framework section of this report. Volumes and characteristics of injected wastes were not determined.

1.6 ENVIRONMENTAL EFFECTS

1.6.1 Introduction

Uranium has been associated with mining wastes since the late 1890s when it was discarded as undesirable component in the mining of radium (and to a lesser extent, vanadium). Twelve mills operated on the Colorado Plateau for different periods from 1901 through the late 1980s. Initially, these mills beneficiated radium, although most if not all were also used for beneficiation of uranium as the industry developed (MINOBRAS, 1978).

Nearly any portion of waste management units at active mines may be a potential source of environmental contamination. Environmental effects resulting from uranium extraction and beneficiation are chiefly derived from two sources: mining activities, and radionuclides present in the wastes. Open pit mining activities may create environmental effects typical of surface disturbances: increased runoff as well as increased erosion by wind and water. Dewatering operations conducted by surface and underground mines may create groundwater depressions that may persist after mining ceases. Potential environmental effects from *in situ* operations are primarily groundwater-related. Since surface disturbance is not extensive, the impacts of surface operations associated with *in situ* mining (e.g. drilling wastes, ponds) are not well documented.

Mill tailings, and particularly the radionuclides contained within, appear to be a major source of environmental impact to air, soil, surface and groundwater. Findings in the *Report to Congress: Potential Health and Environmental Hazards of Uranium Mine Wastes* indicated that the most serious threat to human health was the use of uranium mill tailings in off-site construction. The Department of Energy, through Title I of UMTRCA, is conducting remedial activities on tailings generated by 24 uranium mills throughout the western U.S. (except for one site in New Jersey). UMTRCA's Title II licenses and places

stringent requirements on operations and closure at currently operating (and inactive) mills (USEPA, 1983a). For a discussion of UMTRCA, see the Current Regulatory Framework section of this report.

A discussion of the potential environmental effects associated with uranium mining is presented in the following sections. Specific examples from industry are included in this section, as appropriate. Actual release incidents are described in Appendix A of this report.

This section does not purport to be a comprehensive examination of environmental damages that can occur or that actually occur at mining operations. Rather, it is a brief overview of some of the potential problems that can occur under certain conditions. The extent and magnitude of contamination depends on highly variable site-specific factors that require a flexible approach to mitigation. EPA is aware that many of the potential problems can be, and generally are, substantially mitigated or avoided by proper engineering practices, environmental controls, and regulatory requirements.

1.6.2 Surface Water

1.6.2.1 Mine Dewatering

Surface and underground mines may be dewatered to allow extraction of ore. Dewatering can be accomplished in two ways: (1) pumping from groundwater interceptor wells to lower the water table and (2) pumping directly from the mine workings. At the end of a mine's active life, pumping typically is stopped and the pit or underground workings are allowed to fill with water. The mine water may be contaminated with radioactive constituents, metals, and suspended and dissolved solids.

Prior to being discharged, mine water from uranium mines is usually treated with a flocculent and barium chloride to reduce suspended solids concentrations and to coprecipitate radium. The chemical quality of mine waters differs from the receiving surface waters in several ways. For example, in the Grants Mineral Belt of New Mexico, mine dewatering effluents have been documented to contain elevated concentrations of gross alpha and beta particles; radionuclides radium-226 and lead-210; natural uranium; molybdenum; selenium; and dissolved solids, sulfate in particular. On occasion, arsenic, barium and vanadium are detected (Gallaher and Longmire, 1989). When mine water is discharged to surface waters, it can change the quality of the surface water. Elevated concentrations of metals and radionuclides, constituents typical of mine waters, have been detected in surface waters near uranium mines (EPA, 1983).

In arid climates, like New Mexico, the discharge of mine water to a receiving stream can completely change the hydrologic conditions of the receiving body. Typically, mine water is discharged to ephemeral streams in arid climates. The mine waters have, in some instances, transformed ephemeral streams to perennial streams. These newly created perennial streams often lose flow to subsurface alluvial material which recharges shallow alluvial aquifers. Studies have documented that infiltration of uranium mine dewatering effluents have been accompanied by a gradual change in the overall chemistry of the groundwater, and the groundwater now bears a greater resemblance to the mine dewatering effluent (Gallaher and Longmire, 1989).

The quality of mine water depends upon the dewatering method used. Water removed from wells adjacent to the mine usually is representative of natural groundwater quality, at least while dewatering continues. Mine water removed from the mine, however, can be high in radionuclides, metals, and dissolved solids (EPA, 1984). Practices such as recycling mine water to the mill helps reduce the impacts of mine water to surface water bodies.

1.6.3 Groundwater

Potential and documented effects on groundwater from uranium mining activities vary with the type of activity being conducted. Operation of open pit and underground mines potentially influence groundwater through dewatering operations and through approved discharges as discussed in the surface water section above. Tailings impoundments associated with conventional mills have the potential to leak; while some of the liquid constituents of the tailings are recycled or evaporated, unlined tailings ponds may allow liquids to seep into the ground, eventually reaching groundwater. This is also true for evaporation and radium settling ponds, although some States require liners in all wastewater ponds.

In situ operations inject lixiviant into what is termed the production zone, normally a sandstone aquifer. The potential impacts of these operations result from the increased solubility of uraniferous and other compounds, which facilitates migration of these species into neighboring aquifers. As a result, complete restoration of mined aquifers is not necessarily a simple task.

Dewatering operations at open pit and underground mines may impact local aquifers through drawdowns in the direct vicinity of the mine with (presumably) little lasting effect. However, depending on the transmissivity of the aquifer, the size of the dewatering operation, and the number of mines actively conducting dewatering, impacts to aquifers may be significant. Mining activity from 1970 through 1984 near the Everest Minerals' Highland Uranium Project reportedly withdrew 39,000 acre-feet of water. Although the extent of the drawdown was not stated, a 1991 Wyoming Department of Environmental Quality document reported that the potentiometric surface within the area was "recovering" (WDEQ, 1991).

It should be noted that groundwater impacted or potentially impacted by mining activities is not necessarily suited for domestic use prior to mining. For example, aquifers containing uranium ores in both Wyoming and New Mexico have been documented as having elevated levels of uranium and other radionuclides prior to the initiation of mining activities (WDEQ, 1991; Eadie and Kaufmann, 1977).

Dewatering activities in the Grants Mineral Belt, as discussed in the previous section, has impacted both surface water and alluvial aquifers. Streams receiving mine effluent had higher than baseline concentrations of uranium, radium, lead, selenium, and molybdenum. Studies completed as recently as 1986 indicate that the shallow aquifers underlying these streams had begun to chemically resemble mine water; concentrations of those constituents that may migrate (uranium, selenium, molybdenum) were higher than in "natural waters" (Gallaher and Longmire, 1989). The extent of recovery of both surface and shallow groundwater in the

Grants Mineral Belt, following the decline of uranium mining activities in the early 1980s, was not determined.

Mill sites covered under Title I of UMTRCA have been investigated to determine the extent of migration of tailings constituents. Migration of uranium and other tailings constituents occurs through leaching (percolation of precipitation) and erosion. Migration caused at least local contamination of groundwater at all of the 24 sites investigated. The following groundwater quality parameters at these sites were most frequently exceeded: uranium, molybdenum, manganese, nitrate, sulfate, and gross alpha activity. Additionally, arsenic, iron, selenium, radium and total solids exceeded drinking water maximum Contaminant limits (MCLs) at some sites (USEPA, 1987). The degree of migration is related to numerous factors including the chemistry of the tailings material; the permeability of the impoundment and liner (if present); the amount of precipitation; the nature of the underlying soils; and the proximity to both surface and groundwater. (For updated information, see 60 *Federal Register* 2854, January 11, 1995, which is attached in Appendix C).

Environmental effects associated with early *in situ* leaching operations occurred as a result of lixiviant selection. Early lixiviants included acid solutions and ammonium carbonates. Restoration of aquifers leached with acid lixiviants proved difficult as pH levels were difficult to raise after being dropped. Aquifers leached with ammonium lixiviants were also difficult to restore as the ammonium ions readily attached to clay particles within the production zone and were difficult to remove (Bureau of Mines, 1981b).

Extraction and restoration techniques have evolved and improved since *in situ* techniques were first employed. Carbon dioxide and oxygen are commonly used as the lixiviant in current *in situ* operations; recovery of the lixiviant itself, may not be a serious problem. However, restoration must remove or otherwise neutralize the oxidant in order to restore chemical stability within the aquifer. Recovery of the lixiviant and solubilized constituents at the end of the extraction operation can be complicated if the lixiviant migrates to an area that has poor hydraulic connections to the rest of the production zone. Lixiviant in these hydraulic "dead ends" may continue to solubilize enough constituents to preclude attainment of baseline parameters (Osiensky and Williams, 1990). This type of effect is typically limited to specific wells or portions of the production zone rather than entire production zones.

Although carbon dioxide and oxygen do not constitute contaminants of an aquifer, they function to oxidize and solubilize uranium (and other) constituents of the production zone. Once solubilized, the potential exists for migration of these constituents out of the production zone. Migration of solubilized minerals or lixiviant out of the production zone is termed an excursion. The severity of an excursion is dependant on the constituents involved (all solubilized constituents do not necessarily migrate), the use class of the affected aquifer, and the extent of the excursion. Detecting excursions may be complicated by the fact that constituents that have been solubilized may migrate out of the production zone and become reduced or precipitate prior to reaching a monitoring well. For this reason, selection of adequate parameters for use as upper control limits (UCLs) is critical (NRC, 1986).

In 1986, the NRC conducted an analysis of excursions at *in situ* mines in Wyoming and Texas. The percentage of excursions reported for individual wells compared to all operational wells was not discerned. The frequency of excursions was also not determined although the duration may range from a period of days to more that two years (in one case). The study found that the incidence of vertical excursions can be reduced by fully investigating the integrity of the aquifer prior to initiating extraction. Additionally, the study indicated that once excursions occur, horizontal excursions are more readily controlled than vertical excursions (NRC, 1986).

1.6.4 Air

1.6.4.1 Radon

Underground uranium mines produce exhaust, which typically has Radon-222 in measurable concentrations. Radon-222 is present in the exhaust because it emanates from the ore. The concentration of Radon-222 in mine exhaust varies depending upon ventilation rate, mine volume, mine age, grade of exposed ore, size of active working areas, moisture content and porosity of rock, barometric pressure, and mining practices. A previous EPA study indicates that higher Radon-222 emission rates occur at older mines, probably because there are larger surface areas of exposed ore and subore. By properly capping the exhaust vents and sealing the shaft and mine entrances with bulkheads, radon emission rates from inactive or closed underground mines can be dramatically reduced (EPA, 1983a).

Aboveground sources of radon-222 at both underground and surface extraction and beneficiation operations include exhalation from ore, waste rock, overburden (at surface mines only), and tailings. The amount of radon that emanates from these materials into the surrounding atmosphere can depend upon, among other things, the exposed surface area of the units in which the materials are located; the grade of material; the control mechanisms used; and, in the case of tailings, the method of deposition (EPA, 1983).

Radon also escapes from drill holes. When the development drill penetrates the ore body, the ore and sub-ore formations in the drill hole become exposed to air. Consequently, the radon emanates from the ore into the drill hole and can escape into the atmosphere (EPA, 1983a).

1.6.4.2 Fugitive Dust

A primary source of air contamination at mine sites are fugitive dust emissions from mine pits and underground workings, overburden, mine rock dumps, ore, sub-ore, and haul roads. Tailings may also be a potential source of fugitive dust when particulates are transported by wind. Dust emissions vary depending upon moisture content, amount of fines, number and types of equipment operating, and climate. The movement of large haul trucks can be a source of dust at most uranium mines. To minimize fugitive dust, haul roads are frequently sprinkled with water during dry periods or dust suppressants are applied. During the active life of the mine, water may be applied to these piles to control dust and prevent entrainment. After

mine closure, revegetation or other stabilizing methods may be used to control dust. The potential contaminants are heavy metals and other toxics (EPA, 1983).

1.6.4.3 Soils

The migration of radionuclides from mining or beneficiation operations into the soil can cause an increase in radioactivity of soils. It was found that radium-226 and, to a lesser extent, thorium-232 can adsorb into the structure of clay particles. These entities can also be desorbed by low concentration salt solutions (USBOM, 1984). Any metals that are present in waste rock, sub-ore, or tailings can be leached to the surrounding soil.

Environmental effects of uranium mining activities on soils includes those derived from surface disturbances. The most extensive soil disturbances are created by surface mines although surface facilities constructed for underground or *in situ* mining operations also impact soil, including a loss of vegetation cover. Loss of vegetation cover typically results in increased erosion rates unless measures are taken to stabilize topsoil and divert surface runoff from disturbed areas.

1.7 CURRENT REGULATORY FRAMEWORK

1.7.1 Introduction

Uranium mining activities must meet the requirements of both Federal and state regulations. The first part of this chapter addresses both the primary statutes that give Federal agencies the authority to regulate these activities and the regulations themselves. The latter portion of the chapter presents the regulatory programs of Texas and Wyoming to serve as examples of how State regulatory programs apply to uranium extraction and beneficiation.

The statutes (and associated regulations) that this chapter examines include: the Clean Water Act (CWA), as amended (33 USC 1251 et seq); the Clean Air Act (CAA), as amended (42 USC 7401 et seq); The Safe Drinking Water Act (SDWA), as amended (42 USC 300 (f) et seq); and the Atomic Energy Act (AEA) (42 USC 2021 et seq), as amended by the Uranium Mill Tailings Radiation Control Act (UMTRCA) (72 USC 7901 et seq). The primary Federal agencies responsible for implementing the aforementioned statutes include: the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), and the Department of Energy (DOE). The paragraphs below introduce each of the major statutes, which are described in more detail in subsequent sections.

The CAA gives EPA the authority to regulate emissions of both "conventional" pollutants, like PM_{10} (particulate matter less than 10 microns) and hazardous pollutants, such as radon. Both of these air pollutants are emitted by uranium extraction and beneficiation activities.

The CWA gives EPA the authority to impose effluent limits, via permits, on point-source discharges, including those from during uranium extraction and beneficiation operations, to waters of the U.S. It also

gives EPA the authority to regulate, through permits, storm water discharges from both inactive and active mine sites.

EPA established an Underground Injection Control (UIC) program under the authority of the Safe Drinking Water Act. Through this program, EPA established a permit system to ensure underground sources of drinking water are protected from the injection of process fluids and liquid wastes, including those produced during uranium extraction and beneficiation, into the subsurface via wells.

Under UMTRCA, EPA has the responsibility to establish standards for exposure of the public to radioactive materials originating from mill tailings and for cleanup and control standards for inactive uranium tailings sites and associated vicinity areas. It also gave EPA a mandate to establish standards for managing uranium tailings and wastes at active sites. Also under UMTRCA, DOE's role is to actually clean up and control inactive uranium tailings piles to comply with EPA standards.

UMTRCA requires the Nuclear Regulatory Council (NRC) to concur with remedies DOE selects for cleaning up and controlling inactive sites. Under UMTRCA, the NRC is also responsible for licensing active uranium mills and licensing inactive uranium tailings sites that have undergone remediation. Although the NRC has promulgated radiation protection standards that regulate active and inactive uranium milling sites, the NRC has no regulatory authority over uranium mines, except the aboveground activities of solution mines. The sections below more fully explore the regulatory roles of each of the aforementioned agencies.

The authority of State agencies to regulate uranium extraction and beneficiation activities comes from two sources, Federally delegated programs and State statutory authority. The Federal programs applicable to uranium extraction and beneficiation activities that can be delegated to the States include: the UIC program, the NPDES program, and NRC licensing and radiation protection standards. In order for a State to be able to administer any or all of these Federal programs, the State must have requirements that are at least as stringent as the respective Federal programs.

UMTRCA Title I Sites

Salt Lake City, UT
Green River, UT
Mexican Hat, UT
Durango, CO
Grand Junction, CO
Rifle, CO (two sites)
Naturita, CO
Maybell, CO
Slick Rock, CO (two sites)
Shiprock, NM
Ambrosia Lake, NM
Riverton, WY
Converse County, WY
Lakeview, OR
Falls City, TX
Tuba City, AZ
Monument Valley, AZ
Lowman, ID
Cannonsburg, PA
Edgemont, SD
Bowman/Belfield, SD

1.7.2 Federal Regulatory Program

1.7.2.1 The Uranium Millings Tailings Remediation Control Act

The U.S. Government began to purchase uranium for defense purposes in the early 1940s. Since that time, large quantities of tailings have been generated by the uranium milling industry. In many cases, these tailings have been dispersed from impoundments and piles by natural forces and by humans for construction use in or around buildings or for roads. UMTRCA, which in 1978 amended the AEA, established two programs to protect the public health, safety and the environment from uranium mill tailings. Title I of UMTRCA addresses 22 Congressionally

designated sites (to which DOE added two more) that are now inactive (e.g., all milling has stopped and the site is not licensed by the NRC). A list of these sites can be found in the box below. Title II of UMTRCA addresses active sites (those with NRC or Agreement State licenses) (48 FR 45926).

Risks Posed by Uranium Mill Tailings

Uranium occurs in various minerals as one of three isotopes: U-234, U-235, and the most abundant of the isotopes, U-238. Yellowcake is a generic term used to describe the yellow powder generated as the end product of uranium beneficiation. The purity of yellowcake typically ranges from 60 to 75 percent U_3O_8.[1]

Historically, conventional uranium mining consisted of extracting uranium bearing rock, then crushing, grinding, and froth flotation to produce a uranium concentrate yellowcake. This milling process generated large volumes of tailings which were disposed of in tailings impoundments. Radium-226, thorium-230, and radon-222 (gas) are the radionuclides present in uranium mill tailings that are of principle concern to human health and the environment. In *American Mining Congress v. Thomas* (AMC I), the court recognized the dangers to human health and the environment from uranium mill tailings when it stated that:

> [r]adium decays to produce radon. Radon is an inert gas, some of which escapes from the tailings particles into the atmosphere. Airborne radon degrades into a series of short half-life decay products that are hazardous if inhaled. If the radon gas does not escape the mill tailings piles, its decay products remain in the piles and produce gamma radiation, which may be harmful to people and animals living near the mill tailings piles. Uranium mill tailings also contain potentially dangerous nonradioactive materials such as arsenic and selenium. These toxic and radioactive materials may be ingested with food or water.[2]

Uranium has primarily been mined in the western United States; Arizona, Colorado, New Mexico, South Dakota, Texas, Utah, Washington and Wyoming. A total of 14 uranium mines were operational in 1991; six underground mines, two open pits, and six in-situ facilities. Uranium was also produced to a limited extent as a byproduct of phosphoric acid production at two sites in Florida and one in Louisiana.[3] Both Florida sites no longer produce uranium but are still operating as producers of phosphoric acid.

Regulatory Structure

[1] Merritt, R.C. 1971. *The Extractive Metallurgy of Uranium*. Colorado School of Mines, Golden, CO.

[2] American Mining Congress v. Thomas (AMC I), 772 F.2d 617, 621 (10th Cir. 1985), cert. denied, 476 U.S. 1158 (1986). See also 48 Fed. Reg. 590, 592 (1983). See generally Environmental Protection Agency, Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites 3-68 (1982).

[3] Domestic Uranium Mining and Milling Industry 1992, Viability Assessment. U.S. Department of Energy, Energy Information Administration, 1993. DOE/EIA-0477(92), Distribution Category UC-98, Washington, DC.

A complex set of federal and state regulations are applicable to uranium mining and processing. These include the Atomic Energy Act (AEA)[4], as amended by the Uranium Mill Tailings Radiation Control Act (UMTRCA)[5]; the Clean Air Act (CAA)[6]; the Clean Water Act (CWA)[7]; and the Safe Drinking Water Act (SDWA)[8].

The primary federal agencies responsible for implementing these statutes include: the Nuclear Regulatory Commission (NRC) the Environmental Protection Agency (EPA) and the Department of Energy (DOE).

The Uranium Millings Tailings Remediation Control Act

In many cases, uranium mill tailings have been dispersed from impoundments and piles by natural forces and by humans for construction use in or around buildings or for roads. UMTRCA established two programs to protect the public health, safety and the environment from uranium mill tailings. Title I of UMTRCA addresses 24 inactive sites. An inactive site means that all milling has stopped and the site is not licensed by the NRC. Title II of UMTRCA addresses active sites that are required to have a license from NRC or an Agreement State.[9]

Title I of UMTRCA[10]

Title I defines tailings at inactive uranium milling sites as residual radioactive material. It requires the cleanup of offsite tailings and the long-term control of tailings piles. DOE was charged with remediating these designated sites, with the full cooperation and participation of the states, to achieve compliance with standards prescribed by EPA. EPA has promulgated final health and environmental standards to govern stabilization, control, and clean up of residual radioactive materials (primarily mill tailings) at inactive uranium processing sites.[11] The DOE must meet these standards when remediating Title I sites.

> Residual radioactive material is determined by the Secretary of Energy to be radioactive and can be either:
>
> (1) Waste in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores; or
> (2) Other waste at a processing site which relates to such processing, including any residual stock of unprocessed ores or low-grade materials.
>
> This term is used only with respect to materials at sites subject to remediation under Title I of UMTRCA.

[4] 42 U.S.C. § 2021 et seq

[5] 72 U.S.C. § 7901 et seq

[6] 42 U.S.C. § 7401 et seq

[7] 33 U.S.C. § 1251 et seq

[8] 42 U.S.C. § 300 (f) et seq

[9] A state can apply for and obtain permission from the NRC to become an Agreement State under AEA § 274(a), 42 U.S.C. § 2021(a). Otherwise, NRC exclusively regulates source, special nuclear, and byproduct material. As part of obtaining Agreement status, a state must demonstrate that its statutes and regulations conform to NRC requirements. 42 U.S.C. § 2021(d)(2).

[10] 42 U.S.C. § 7918.

[11] 40 C.F.R. 192 (1992).

EPA promulgated standards for two types of remedial actions: control and cleanup. Control places tailings in a situation that will minimize their long-term risk to humans. Cleanup reduces the potential health risks resulting from dispersed tailings. All remedial actions must be selected and performed with the concurrence of the NRC. Upon completion of the remedial action at the 24 designated sites, the NRC must issue a license to ensure that public health and the environment are protected. The license may require DOE to conduct monitoring, maintenance, or any other actions the NRC deems necessary.[12]

The Uranium Mill Tailings Remedial Action Amendments Act of 1988 provides an extension of the UMTRCA Title I deadline for the DOE to finish remediating the 24 designated sites. It allowed DOE until Sept 30, 1994 (previously 1990) to perform remedial actions at designated sites. The authority to perform groundwater restoration was extended without limitation.

The court in *AMC I* upheld most of EPA's standards except for the groundwater provisions of Title I regulations.[13] EPA is currently issuing new groundwater standards as a result of *AMC I*.[14] The previous standards for Title I sites were in the form of qualitative groundwater guidance in which DOE chooses the constituent concentration levels that groundwater must meet. When *AMC I* remanded EPA's standards, it instructed EPA "to treat these toxic chemicals that pose a groundwater risk as it did in the active mill site regulations."[15] In 1987, NRC promulgated final rules for groundwater protection at uranium mill tailings sites that conform to provisions of EPA's standards for groundwater protection at 40 C.F.R. § 192(d) and (e).[16] UMTRCA required agencies to use the available proposed standards until final ones were promulgated.[17]

In 1995, EPA issued final regulations to correct and prevent contamination of groundwater beneath and in the vicinity of inactive uranium processing sites by uranium tailings.[18] The regulations apply to tailings at 24 locations that qualify for remedial action. They provide that tailings must be stabilized and controlled in a manner that permanently eliminates or minimizes contamination of groundwater beneath stabilized tailings, so as to protect human health and the environment. They also provide for cleanup of contamination that occurred before the tailings are stabilized. The rule also establishes groundwater protection standards that include a list of specific hazardous constituents relevant to each waste management area, a concentration limit for each hazardous constituent, the point of compliance, and the compliance period.

EPA promulgated final standards for the control of residual radioactive material from non-operational uranium processing sites designated in Title I of UMTRCA in Subpart A of 40 C.F.R. § 192. The purpose of

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[12] 55 Fed. Reg. 45,591 (1990).

[13] American Mining Congress v. Thomas, 772 F.2d 617 (10th Cir. 1985), cert. denied, 476 U.S. 1158 (1986). Title I regulations are found in 40 C.F.R. 192.20(a)(2)-(3).

[14] 60 Fed. Reg. 2854 (1995).

[15] AMC I, 772 F.2d 617, 640 (10th Cir. 1985).

[16] 52 Fed. Reg. 43,553 (1987).

[17] See AMC I at 623. See also 55 Fed. Reg. 45,591 (1990).

[18] 60 Fed. Reg. 2854 (1995).

Subpart A is to provide for long-term stabilization and isolation in order to inhibit misuse and spreading of residual radioactive materials, control releases of radon to air, and protect water. These standards require that the remediation:

- be designed to be effective for up to one thousand years to the extent reasonably achievable, but at a minimum for 200 years,
- provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not exceed an average release rate of 20 Pci/m^2/s,
- provide reasonable assurance that releases of radon-222 from residual radioactive material will not increase the annual average concentration of radon-222 in air by more than one-half picocurie per liter.

Under Subpart B of 40 C.F.R. § 192, EPA promulgated final standards for the cleanup of land and buildings contaminated with residual radioactive materials at the 24 designated inactive uranium processing sites. EPA requires that remedial actions be conducted to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:[19]

- The concentration of radium-226 in land, averaged over any area of 100 square meters shall not exceed the background level by more than:
  - 5 picocuries per gram (Pci/g), averaged over the first 15 cm of soil below the surface.
  - 15 Pci/g averaged over 15 cm thick layers of soil more than 15 cm below the surface.
- In any occupied or habitable building:
  - The objective of the remedial action shall be, and reasonable effort shall be made to achieve, an annual average radon decay product concentration (including background) not to exceed 0.02 WL. Regardless, the radon decay product concentration, including background shall not exceed 0.03 WL.
  - The level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

WL (working level) is:
"Any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts." (40 CFR 192)

Subpart C of 40 C.F.R. § 192 allows DOE, with NRC concurrence, to apply supplemental standards in lieu of the standards in Subparts A and B. Before using these supplemental standards, certain conditions must be present; for example, the remedial actions required to satisfy Subpart A or B pose a clear risk of injury to workers or to members of the public.

Title II of UMTRCA[20]

[19] 40 C.F.R. § 192(b) (1992).

[20] 42 U.S.C. § 2022.

Title II of UMTRCA applies to currently operating uranium mill tailings facilities licensed by the NRC or an Agreement State. Title II regulates uranium byproduct materials such as mill tailings at operating sites. The Title II program contains requirements for a final disposal of tailings, the control of effluents into groundwater, and radon emissions during and after milling operations. UMTRCA required EPA to establish standards for operating sites in a manner consistent with standards established under Subtitle C of the Solid Waste Disposal Act, as amended.[21] However, the tailings as a substance are exempt from EPA's RCRA Subtitle C regulations.[22]

The standard setting requirements are divided into two parts. The first part applies to the management of tailings during the active life of the pile and during the subsequent closure period, which begins after cessation of milling operations but prior to completion of final disposal. The second part specifies standards for after the piles are closed, which govern the design of disposal systems.[23] The site must be closed in a manner that meets applicable NRC standards before the NRC or Agreement State terminates the operating license and issues a long-term care license.[24] The NRC requires a detailed Long-Term Surveillance Plan (LTSP) from DOE or an appropriate State which addresses ownership (whether Federal or State), disposal site conditions, the surveillance program, required follow-up inspections, and how and when emergency repairs and, if necessary planned maintenance, will be accomplished.[25]

In 1983, EPA proposed general environmental standards for uranium and thorium mill tailings sites licensed by NRC or one of its Agreement States.[26] The NRC published amendments to 10 C.F.R. § 40 to conform its rules to EPA's general standards in 40 C.F.R. § 192, as it affected matters other than ground water protection.[27]

EPA promulgated final rules in Subpart D of 40 C.F.R. § 192 to establish standards for the management of uranium byproduct materials at Title II sites, pursuant to § 84 of the AEA, as amended. Industry petitioners challenged these rules in *American Mining Congress v. Thomas*

> Byproduct material means the tailings or wastes produced by the extraction or concentration of uranium from any ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes. Underground ore bodies depleted by such solution extraction operations do not constitute "byproduct material" (40 CFR 192).

[21] 42 U.S.C. §§ 6901-6992k.

[22] There is no permit required by EPA for the disposal of byproduct material. 42 U.S.C. § 2022(b)(2). Additionally, uranium tailings are exempt from RCRA Subtitle C regulations (hazardous wastes) by 40 C.F.R. § 261.4(b)(7) (1992).

[23] 58 Fed. Reg. 32,174 (1993).

[24] 55 Fed. Reg. 45,591 (1990).

[25] Id.

[26] 48 Fed. Reg. 19,584 (1983). Final standards were published in 48 Fed. Reg. 45926 (1983) and codified in 40 C.F.R. § 192(D) and (E).

[27] 50 Fed. Reg. 41,852 (1985).

(AMC II).[28] The *AMC II* court found that EPA need not make a finding of a "significant risk" prior to promulgating regulations for mill tailings; that EPA may issue standards to apply within the boundaries of the mill sites; that the standards do not unlawfully compel specific engineering and design methods by the implementing agencies; and that EPA properly considered cost and benefit factors in establishing these standards.[29]

Uranium byproduct materials include the tailings or wastes produced by the extraction or concentration of uranium. The final standards address both uranium ore processing operations and closure and post-closure for uranium byproduct management facilities. The uranium ore processing operation standards require:

- impoundments containing uranium byproduct material such as tailings to meet design criteria established by EPA for owners and operators of hazardous waste treatment, storage and disposal (TSD) facilities[30]

- managing uranium byproduct materials to conform to:

  - a combined radium-226 and radium-228 standard of 5 Pci/l,

  - a gross alpha-particle activity (excluding radon and uranium) standard of 15 Pci/l for groundwater,

  - the groundwater protection standards[31] and the monitoring requirements[32] that were established for owners and operators of hazardous waste TSD facilities,

  - the Environmental Radiation Protection Standards for Nuclear Power Operations[33], and

  - the Ore Mining and Dressing Point Source Category: Effluent Limitations Guidelines and New Source Performance Standards, Subpart C, Uranium, Radium, and Vanadium Ores Subcategory.[34]

Uranium byproduct management facilities must meet the following closure and post-closure requirements:

[28] American Mining Congress v. Thomas (AMC II), 772 F.2d 640 (10th Cir. 1985) 16 Envtl. L. Rep. 20,069.

[29] Id.

[30] 40 C.F.R. § 264.221 (1992).

[31] 40 C.F.R. § 264.92 (1992).

[32] 40 C.F.R. § 264.98 (1992).

[33] 40 C.F.R. § 190 (1992).

[34] 40 C.F.R. § 440 (1992).

- closure and post-closure requirements for nonradiological hazards, which EPA promulgated for hazardous waste treatment storage and disposal facilities,[35]

- the disposal areas must be designed to provide reasonable assurance of effective control of radiological hazards for at least 200 years, and

- the disposal areas must be designed to limit releases of radon-222 from uranium byproduct materials to the atmosphere so as not to exceed an average release rate of 20 Pci/m^2/s (the same standard as for Title I sites). This requirement, however, is not applicable to any portion of a disposal site that contains a concentration of radium-226 that, as a result of uranium byproduct material, does not exceed the background level by more than:

  - 5 Pci/g, averaged over the first 15 cm below the surface

  - 15 Pci/g averaged over 15 cm thick layers more than 15 cm below the surface.

1.7.2.2 Nuclear Regulatory Commission

The NRC regulates active uranium milling and inactive uranium mill tailings disposal sites through licenses. It does not regulate the actual mining of uranium, except the above ground activities associated with solution mining. The NRC establishes its procedures and criteria for the issuance of licenses to receive title to, receive, possess, use, transfer, or deliver source and byproduct materials.[36] The authority for issuing these rules comes from the AEA, Title II of the Energy Reorganization Act of 1974, and Titles I and II of UMTRCA.

Source material is:

- Uranium or thorium, or any combination thereof, in any physical or chemical form, or

- Ores which contain by weight one twentieth of one percent (0.05%) or more of:
  - uranium
  - thorium, or
  - any combination thereof.

Source material does not include special nuclear material, for example plutonium or uranium 233 (10 CFR 40).

In *Quivira Mining Company v. NRC (Quivira Mining)*, the court held that NRC can issue regulations under UMTRCA that establish standards to follow in licensing and relicensing uranium mills and tailings sites.[37] The *Quivira Mining* court also held that although NRC performed no new cost-benefit studies in promulgating criteria for its rules, it reasonably relied on the cost-benefit analysis performed by the EPA when it issued its active site regulations.[38]

In a similar case addressing NRC's implementing criteria from the 1987 amendments to UMTRCA, *American Mining Congress v. NRC (AMC III)* held that the NRC properly considered the costs and benefits of its 1987 amendments when it conformed the amendments to the EPA's UMTRCA regulations concerning public health and safety that had already assessed costs and benefits.[39] The *AMC III* court held that since Congress has not stated whether the

[35] 40 C.F.R. § 264.111 (1992).

[36] 10 C.F.R. § 40 (1992).

[37] Quivira Mining Company v. NRC, 866 F.2d 1246 (10th Cir. 1989), 19 Envtl. L. Rep. 20,778.

[38] Id.

[39] American Mining Congress v. NRC (AMC III) 902 F.2d 781 (10th Cir. 1990) 20 Envtl. L. Rep. 21,054.

NRC must independently assess the costs and benefits of its regulations and the NRC is required to conform to EPA's health and safety regulations, NRC's interpretation of the UMTRCA is permissible and avoids replicating EPA's properly conducted cost-benefit analysis.[40] The *AMC III* court also held that EPA acted permissibly under the UMTRCA when it promulgated regulations that imposed RCRA requirements on uranium mill tailings.[41]

Remediated Nonoperating Uranium Mill Tailings Sites

The NRC has issued general licenses for Title I and Title II UMTRCA sites which have undergone remediation. Title I UMTRCA sites, the 24 designated inactive sites, are not subject to any licensing requirements during DOE's remediation, but Title II sites, the active sites, are subject to licensing requirements. The general licenses are for custody and long-term care of:

- Residual radioactive material at uranium mill tailings disposal sites remediated under Title I of UMTRCA
- Byproduct material at uranium or thorium mill tailings disposal sites regulated under Title II of UMTRCA.

These general licenses become effective when the NRC accepts a site's Long-Term Surveillance Plan (LTSP), from either the DOE or Agreement State. There is no termination of these general licenses. The LTSP must contain procedures for establishing groundwater monitoring, groundwater protection standards, inspections, and maintenance measures.

Operating Mill Tailings Sites

Operating mills and mill tailings sites must have site-specific NRC licenses for possessing and using

Highlights of NRC's Appendix A Requirements:

- Permanently isolate tailings such that active maintenance is not necessary,
- Comply with EPA's groundwater protection standards in 40 CFR 192, Subpart D,
- Conduct monitoring, including groundwater monitoring,
- Reduce all airborne effluent releases as low as reasonable achievable, by means of emission controls on mills and controlling dust from tailings piles,
- Establish financial surety to carry out decontamination and decommissioning of the mill and site, and for reclamation of tailings or waste disposal areas,
- Mills must pay a minimum of $250,000 (1978 dollars) to US Treasury or appropriate State agency, prior to license termination, for long-term surveillance costs, and
- Title to the byproduct material licensed in this part and land used for the disposal of this material must be transferred to the US or to the State (at its option).

[40] Id.

[41] Id.

source or byproduct material.[42] The NRC requires the license applicant to file an application for this license at least nine months prior to commencing construction of a plant or facility in which the activity will be conducted.[43] Further, the NRC has determined that the issuance of a license to possess and use source material for uranium milling is a major federal action which significantly affects the environment.[44] Therefore, pursuant to the National Environmental Policy Act, an Environmental Impact Statement must be prepared and submitted with the license application.

The license application must contain a proposed decommissioning funding plan or a certification of financial assurance for decommissioning.[45] Each decommissioning funding plan must contain a cost estimate for decommissioning and a description of the method of financial assurance.[46] Each licensee must keep records of information important to the safe and effective decommissioning of the facility which includes records of spills involving contamination.[47]

An application for a site-specific license must contain proposed written specifications relating to milling operations and the final disposal of the byproduct material to achieve the requirements that the NRC set forth in Appendix A of 10 C.F.R. § 40. Appendix A establishes technical, financial, ownership and long-term site surveillance criteria relating to siting the operation, decontamination, decommissioning, and reclamation of mills and tailings.

Radiation Protection Standards

Pursuant to the AEA and the Energy Reorganization Act of 1974, the NRC established standards for protection against radiation hazards resulting from Title I and Title II activities licensed by the NRC.[48] The regulations establish standards for permissible doses, and levels and concentrations of radiation for restricted and unrestricted areas.[49] They also establish precautionary procedures to be implemented (e.g. personnel monitoring, caution signs, procedures for handling packages, instruction of personnel and storage and control of licensed materials in unrestricted areas). Waste disposal criteria are also established. For example, NRC requires tailings and associated waste to be disposed of by transfer to an authorized recipient or by applying for NRC approval of proposed procedures to dispose of licensed material.[50] The regulations provide for criteria for disposal by release into sanitary sewage systems and other methods.[51] They also provide

[42] 10 C.F.R. § 40 (1992).

[43] Id.

[44] 10 C.F.R. § 51 (1992).

[45] Id.

[46] Id.

[47] Id.

[48] 10 C.F.R. § 20 (1992).

[49] Id.

[50] Id.

[51] Id.

requirements for records, reports and notification on radiation exposure of individuals for whom personnel monitoring is required; for disposal of licensed materials; for theft or loss of licensed materials; and for notification of incidents involving source material.[52]

Uranium Mill Tailings Sites Not Addressed Under UMTRCA

UMTRCA was enacted to provide remediation and protection from uranium tailings produced as a result of government contracts but not private contracts.[53] The 24 Title I sites have a special status because of their government contract relationship and are explicitly provided funding for remediation under UMTRCA. However, there are 12 private sites being addressed under Superfund that owe their problems to uranium mill tailings and other radioactive constituents.[54]

Because of the intrinsic hazard of many mining wastes, EPA relies primarily on the existing authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to require removal and remediation at sites where mining wastes pose a hazard to human health or the environment.[55] Without this Superfund safety net, persons suffering environmental damages from mine sites would have to rely on common-law remedies such as trespass, nuisance, and negligence.

This Superfund safety net was dealt a near fatal blow in the district court decision of *Iron Mountain* where the mining industry argued that the Bevill Amendment expanded the exclusion to include CERCLA liability.[56] The Bevill Amendment exempts uranium mill tailings from EPA's RCRA Subtitle C regulations.[57] The *Iron Mountain* court addressed whether Congress intended for the Bevill exclusion to also protect mining wastes from CERCLA liability. The *Iron Mountain* court held that "[t]he plain meaning of [CERCLA] § 101(14) suggests that only wastes not excluded by the Bevill Amendment or by some other exclusion may be regulated by CERCLA."[58] *Iron Mountain* held that "even if mining wastes are covered by CERCLA, certain wastes are excluded from coverage by reference to the Bevill Amendment in § 101(14)(C)."[59] The *Iron Mountain* court specifically rejected *Eagle-Picher* which held that an excluded mining waste may be subject to CERCLA liability if its components otherwise qualify as a hazardous substance due to its toxicity or other characteristics.[60]

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[52] Id.

[53] See Hecla Mining Co. v. U.S., 909 F.2d 1371 (10th Cir. 1990). 21 Envtl. L. Rep. 20,256.

[54] Mining Waste Sites on the NPL, Executive Summary, Preliminary Draft, 1992. Environmental Protection Agency, Office of Solid Waste. (Document available from the author.)

[55] 42 U.S.C. §§ 9601-9626 (1988).

[56] United States v. Iron Mountain Mines, Inc., 812 F. Supp. 1528, (E.D. Cal. 1992) reaff'd, recons. granted, summ. judgment denied, United States v. Iron Mountain Mines, 1993 U.S. Dist. LEXIS 1665, (E.D. Cal. 1993).

[57] 40 C.F.R. 261.4(b)(7) (1992).

[58] Iron Mountain at 1540.

[59] Iron Mountain at 1540.

[60] Eagle-Picher Industries v. EPA, 759 F.2d 922 (D.C. Cir. 1985).

In an unrelated case addressing the same issue, the Ninth Circuit in *Louisiana-Pacific* implicitly overruled *Iron Mountain* with respect to CERCLA coverage of Bevill exempt mining waste.[61] *Louisiana-Pacific* held that the Bevill exclusion only provides limited protection from CERCLA liability and that hazardous constituents released from mining wastes can be regulated under CERCLA.[62]

Summary of Major Court Actions Applicable to Uranium Mining

The four major cases interpreting UMTRCA are *AMC I, AMC II, Quivira Mining*, and *AMC III*. *AMC I* addressed EPA's UMTRCA inactive site regulations under Title I and for the most part upheld EPA's standards. *AMC II* upheld EPA's standards at active Title II sites. The decisions in *AMC I* and *AMC II* affirm Congress's strong interest in the expeditious control of threats to human health and the environment at uranium mill tailings disposal sites.[63]

Quivira Mining addressed and upheld NRC's implementing criteria. *AMC III* addressed and upheld amendment to NRC's implementing criteria. The decisions in *Quivira Mining* and *AMC III* set forth the scope of the cost benefit analysis used by EPA and NRC and concluded that it was proper for NRC to rely on earlier cost benefit analysis developed by EPA.[64]

The practical effect of *Louisiana-Pacific* is that private uranium mining activities (non-UMTRCA sites) are subject to Superfund liability, regardless of management practices and other environmental exemptions. The net result is that private uranium mine owners and operators are subject to Superfund liability just like most other industries. The Superfund safety net for uranium and other radioactive mining wastes remains intact.

1.7.2.3 Department of Energy

Under the authority of the AEA, as amended, DOE has promulgated regulations for leasing public lands controlled by DOE for uranium exploration and mining (10 CFR 760). (Some, but not all, public lands with known uranium deposits were withdrawn by DOE from other land management agencies; details surrounding the withdrawal of these lands were not obtained). Only citizens of the U.S. or U.S. corporations are eligible lessees. DOE issues leases through competitive bidding. DOE may, if it so chooses, require periodic submissions of plans for controlling environmental impacts. The lessee will be required to conduct operations to minimize environmental effects, to comply with all applicable State and Federal statutes and regulations, and to rehabilitate affected areas.

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[61] Louisiana-Pacific Corp. v. ASARCO, Inc., 6 F.3d 1332 (9th Cir. 1993), amended 13 F.3d 1378 (1994). It should be noted that Superfund is not the only safety net. When Iron Mountain held that mining wastes were exempt from CERCLA, EPA issued a RCRA § 7003 imminent hazard order to address the wastes under 42 U.S.C. § 6973. See Iron Mountain Cleanup Ordered Under RCRA After Court Decides Mining Wastes Exempt, 24 Env't Rep. (BNA) 184 (May 28, 1993).

[62] "It is clear from the plain language and structure of section 9601 that the specific exception for slag in subsection (C) applies only to that subsection and that slag is regulated by CERCLA to the extent that it falls under any other subsection of section 9601(14)." Louisiana-Pacific Corp. v. ASARCO, Inc., 6 F.3d 1332, 1339 (9th Cir. 1993), amended 13 F.3d 1378 (1994).

[63] 58 Fed. Reg. 32,174, 32,179 (1993).

[64] Id.

DOE is also responsible for remediating UMTRCA Title I sites to meet EPA standards, as described above. Any remedy DOE selects to undertake pursuant to the UMTRCA must have NRC approval prior to beginning remediation activities. As previously mentioned, DOE is responsible for the 24 Title II sites.

1.7.3 Clean Air Act

The three major components of the Clean Air Act program relevant to uranium extraction and beneficiation operations are the National Ambient Air Quality Standards (NAAQS), which regulate six criteria pollutants; the New Source Performance Standards, which regulate newly operating or new expansions of major sources of air pollutants; and the National Emission Standards for Hazardous Air Pollutants (NESHAPS), which regulate specific toxic pollutants emitted by specific industries.

Under the CAA (42 USC §7409, Section 109) EPA established national primary and secondary air quality standards for six "criteria" pollutants. These are known as the National Ambient Air Quality Standards (NAAQSs). The NAAQSs are maximum acceptable concentration limits for six air pollutants, one of which is suspended particulate matter of less than 10 microns in diameter. To attain the air quality goals set by the CAA, States and local authorities have the responsibility of ensuring their regions are in compliance with the NAAQSs. In addition, states may promulgate more stringent ambient air quality standards. Although fugitive dust control is not an explicit requirement of the Act, most States require fugitive dust suppression measures as part of their State Implementation Plans (SIPs) to achieve the NAAQS for particulate matter. Fugitive dust is common at uranium mining operations: it arises from mine pits, overburden, mine rock dumps, ore, sub-ore, and haul roads.

New Source Performance Standards (NSPSs), authorized under CAA §111, also have been promulgated for particulate emissions from all new or expanded uranium extraction activities (40 CFR 60, Subpart LL). However, uranium beneficiation activities and all underground processing facilities are exempt from the NSPSs. Also, NSPS particulate emission concentration standards only apply to stack emissions. The NSPSs require operations to contain stack-emitted particulate matter in excess of 0.005 grams per dry standard cubic meter (dscm). In addition, stack emissions must not exhibit greater than seven percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device. Also, on or after 60 days following the achievement of the maximum production rate (but no later than 180 days after initial startup), operations must limit all fugitive dust emissions to 10 percent opacity.

Standards have been established for radionuclide emissions from various sources, including uranium extraction and beneficiation activities, to the ambient air (40 CFR 61) under the authority contained in the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) portion of the CAA. EPA regulations that apply to uranium extraction and beneficiation activities are outlined below:

- Subpart B sets standards for active underground uranium mines. The standards in this subpart apply to an owner or operator of an underground uranium mine that has mined, will mine or is designed to mine over 100,000 tons of ore during the life of the mine, or has or will have an annual ore production rate greater than 10,000 tons, unless it can be demonstrated to EPA that the mine will not exceed 100,000 tons during the life of the mine. The regulation sets an emission standard for radon from the mine not to exceed 10 mrem/y for any member of the public. Reporting requirements are also specified in the regulation.

- Subpart H sets standards for facilities owned or operated by DOE, excluding inactive facilities regulated by Titles I and II of UMTRCA, which emit any radionuclide other than radon-222 and radon-220 into the air. Emissions of radionuclides from these facilities to the ambient air shall

not exceed those amounts which would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

- Subpart I sets standards for NRC-licensed facilities and to facilities owned or operated by any Federal agency other than the DOE (none were identified), except it does not apply to any Title I UMTRCA facilities that have undergone remediation as provided for in 40 CFR Part 192. Emission standards of radionuclides released from regulated facilities to the ambient air shall not exceed amounts which would cause any member of the public to receive in any year an effective dose equivalent of 3 mrem/yr.

- Subpart T sets standards for radon emissions from the disposal of uranium mill tailings. The regulation applies to the owners and operators for all sites that are used for the disposal of tailings that are listed in Title I of the Uranium Mill Tailings Control Act of 1978 or regulated under Title II of the same Act. Radon-222 emissions to the ambient air from uranium mill tailings units that are no longer operational shall not exceed 20 $pCi/m^2/s$.

- Subpart W sets emission standards for radon emissions from mill tailings at operational mills. It applies to owners or operators of facilities licensed to manage uranium byproduct materials from uranium mills and their associated tailings. Radon-222 emissions to the ambient air from regulated facilities shall not exceed 20 pCi/m2-s. Tailings impoundments built after Dec. 15, 1989 must be designed, constructed and operated to meet either phased disposal in lined tailings impoundments that are not greater than 40 acres, or continuous disposal of tailings such that tailings are dewatered and immediately disposed with no more than 10 acres uncovered at any time. Tailings disposal must be in accordance with 40 CFR 192.32(a).

EPA received several petitions for reconsideration of Subpart T because of concern that it overlapped with UMTRCA requirements for the management of uranium byproduct materials (Subpart D of 40 CFR Part 192). As a result the EPA, NRC, and Agreement States signed a Memorandum of Understanding (MOU) in October of 1991 that outlines the steps each will take to eliminate regulatory redundancy and to ensure uranium mill tailings are closed as expeditiously as practicable. On June 8, 1993, EPA proposed amending UMTRCA regulations contained in 40 CFR Part 192, Subpart D (58 FR 32174). These proposed regulations include a requirement for installing a permanent radon barrier designed to achieve the 20 pCi/m2-s radon emission standard, a compliance schedule for meeting the 20 pCi/m2-s radon emission standard, and a monitoring requirement to ensure tailings impoundment designs are effective at achieving the aforementioned standard. In the preamble to this proposed rule, EPA stated its intentions to eventually rescind Subpart T of 40 CFR 61 (NESHAPs), once it has been assured that the amended UMTRCA standards are as protective of public health with an ample margin of safety, as are the NESHAPS rules. NRC and the Agreement Sates agreed to amend the licenses of all sites whose milling operations have ceased and whose tailings piles remain partially or totally uncovered. The amended license would require the mill operator to establish a tailings closure plan.

1.7.4 Clean Water Act

Under section 402 of the CWA (33 USC §1342), all point-source discharges of pollutants to waters of the United States must be permitted under the National Pollutant Discharge Elimination System (NPDES). A

point source is defined as any discrete conveyance, natural or man-made, including pipes, ditches, and channels. NPDES permits are issued by EPA or delegated States.

Effluent limits imposed on an NPDES permittee are either technology-based or water-quality-based. National technology-based effluent guideline limitations have been established for discharges from uranium mines and mills under the Ore Mining and Dressing Point-Source Category (40 CFR Part 440, Subpart C). These regulations provide effluent limitations based upon best practicable control technology (BPT) and best achievable technology (BAT) for uranium mills and open-pit and underground uranium mines, including mines using *in situ* leach methods. Discharges from regulated operations must meet best available technology/best practicable technology (BAT/BPT) standards for zinc, arsenic, ammonia, dissolved radium 226, total radium 226, uranium, total suspended solids (TSS), chemical oxygen demand (COD), and pH. The specific effluent standards for these contaminants are shown in Table 1

Table 1-1. Effluent Limitation Guidelines for Discharges from Mines and Mills in the "Uranium, Radium, and Vanadium Ores Subcategory"

(milligrams per liter, except as noted)

Effluent characteristic	Mine drainage				Mill discharges		
	BPT limits		BAT limits		BPT limits		BAT limits
	One-day max	30-day average	One-day max	30-day average	One-day max	30-day average	
TSS	30.	20.	N/A		30.	20.	N/A
COD	200.	100.	200	100	N/A	500.	
As	N/A		N/A		1.0	0.5	
Zn	1.0	0.5	1.0	0.5	1.0	0.5	
Ra-226 (dissolved) (pCi/L)	10.	3.	10.0	3.0	10.	3.	
Ra-226 (total) (pCi/L)	30.	10.	30.0	10.0	30.	10.	
U	4.	2.	4.0	2.0	N/A		
pH (s.u.)	6.0 - 9.0		6.0 - 9.0		6.0 - 9.0		

New Source Performance Standards			
Effluent characteristic	Mine drainage		Mill discharges
	One-day maximum	30-day average	
TSS	30.	20.	No discharges of process wastewater allowed, except: when net precipitation exceeds annual evaporation, the difference may be discharged subject to BPT limits for mine drainage.
COD	200.	100.	
Zn	1.0	0.5	
Ra-226 (dissolved) (pCi/L)	10.	3.	
Ra-226 (total) (pCi/L)	30.	10.	
U	4.	2.	
pH (s.u.)	6.0 - 9.0		

N/A Not applicable (no standards promulgated)

NOTE: Limitations apply to discharges from open-pit or underground mines from which uranium, radium, and vanadium ores are produced; and to mills using the acid leach, alkaline leach, or combined acid and alkaline leach process for the extraction of uranium, radium, and vanadium. BPT and NSPS mine drainage limitations do not apply to *in situ* operations; BAT mine drainage and all mill discharge limitations do apply to such facilities. In addition, overflows from facilities designed/operated/maintained to contain or treat flows from the 10-year/24-hour storm event may qualify for "storm exemption."

SOURCE: 40 CFR 440 Subpart C: 440.32 (BPT), 440.33 (BAT), 440.34 (NSPS)

. EPA has also promulgated effluent guidelines for new uranium mines and mills, known as New Source Performance Standards (NSPSs). New source performance standards for mines are also listed in Table 1. New mills using acid leach, alkaline leach, or combined acid and alkaline leach process for uranium extraction or mines and mill using *in-situ* leach methods are not allowed to discharge process wastewater, unless annual precipitation exceeds annual evaporation.

The permit writers must also ensure that the NPDES permit will protect water quality. Permit writers must also determine whether technology-based effluent limitations i.e., BPT, BAT, and/or NSPS) are adequate to ensure that applicable water quality standards are met. Where technology-based limits are not sufficiently stringent, water-quality-based effluent limitations must be developed. As a result, a NPDES permit may include technology-based effluent limitations for some pollutants and water-quality-based effluent limitations for other pollutants. Individual states are required to adopt water quality criteria at least as stringent as Federal levels. The application of these criteria is based on the designated use of a specific receiving water (drinking water supply, aquatic life, and/or recreational use). Also, each State has been required to develop instream water quality standards to protect the designated uses of receiving waters.

Contaminated storm water runoff from some mining operations has been documented as causing water quality degradation. In the past, point source storm water discharges have received limited emphasis under the NPDES program. However, EPA recently promulgated regulations (55 FR 47990; November 16, 1990) that specifically address point-source discharges of storm water from industrial facilities, including active and inactive/abandoned mine sites. These regulations require NPDES permits for all point source discharges of contaminated storm water from mine sites. The implementation strategy calls for discharges to be covered in individual (facility-specific) or general (State or EPA Region-specific) NPDES permits. Some of the States authorized to implement the NPDES program (e.g. Colorado, Wyoming) have developed general permits for storm water discharges from mining facilities. For States not NPDES-authorized (e.g. Texas, Arizona), EPA is developing a general permit. EPA is also developing a separate general permit for storm water discharges from inactive/abandoned mines on Federal lands.

Some discharges from mine sites do not meet the definition of a "point source discharge." These discharges are nonpoint source discharges. Under Section 319 of the CWA, States are required to prepare nonpoint-source assessment reports and to develop programs to address nonpoint sources on a watershed-by-watershed basis. Each State must report to EPA annually on program implementation and resulting water quality improvements.

1.7.5 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) was enacted in 1974 and amended in 1986. It protects the quality of drinking water by establishing standards for drinking water quality and treatment and distribution systems, and by regulating the injection of waste and non-waste materials into disposal or other injection wells. The SDWA's most direct impact on the uranium industry is through the Underground Injection Control (UIC) Program, which aims to protect underground sources of drinking water.

EPA is responsible for implementing (or overseeing the implementation of) the UIC program. EPA regulations can be found in 40 CFR Parts 144-146. Upon EPA approval, States can be delegated the responsibility for implementing all or part of the UIC program in their jurisdiction.

EPA's UIC regulations protect underground sources of drinking water (USDWs) by prohibiting the direct injection or migration of foreign fluids into these aquifers. An underground source of drinking water is defined as any aquifer or its portion that supplies a public water system or contains fewer than 10,000 mg/l total dissolved solids (TDS). An aquifer may be exempted from UIC regulation if it is shown to be completely isolated with no possible future uses. In general, Federal regulations prohibit any underground injection unless authorized by permit or by rule. In addition, no owner/operator of a well may construct, operate, maintain, convert, plug, or abandon an injection well in a manner which allows the movement of contaminated fluid into underground sources of drinking water.

The program establishes requirements for five injection well categories. Regulations vary according to the class of well. These categories are outlined below.

Class I: Injection wells for hazardous, industrial, non-hazardous, and municipal wastewater disposal below the lower most formation, within 1/4 mile of the wellbore, containing an underground source of groundwater.

Class II: Injection wells for fluids related to oil and gas production such as salt water disposal wells, enhanced oil recovery wells and hydrocarbon storage wells.

Class III: Injection wells related to mineral extraction such as *in situ* production of uranium, only for ore bodies which have not been conventionally mined.

Class IV: Disposal of radioactive or hazardous waste into or above a formation which contains an underground source of drinking water within 1/4 mile. Section 3020(a) of RCRA prohibits the construction and operation of Class IV wells.

Class V: Injection wells not included in the other classes. This includes solution mining of conventional mines, such as stope leaching and low-level radioactive waste wells.

Classes I, III and V are potentially applicable to the uranium extraction and beneficiation industry. The Federal requirements for these wells are summarized in the subsections that follow.

1.7.5.1 Class I Nonhazardous Wells

Area of Review and Corrective Action Plan

Applicants for permits to inject into Class I wells must identify the locations of all known wells within the injection wells "area of review" that penetrate the injection zone. The "area of review" is the area surrounding an injection well described in accordance with listed criteria, or in the case of an area permit, is the project area plus a circumscribing area (either one-quarter mile or calculated according to criteria in the regulations).

For wells in the area of review that are improperly sealed, completed, or abandoned, the applicant must also submit a corrective action plan. The purpose of this is to ensure that pre-existing wells do not provide a conduit between the injection zone and underground sources of drinking water. An approved plan must consist of steps or modifications as necessary to prevent movement of fluid into underground sources of drinking water.

EPA (or the State) may require as a permit condition that injection pressure be limited so that pressure in the injection zone does not exceed hydrostatic pressure at the site of any improperly completed or abandoned well within the area of review. This limitation can be part of a compliance schedule and may last until all other required corrective action has been taken.

The regulations list various factors upon which EPA (or the State) may base its decision that a corrective action plan is inadequate. They include (1) the nature and volume of injected fluid; (2) the nature of native fluids or byproducts of injection; (3) the potentially affected population; and (4) abandonment procedures in effect at the time the well was abandoned. Each plan, for an existing well, must include a compliance schedule requiring corrective action to be completed as soon as possible. No new injection well may be used for injection until all required corrective action has been taken.

Mechanical Integrity Testing

Submission of an application for EPA approval of a State UIC program must include a program description, including an explanation of how the State will implement mechanical integrity requirements required under the regulations.

A well must meet the following mechanical integrity requirements. First, there can be no significant leak in the casing, tubing, or packer. One of the following methods must be used to determine that there are no impermissible leaks: (1) monitoring the annulus pressure; (2) pressure test with liquid or gas; or (3) a method authorized by the State or EPA other than the above, with the written approval of the Administrator. Second, there may be no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the well bore. There must be no significant fluid movement as determined by: (1) the results of a temperature or noise log; or (2) a method authorized by the State with the written approval of the Administrator or by EPA.

When conducting and evaluating these tests, the owner or operator and the EPA (or the State) must apply methods and standards generally acceptable in the industry. In reporting the results of integrity testing to EPA (or the State), the owner or operator must include a description of the test(s) and the methods used. In making an evaluation, EPA (or the State) will review monitoring and other test data submitted since the previous evaluation.

Technical Criteria and Standards

Among the technical criteria that apply to UIC programs to regulate Class I nonhazardous injection wells are the following: (1) construction requirements, including that wells be sited so that they inject into a formation beneath the lowermost formation containing an underground source of drinking water within one quarter mile of the well bore, and that wells be cased and cemented to prevent movement of fluids into underground sources of drinking water; (2) operating requirements, including that injection between the outermost casing protective of underground sources of drinking water and the well bore is prohibited; and (3) monitoring requirements, including that analysis be conducted of injected fluids with sufficient frequency to yield representative data of their characteristics.

1.7.5.2 Class III Wells

Area of Review and Corrective Action Plan

Requirements with respect to the establishment of an area of review and the submission of a corrective action plan described above under Class I nonhazardous wells also apply to Class III wells. Additional requirements apply to Class III wells: when EPA (or the State) is considering the appropriate corrective action, EPA (or the State) must consider the overall effect of the project on the hydraulic gradient in potentially affected underground sources of drinking water. If the decision is made that corrective action is not necessary, the required monitoring program must be designed to verify the validity of such a determination.

Mechanical Integrity Testing

The same requirements that apply to Class I nonhazardous wells apply to Class III. However, there is one difference with respect to methods that may be used to determine the absence of significant fluid movement. Acceptable methods for such purposes include: (1) where the nature of the casing precludes the use of the logging techniques prescribed in the regulations, cementing records may be used to demonstrate the presence of adequate cement to prevent such migration; (2) where EPA (or the State) elects to rely on cementing records to demonstrate the absence of significant fluid movement, the monitoring program required by regulations shall be designed to verify such an absence; and (3) as finalized in January 1992, EPA allows the use of the water-brine interface mechanical integrity test for salt solution mining. (57 *Federal Register* 1109, January 10, 1992).

Technical Criteria and Standards

Technical criteria applicable to Class III injection wells include (1) construction requirements, including that wells must be cased and cemented to prevent migration of fluids into or between underground sources of drinking water and that casing and cementing used for newly drilled wells must be designed to last the life of the well. Among the factors which must be considered in determining casing and cementing requirements are depth to injection zone, injection pressure, and type and grade of cement; (2) operating requirements, including that except during well stimulation, injection pressure at the wellhead must be calculated to assure that the pressure in the injection zone during injection does not initiate new fractures or propagate existing ones; and (3) monitoring requirements, including monitoring of the nature of injected fluids at time intervals

sufficiently frequent to yield data representative of their characteristics; and (4) reporting requirements, including quarterly reporting to the EPA (or the State) on required monitoring and reporting on results of mechanical integrity testing.

1.7.5.3 Class V Wells

In general, Federal regulations state that for Class V wells, injection is authorized by EPA until additional requirements under future regulations are promulgated. This means that such injection operations are authorized by *rule*, so no Federal permit is required. EPA has not yet promulgated regulations governing this class of wells.

It should be noted that individual States with approved Class V UIC programs may have their own technical requirements which apply to Class V wells in those States. (See discussion above on General State UIC Program Requirements). Some States with approved UIC programs may require permits, while other such States may authorize injection by rule.

A general provision of the UIC regulations that applies to Class V wells, is that no injection may be conducted in a manner that allows the movement of contaminated fluid into underground sources of drinking water.

Regulations require that within one year of the effective date of the UIC program in a particular State, the owners and operators of Class V wells in the State notify the State of these wells and submit required inventory information, including (1) facility name and location; (2) nature and type of injection wells; (3) operating status of such wells.

For EPA-administered UIC programs only, additional information must be submitted by owners and operators of certain types of Class V wells (in addition to other well classes). Among the types of Class V wells for which additional data may be requested by EPA are brine return flow wells. Data required to be submitted may include (1) a listing of all wells, including location of wells; (2) dates of completion of such wells; (3) identification and depth of the formation into which each well is injecting; (4) casing and cementing record, tubing size, and depth of packer; (5) average and maximum injection pressure at the wellhead; and date of the last mechanical integrity test, if any.

Under the UIC regulations, each State, in turn, is required to submit a report and recommendations to EPA, within three years of the approval of the State UIC program, concerning Class V wells. The report must contain data on (1) construction features of Class V wells in the State and the nature and volume of injected fluids; (2) an assessment of the contamination potential of such wells, using hydrogeological data available to the State; (3) an assessment of available corrective alternatives and their environmental and economic consequences; and recommendations for regulatory approaches and remedial actions where appropriate.

1.7.6 Selected State Regulatory Requirements

This section addresses applicable laws, regulations and permits that apply to the uranium extraction and beneficiation industry in Texas and Wyoming since these States contain the vast majority of operating facilities. The section on State regulation is intended to provide an example of State regulatory programs. It is not intended to be a comprehensive summary of regulatory programs in these or other uranium mining States. Wyoming is authorized by EPA to administer NPDES and the UIC program but is not authorized by the NRC for implementation of a AEA/UMTRCA program. Texas is not an EPA-delegated State for NPDES permitting but has been delegated responsibility for the UIC program under SDWA and is also authorized by NRC to implement the AEA/UMTRCA program. Therefore, EPA writes NPDES discharge permits for uranium extraction and beneficiation in Texas for discharges to surface waters and the NRC issues permits for uranium milling operations in Wyoming.

1.7.6.1 Texas

Uranium extraction and beneficiation regulation in Texas is in a state of transition. Until recently, the Texas Water Commission's UIC program had jurisdiction over injection wells, and the Texas Department of Health's Bureau of Radiation Control handled all radiation and radioactivity at uranium mines and mills, regardless of media (soil, air, or water). In March of 1992, the State legislature passed Senate Bill 2, which gave jurisdiction of disposal of radioactive waste at *in-situ* mines to the Texas Water Commission. The same legislation created a new agency, the Texas Natural Resources Conservation Commission (NRCC) (to become effective on Sept 1, 1993). The entire Texas Air Control Board, the entire Texas Water Commission (TWC), and parts of the Texas Department of Health's Bureau of Radiation Control will be moved to the NRCC. Further, there are new bills currently in the State legislature that could move all of the uranium extraction and beneficiation regulatory functions, including licensing and inspections, to the NRCC.

Water Commission

The Texas Water Commission regulates some aspects of *in situ* uranium mining pursuant to the Texas Water Quality Act, Chapters 26 and 27 of the Texas Water Code. The TWC does not address surface water discharges associated with uranium extraction and beneficiation because Texas is not a NPDES-authorized state. The Commission is the State authority administering the EPA-delegated UIC program. Under the UIC program, the Commission has been responsible for the permitting of non-radiological contaminants in injection fluids. Recently, however, the Commission has also become responsible for administering NRC's authority over disposal of radioactive waste at *in situ* mines, via injection wells. This authority stems from Texas becoming an NRC Agreement State in the early 1960's. Previously, the Department of Health administered NRC's radiological contaminant requirements at *in situ* mines, but the authority was transferred to the TWC in an effort to minimize the number of permits needed by uranium solution mines (Kohler, 1993). A Memorandum of Understanding (MOU) between the two agencies establishes responsibilities for each of the program elements (Kohler, 1993). The Commission issues site-specific permits for solution mining, which includes UIC and NRC requirements, and also issues subsequent production area authorizations under the site-specific permit (TDWR, 1984). Some of the NRC and UIC (Class II wells) solution mining permit requirements include:

- Restoration procedures such as plugging of wells and restoration of ground cover
- Liners for all wastewater ponds
- Leakage detection, repair procedures, and freeboard limits for all ponds
- Controlled access to the ponds to prevent entrance by wildlife and unauthorized persons
- Runoff and spill control measures
- Preventive maintenance such as inspection for ponds, pipelines, dikes, trenches, and storage areas
- Disposal of all radioactive wastes pursuant to Department of Health requirements
- Disposal of non-radioactive solid and semi-solid wastes at an authorized waste disposal site in accordance with the Texas Water Commission rules
- Use of non-ammonia leaching solution at production areas
- Sampling of monitoring wells every 3 months
- Proof of mechanical integrity of all injection wells
- Financial assurance, usually in the form of a bond, for proper plugging and abandonment of wells, for any surface contaminant cleanup and restoration, including groundwater remediation to levels that would allow unrestricted use
- Aquifer restoration to pre-mining conditions once mining has ceased.

Department of Health

Texas is a NRC-Agreement State, and the Department of Health's Bureau of Radiation Control (BRC), in conjunction with the TWC, is responsible for administering the NRC radiation regulatory program for uranium extraction and beneficiation (see above). Texas has incorporated the NRC regulations pertaining to uranium extraction and beneficiation into Texas' Regulations for Control of Radiation (Haygood, 1993).

Previously, the BRC licensed (byproduct material) and conducted inspections at *in situ* mining facilities. As noted above, both of these responsibilities, however, have been assumed by the TWC in an effort to minimize the number of licenses (and permits) required from the industry (Haygood, 1993). The BRC, however, is still responsible for licensing uranium mills. Additionally, the BRC also implements the NESHAPs provisions for radon at uranium *in situ* mines and uranium mills. The BRC has no authority over uranium surface mines.

Railroad Commission (TRC)

The TRC regulates uranium surface mining, pursuant to the Texas Uranium Surface Mining and Reclamation Act. It has jurisdiction over private lands, while the General Land Office has jurisdiction over State lands (through a letter of agreement, the Commission actually regulates operations on State lands under the General Land Office authority). As part of this responsibility, the TRC issues bonds to ensure reclamation will be completed after mining has ceased (EPA, 1984). The TRC also regulates the exploration phase of *in-situ* uranium mining. Once production of wells begins, however, the Water Commission has regulatory jurisdiction. The TRC has promulgated its regulations in Rules of the Surface Mining and Reclamation Division (EPA, 1984).

General Land Office

The General Land Office issues prospecting permits and mining leases on State lands. The General Land Office has authority to regulate uranium mining on State lands, but does not exercise its authority because it has turned it over to the Railroad Commission in a letter of agreement between the two agencies. It requires a plan of operations as part of the mining lease application and may specify certain reclamation requirements for obtaining a lease. Usually, however, the General Land Office leases simply incorporate by reference the Railroad Commission's mining requirements (Farr, 1993).

Air Control Board

The Board is responsible for regulating non-radioactive air emissions, and must ensure that Texas complies with National standards. The Board regulates fugitive dust from "non-agricultural operations," which includes uranium extraction and beneficiation, and particulate matter emitted from stacks (Betrick Hameron, 1993). The Board's standards parallel those set by EPA (see above). NESHAPs standards for radon emissions from uranium extraction and beneficiation are implemented by the BRC, as noted above.

1.7.6.2 Wyoming

Most of the permits required by uranium mining and beneficiation operations in Wyoming must be obtained through the Wyoming Department of Environmental Quality (WDEQ). The WDEQ consists of four divisions: land quality, water quality, air quality and solid waste. Permits for impoundments and reservoirs are issued by the State Engineer's Office (SEO); the SEO also handles issues involving water rights. Wyoming is not a NRC delegated state, so, uranium milling and *in situ* operators must apply to the NRC for a Source Materials License.

Department of Environmental Quality

Land Quality Division (LQD). The LQD is the lead agency in permitting mining operations and is the sole authority for issuing mining permits. The LQD and WQD jointly issue Groundwater Pollution Control permits for *in situ* operations. Groundwater monitoring data are submitted to and reviewed by the LQD. The LQD is responsible for bonding provisions and annual inspections. In addition, the LQD distributes

guidelines addressing numerous permit-related topics including *In Situ* Mining, Hydrology, Soils and Overburden, and Vegetation. Land Quality Division Mining Permit Requirements include:

- Baseline Groundwater Quality Survey - for the permit area and each mining unit (UCLs are determined at this time)
- Hydrogeologic Characterization
- Surface Water Baseline (quality and quantity)
- Geological Assessment
- Detailed Mineral Extraction and Reclamation Plan.
- Bonding (for the cost of reclaiming affected land or ground water disturbed by mining)
- Vegetation survey (including Threatened and Endangered Species)
- Soils Assessment
- Wildlife Inventory.

Water Quality Division (WQD). Since Wyoming has been delegated NPDES and UIC programs, the WQD issues all permits for surface water discharges (i.e., NPDES) and underground injection (injection/production wells and disposal wells). The operation of injection and production wells are also covered under the LQD/WQD Groundwater Pollution Control permits. Wastewater Land Application Facility permits are required by *in situ* operators who dispose of excess process water through land application.

State Engineer's Office

The SEO requires that all dams and impounding structures be certified by a professional engineer. The office is also the lead agency for impacts on water rights.

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APPENDIX A

NPL SUMMARIES RELATED TO URANIUM EXTRACTION AND BENEFICIATION

Appendix A
NPL Summaries Related to Uranium Extraction and Beneficiation

This Appendix includes summaries of Superfund National Priorities List (NPL) sites related to extraction and beneficiation of uranium. The original summaries were prepared by EPA in 1991. Excerpts from these summaries are included in this profile as case study examples of select mining operations. The summaries provide a brief description of the operation, but focus on site-specific environmental effects and, in several cases, provide a brief summary of EPA actions at the site. The NPL examples illustrate some of the problems associated with uranium mining. As stated in the introduction, uranium processing wastes are not addressed in this profile. Although there are uranium processing-related sites on the NPL, they have not been discusses in this Appendix. At some sites discussed, however, both tailings and processing wastes contributed to the environmental hazards that resulted in their listing on the NPL.

Homestake Mill; Grants, New Mexico

Operating History

The Homestake Mill Superfund Site is located in Cibola County, New Mexico, approximately 5.5 miles north of Milan, New Mexico. The site consists of an uranium processing mill and two tailings embankments at an elevation of approximately 6,600 feet. The mill began operating in 1958, and was originally licensed by the Atomic Energy Commission. The Mill has a nominal design capacity of 3,400 tons per day (tpd). The site was placed on the NPL in September 1983. In June 1990 the Mill stopped operating and went on "standby status."

When operating, the Mill employed an alkaline leach-caustic precipitation process for extracting and concentrating uranium oxide (yellow cake) from ores that historically averaged from 0.05 to 0.30 percent U_3O_8, to produce yellowcake. Tailings from the process are composed of uranium-depleted fine and coarse sand and slimes.

Two separate embankments have been used to dispose of tailings generated at the mill. The most recently used embankment consists of two impoundments, and covers approximately 175 acres with tailings that total 17 million cubic yards (21 million tons) and measure 90 to 100 feet high. The tailing embankment is constructed of coarse tailing material, and at least 60 acres were covered by water. The second embankment, which has not been in use since 1962, covers approximately 45 acres, measures 25 feet high, and contains 1.225 million tons of tailings. More than 95 percent of the top of this embankment is covered with at least 6 inches of soil.

Tailings were slurried from the Mill to the embankments. The tailings were deposited on (and within) the embankment by means of wet cyclones, which separate the material into coarse and fine splits. The tailing piles have been stabilized with solid materials such as erosion control blankets and used tires, wetting the piles with water, and chemical-stabilization agents that form a crust on the surface to reduce water and wind erosion.

An injection and collection effort has resulted in a decrease in the groundwater contaminant plume, which no longer extends past the facility boundary.

Environmental Damages and Risks

The EPA evaluated risks to public health from exposure to the levels of radon found during the study. Lung cancer lifetime risks per year for the 17 residents of the 8 houses [with more than 4 pCi/l average annual indoor radon concentrations] range from 0.000031 to 0.00059 and center around 1 in 10,000 per year of residency for all age groups. The evaluation indicates that this is not considered a significant risk, as the models used are very conservative. Further, the mill site is not believed to be the main source of the radon contamination.

Lincoln Park Site; Canon City, Colorado

Operating History

Uranium milling began at the Cotter site in 1958. The first mill operated until 1979 using an alkali process. An acid leach mill process began in 1979, but has been inactive since 1986. The site covers approximately 1.4 square miles in south central Colorado and consists of two inactive mills, a partially reclaimed tailings pond disposal area, and an inactive tailings pond disposal area.

During the milling process, molybdenum and vanadium were recovered as by-products during uranium concentrate production. During the period of alkali milling (prior to 1979), 10 ponds were used for storage of process liquid and fresh water, for the disposal of tailings, and for storage of fresh water. These ponds are unlined except for Pond 2 (lined in 1972); Pond 3 (lined in 1981); and Pond 10 (lined in 1976).

In December 1979, when the acid milling process began, a double-lined impoundment was installed with drains above the synthetic membrane and below the clay layer and synthetic membrane. Tailings from this acid leach process and water collected from ground-water interceptors are stored in this impoundment. It consists of two sections: (1) a 91-acre primary impoundment for the storage of acid leach mill wastes; and (2) a 44-acre secondary impoundment. During the period between April 1981 to August 1983, the contents of Ponds 1, 2, 4, 5, 6, and 8 (2.2 million cubic yards of tailings) were moved to a double-lined secondary impoundment. Ponds 9 and 10 were removed in 1978 during construction of the secondary impoundment.

Reagents used in the milling process included sulfuric acid, ammonia, ammonium sulfate, kerosene, tertiary amines, sodium and calcium salts, potassium permanganate, zinc sulfate, and organic flocculents.

The Mill occasionally processed custom ores such as waste raffinate from other mills and precipitates or slags from other processes. In one instance, Polychlorinated Biphenyl (PCB)-contaminated ore was processed, which contaminated some of the plant areas. Trichloroethylene was used to extract the PCBs from the contaminated soils. This issue was being investigated by EPA at the time the Remedial Investigation was prepared in 1986.

A catalyst plant on the Mill site was operated briefly in 1978 and 1979 to recover metal values from spent catalyst material. Spent sulfuric acid catalyst material is currently stockpiled north of the old Mill.

Sources of contamination include the uranium ore stockpile, tailings, and raffinate; contaminated soils and groundwater; leaks from the old tailings ponds; and suspected leaks from the new impoundment area. Contaminants include radium, nickel, molybdenum, cobalt, copper, arsenic, zinc, lead, and cadmium. The Cotter site is located south and almost adjacent to the semirural area of Lincoln Park and 3.5 miles south of Canon City. The site is located in a topographic bowl known as "Wolf Park Basin." Offsite ground-water contamination from the Cotter site was first noted in the Lincoln Park area in 1968. Prior to a 1988 State-ordered clean-up, a number of residences used water from wells on their property, either in addition to their

Canon City tap water or as their sole supply. Homes in the impacted area are presently supplied with Canon City water. Most land around the Mill is used for grazing livestock and wildlife habitat.

Environmental Damages and Risks

The AEC was the regulatory agency responsible for oversight of the facility from 1958 to 1968. Between 1959 and 1966, the site was cited 18 times for failing to track radioactive releases. The State of Colorado Department of Health assumed regulatory oversight in 1968 and cited Cotter Corporation 82 times for various violations under the Nuclear Regulatory Commission regulatory process between 1968 and 1984. Among the state citations were exceedance of "As Low As Reasonably Achievable" particulate emissions, discharge and releases from tailings discharge pipes, and poor recordkeeping on control of off-site surface-water contamination.

Contaminated groundwater at the site is transported downgradient into the Lincoln Park area. Ground-water contamination was first noted in Lincoln Park in 1968. Concentrations of molybdenum in Lincoln Park groundwater were in the range of 24 to 60 mg/l (compared to a background level of about 0.005 mg/l). These levels were described as injurious to cattle and unsuitable for irrigation of crops used for cattle feed. A contaminant plume of uranium and molybdenum extends from the Cotter site (in the shallow pathway along the Sand Creek drainage) into Lincoln Park and eventually to the Arkansas River. Concentrations of molybdenum and uranium at the Mill site from 1981 to 1984 ranged up to 231 and 116 mg/l, respectively, in Lincoln Park. Concentrations in Lincoln Park ranged up to 0.92 and 13.2 mg/l. Maximum concentrations in Lincoln Park of lead and selenium, as well as gross alpha and beta, exceeded Maximum Contaminant Levels for drinking water.

Wind transport of contaminants has been observed since 1958. Emissions of radionuclides and hazardous metals have been measured through air and soil sampling. Offsite soil concentrations of metals are at (or above) a level of concern for agriculture use, cattle grazing, and wildlife. In particular, soil concentrations were above critical values for molybdenum, cobalt, nickel, arsenic, copper, zinc, and cadmium. In general, it was found that contamination decreased with distance from the Cotter site. Contaminated offsite soils are, in turn, entrained in surface flow, and contaminants are transported in the intermittent streams to the Arkansas River.

Offsite vegetation samples were also shown to be contaminated, with levels exceeding levels toxic to plants and/or animals of molybdenum, zinc, and cadmium.

Uravan Uranium Mill; Uravan, Colorado

Site Overview

The Uravan Uranium mill complex is located approximately 90 miles southwest of Grand Junction along State Highway 141 in Montrose County, Colorado. The mill was built at Club Mesa, west of the San Miguel River canyon.

Standard Chemical Company began operating the Uravan Mill facility in 1915 to recover uranium, vanadium, and radium from mined ores. Ore was received at the Uravan Mill from approximately 60 different underground mines in the Uravan mineral belt, most of which were within 35 to 40 miles of the mill. Union Carbide bought the facility from Standard Chemical through the U.S. Vanadium Company in 1936 and continued to process uranium and radium at the site. While in operation, the mill processed approximately 1,000 tons of ore per day.

Stockpiled ore was crushed, ground, and then beneficiated onsite. Beneficiation at the mill included hot, strong acid leaching in a two-stage circuit followed by the recovery of pregnant solutions in thickeners. Uranium was recovered from the pregnant solution and separated from vanadium by column ion exchange, with the final yellowcake product precipitated with ammonia. The uranium yellowcake and crude vanadium precipitate was then further processed at another Union Carbide facility in Rifle, Colorado.

Plant tailings from the thickener circuit were pumped into tailings piles which, by late 1984, covered over 80 acres and contained approximately 10 million tons of tailings. The tailings have a low pH and are contaminated with both metals and radionuclides.

Raffinate, a liquid or crystallized waste of primarily hydrated ammonium sulphate from the milling and extraction process, contains ammonium-aluminum salts, dissolved ore elements, and spent processing reagent. These wastes contain hydrated ammonium sulfate, uranium, vanadium, iron, sodium, radium, calcium, silver, silicon, potassium, sulfate, carbon, mercury, lead, molybdenum, manganese, zinc, cobalt, copper, chromium, and nickel. The liquid form of this waste was stored in evaporating ponds, while the crystallized waste was stored in onsite repositories. The river ponds along the San Miguel River are below the level of the potential maximum flood. Analyses of liquid and solid components of Uravan wastes show high levels of many metals.

The principal waste management areas onsite and in associated areas are:

- Atkinson Creek Crystal Disposal Area - Unlined storage pit along the San Miguel River containing 200,000 cubic yards of raffinate crystals.

- Club Ranch Ponds - Six unlined ponds covering 32 acres located along the San Miguel River that contain 30 million gallons of liquid raffinate and 560,000 cubic yards of raffinate crystals.

- River Ponds - Seven unlined ponds constructed in old tailings piles containing 200,000 cubic yards of neutralized mill sludge and contaminated soils. The seven ponds are located along both sides of the San Miguel River. These were used as holding areas for liquid waste collected in the mill area before they were discharged into the San Miguel River.

- Tailings Piles - About 10 million tons of mill tailings contained in three piles (at two sites) that are located on the Club Mesa, 400 feet above and west of the mill site.

- Club Mesa Area - Disposal area on Club Mesa consisting of two clay-lined sludge storage areas, storage ponds, raffinate spray evaporation area, and associated contaminated soils; contains 250,000 cubic yards of raffinate crystals, 150,000 cubic yards of neutralized sludge, 40,000 cubic yards of contaminated pond material, and 44,000 cubic yards of contaminated soil.

- Plant Areas - Two plant locations with surficial contamination including containment structures, ore stockpile area, equipment and auxiliary wastes, and heap leach sites containing 15,000 tons of ore.

- Town and Adjacent Areas - Several small communities and three larger population centers located along the San Miguel River are within 50 miles of the site. Old tailings and contaminated soil have been found in these areas.

Mining, milling, and waste disposal activities have resulted in:

- Wind and surface-water dispersal of the tailings materials and the uncontrolled release of radon from the Tailings Piles

- Seepage of contaminated liquids into soils and groundwater from several areas in the mill complex and waste disposal areas

- Concentrations of large quantities of wastes in locations that pose a risk to public health and the environment, based on considerations of the potential for release of hazardous materials to the environment.

Environmental Damages And Risks

Initial interest in the site was prompted by the State of Colorado's belief that contamination (resulting from poor waste management practices at the Uravan facility) was impacting the State's natural resources.

Several small communities (Nucla, Naturita, Vancorum, Redvale, Norwood, Placerville, Saw Pit, Paradox, Bedrock, Gateway, Olathe, Whitewater, Glade Park, Monticello, and Moab) and three larger population centers (Grand Junction, Delta, and Montrose) are within 50 miles of the site. The total area population is thought to be around 3,000 people, down from 5,500 in 1960. (According to EPA, residents of Uravan were advised to move away in 1985 due to the high levels of radioactivity measured in the area. By 1986, only 50 permanent residents remained. In 1988, after all permanent residents had relocated, all company homes and buildings in Uravan were demolished.) No drinking water is drawn from the San Miguel River downstream of the facility site, although water is drawn to irrigate local hay fields.

Without remediation, the potential risk to human health as a result of the site contamination is thought to be moderate. This is because of the modest size of the population actually residing in the risk area. It was concluded that even if the facility experienced a large release of contaminants into the environment, based on present population, very few people would be affected. Radiological and nonradiological contaminants in the tailings area represent the source or origin of the greatest potential human health hazard associated with the Uravan Mill.

Potential radiological environmental hazards arise from the radioactivity released during the milling of natural uranium and are primarily associated with the natural decay of uranium 238, the parent isotope, and its radioactive daughters present in the ore. In the tailings pile specifically, the decay and ingrowth of the short-lived radon gas and its daughters represent major contributions to the potential radiological hazard associated with the Uravan Mill. As of 1986, radiation sources associated with the tailings piles constituted over 50 percent of the total airborne radioactivity released from the Uravan uranium milling operation. This was expected to increase to 90 percent of the total airborne radioactivity released from the mill, which permanently closed in 1991. The longer the operational or active open surface lifetime, the greater the potential hazard of the tailings pile radiation source due to potential releases. However, according to EPA, nearly all tailings piles have been capped, and are not as large a source of airborne radioactivity.

Both forage and vegetables in the site area are consumed by wildlife and livestock. These contaminants will bioaccumulate as a result of consumption by either animals or humans that are primary or secondary consumers. The high dispersion of contaminants in the area is attributed to wind transport of contaminated particles.

Monticello Mill Site; San Juan County, Utah

Operating History

The Monticello Mill Tailings site is an abandoned uranium/vanadium mill occupying 78 acres in, and adjacent to, the City of Monticello, San Juan County, Utah. The tailings and residual ore remaining at the site have contaminated soils, groundwater, and surface water in Montezuma Creek, which flows through the Mill site. An additional 300 acres of peripheral properties (properties adjacent to the Mill site and a 3.3-mile reach of Montezuma Creek between the Town of Monticello and Vega Creek) have been contaminated by airborne particles from tailings and water-transported tailings and ore from leftover piles.

The Monticello Mill site began operation as a vanadium ore-buying station in the 1940's. As ore production increased, a vanadium mill was constructed with government funding. The Mill began vanadium production in 1942 and uranium-vanadium sludge production in 1943 for the Manhattan Engineer District. The mill was closed in February 1944; it was reopened in 1945 and produced uranium-vanadium sludge until 1946. A salt-roast process was used to convert vanadium minerals to soluble form. After pyrite was added to react with some of the calcium (in the excess lime in the ore) to form calcium sulfate, the hot ore was quenched in sodium carbonate to dissolve most vanadium and precipitate out calcium carbonate. Remaining sands, after successive washings, were transferred to tailings ponds. The addition of sulfuric acid to the "pregnant liquor" (i.e, the vanadium-bearing solution) induced the precipitation of vanadium pentoxide. The precipitate was washed to remove sodium chloride and sodium sulfate, and the wash water was discharged to the creek.

In 1948, the Atomic Energy Commission (AEC) bought the Monticello Mill site from the War Assets Administration and operated a uranium mill at the site until January 1960. Numerous uranium milling processes were used during this period to accommodate the wide variety of ore types received at the mill. Up to 1955, processes included raw ore carbonate leach, low-temperature roast/hot carbonate leach, and salt roast/hot carbonate leach; acid leach-resin-in-pulp (RIP) and raw ore carbonate leach from 1955 to 1958; and a carbonate pressure leach RIP process from August 1958 until closure of the mill in 1960. The ore-buying station remained open until March 31, 1962. Other than parts of the land transferred to the U.S. Bureau of Land Management, since 1949 the site has remained under the control of the AEC and its successor agencies [first the U.S. Energy Research and Development Administration and, more recently, the U.S. Department of Energy (DOE)].

Four tailings impoundments were constructed at the Monticello Mill site. Two tailings impoundments, the Vanadium Pile and the Carbonate Pile, received waste material prior to the 1955 installation of the acid leach RIP plant. The Carbonate Pile received tailings from the AEC salt roast/hot carbonate leach milling process. It is not known which of the several milling processes in use prior to acid leach-RIP produced the tailings in the Vanadium Pile. The Vanadium Pile and the Carbonate Pile may have been used simultaneously. The Acid Tailings Pile received waste in 1955 and 1956 from the operation of both the acid leach-RIP and carbonate-leach plants. Tailings from the acid leach process were combined with carbonate plant tailings and calcium hydroxide for neutralization and then pumped to the Acid Pile (where a portion of pond overflow was recycled through the leach circuit). The remaining overflow was discharged to Montezuma Creek. To reduce discharges to Montezuma Creek, the Acid Pile was constructed with a 6-inch liner of compacted bentonite to prevent seepage; tailings-pond effluent was partially recycled. A fourth tailings impoundment, referred to as the East Pile, was constructed to increase capacity. It received tailings from 1956 to 1960.

During the Mill's period of operation, the tailings impoundments were moist. However, within a year of shutdown, the surfaces dried out and tailings sand began to migrate as sand dunes. In addition, water erosion "became a problem."

AEC began stabilizing the piles in the summer of 1961 by grading, adding 8 to 12 inches of fill, adding topsoil, and planting native grasses. Concurrent with the tailings-pile stabilization, the Mill facilities were dismantled. Equipment was sold, burned, or buried onsite in trenches excavated near the Carbonate Pile (and covered with tailings).

During the summer of 1965, contaminated surface soil was removed from peripheral properties previously used for ore storage. This soil may have been used as fill material to partially bury the mill foundations. Following a radiation survey of the South Stockpile Area and Ore-buying Station in 1972, contaminated soil was removed from these areas in May 1974 and August 1975. Nearly 15,000 cubic yards of contaminated soil, which was placed on top of the East Pile, was graded, contoured, and reseeded. Mill foundations were demolished and bulldozed into adjacent pits.

The Monticello Mill site was accepted into the Surplus Facilities Management Program in 1980 and the Monticello Remedial Action Project was established to restore the government-owned Mill site to safe levels of radioactivity; to dispose of (or contain) the tailings in an environmentally safe manner; and to perform remedial actions at offsite (vicinity) properties that had been contaminated by radioactive material from mill operations. Site characterization activities commenced in 1981.

According to EPA, approximately 1.8 million cubic yards of tailings and contaminated soil are located in the tailings-impoundment area on the east side of the mill. An additional 100,000 cubic yards of contaminated materials have been identified in the Mill area. The tailings and contaminated soils contain elevated levels of both radioactive and nonradioactive contaminants of concern. These constituents are products of the uranium 238-decay cycle (including radium 226) arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, and zinc.

As of 1990, the population within 1.5 miles of the site was estimated at 1,900. The population is concentrated north and west of the Monticello Mill site. The Mill site is located in a controlled land zoning district that permits a mix of agricultural, residential, commercial, and industrial use. The average annual precipitation in the Monticello area is 18.3 inches. Prevailing annual winds are generally from the south, west-southwest, and northwest.

Environmental Damages and Risks

Radiological Contamination

The Public Health Assessment identified radon gas and gamma radiation as the major radiologic contaminants of concern. Adverse health effects arise from the inhalation of radon gas (a decay product of the radium 226 found in the tailings), as the lungs are exposed to the full radiation dose of the radon daughters. In contrast, gamma radiation creates adverse health effects as a result of full-body exposure.

Five potential exposure pathways were identified and considered for quantitative analysis:
(1) inhalation and ingestion of airborne radioactive particulates; (2) ingestion of contaminated foods (plant and animal) produced in areas contaminated by wind-blown tailings; (3) ingestion of surface water contaminated by tailings; (4) inhalation of radon and radon daughters; and (5) direct exposure to gamma radiation emitted from the tailings.

The first two pathways were concluded to present insignificant exposure to humans since radiologic analysis of air particulate samples typically yielded levels below detection. The third pathway (ingestion of contaminated surface water) was not considered a "probable pathway" because: (1) elevated radium concentrations have not yet been detected in Montezuma Creek; and (2) although elevated concentrations of uranium have been detected in the Creek, the uranium dose rate is low at low concentrations and it has a very long half-life (because of this, uranium exposure was examined under nonradiological risks).

Two pathways remained: (1) inhalation of radon and radon daughters; and (2) direct exposure to gamma radiation emitted from the tailings. The cancer risk associated with inhalation of radon and radon daughters

from the Mill site and peripheral properties was estimated to be 0.0038 excess annual cancer incidences to the Monticello population. Cancer risks from whole-body gama radiation exposure were an estimated 0.02 excess annual cancer incidences for the Monticello population. (The Radiological Risk Assessment was performed on a population basis prior to later EPA guidance on performing radiological risk assessments on an individual basis).

Nonradiological Contamination

The following nonradioactive elements were selected as "highest risk" or indicator contaminants at the Mill site or peripheral properties: arsenic, copper, lead, molybdenum, selenium, uranium, vanadium, and zinc. Noncarcinogenic health effects can arise from acute and chronic exposures to all eight elements; only arsenic was considered to be a human carcinogen.

Four potential exposure pathways were identified based on the population and activity patterns in the vicinity of the Mill site: (1) resuspended dust inhalation; (2) soil ingestion; (3) vegetable ingestion; and (4) beef ingestion. The first pathway was excluded from further quantitative analysis because particulate concentrations were at background levels or below, and the Remedial Investigation determined that lead concentrations were well below NAAQS. The second pathway was also excluded because current and expected future access to the site (it is currently fenced) is, and will be, very limited. The vegetable and animal ingestion pathways were retained for quantitative analysis, since the pathways are considered to be indirect exposure routes resulting from contaminated surface water used to irrigate fields and water livestock.

A human "dose" (intake) was calculated for each indicator metal and pathway (vegetable and beef ingestion) for both adults and children based on the average and maximum concentrations of indicator metals found in soils. Each "dose" was compared to an EPA- developed reference dose for chronic (long-term) exposure to each metal. This comparison revealed that no reference doses were exceeded based on average metal concentrations; and therefore, the calculated doses are not likely to be associated with health risks. However, when maximum metal concentrations were used, uranium, copper (including the vegetable pathway), and zinc (the beef pathway, including or excluding the vegetable pathway) "doses" for children were exceeded. It was concluded, however, that it was unlikely that individuals would receive chronic exposure to these maximum concentrations (because the site is uninhabited and because of past land-use patterns). Thus, there was "no apparent health risk".

Arsenic is the only Mill site contaminant of concern that was considered a carcinogen by EPA. Cancer risk due to ingested arsenic (via the vegetable pathway) was calculated using soil concentrations. At maximum soil concentrations, the excess lifetime cancer risk is 2.7×10^{-5}; and it is 7.0×10^{-6} for average soil concentrations. Calculated cancer risk due to ingested arsenic (via the beef pathway) was calculated using soil concentrations. At maximum soil concentrations, the cancer risk is 2.0×10^{-5}; and it is 2.0×10^{-6} for average soil concentrations. It was concluded that "arsenic may pose a public health impact under the existing conditions at the site".

United Nuclear Corporation, Churchrock Site; Gallup, New Mexico

Operating History

The United Nuclear Corporation (UNC) Churchrock Site is an inactive uranium mill and tailings-disposal site located in an isolated area of McKinley County, 15 miles northeast of Gallup, New Mexico. The Mill was operational from 1977 to 1982. The Mill, designed to process 4,000 tons of ore per day, used the conventional acid-leach solvent-extraction method to extract uranium. The ore processed at the site (average ore grade 0.12 percent uranium oxide) came from UNC's Northeast Churchrock and Old Churchrock mines

as well as the nearby Kerr-McGee Quivera mine. The waste tailings were pumped to a 100-acre tailings-disposal area. According to radioactive materials license records, between 3.4 and 3.6 million tons of acidic tailings were disposed of at the site.

UNC's tailings-disposal area is located directly east of Pipeline Canyon. The tailings-disposal area was subdivided by cross-dikes into cells identified as the South Cell, Central Cell, and North Cell areas. Two soil-borrow pits are in the Central Cell area. In July 1979, the dam on the South Cell breached, releasing approximately 93 million gallons of tailings and pond water to the Rio Puerco River. The dam was repaired and clean-up actions were taken.

In October 1979, the New Mexico Environmental Improvement Division (NMEID) ordered UNC to implement a discharge plan to control contaminated tailings seepage which was responsible for ground-water contamination. Ground-water pumping and evaporation was initiated in 1981. From 1979 to 1982, UNC neutralized tailings with ammonia and/or lime. In May 1982, UNC announced that it was going to temporarily close the Churchrock Uranium Mill due to depressed uranium market conditions. The market did not recover, and UNC closed the facility. In 1987, UNC submitted a closure plan to NRC to decommission the Mill. In 1983, EPA designated the Churchrock site an NPL Site and initiated a Remedial Investigation effort.

Environmental Damages And Risks

Arsenic, cadmium, lead, molybdenum, cobalt, manganese, chromium, and radionuclides (including uranium and thorium) are the constituents of concern at the site. Although no people reside within the site boundary, adjacent land includes the Navajo Indian Reservation to the north and land to the east and south held in trust for the Navajo Tribe and administered by the Bureau of Indian Affairs. Ten wells are located in slightly over a 3-mile radius of the site; the closest is 12,000 feet northeast of the site. Four of these wells are operational, and are used for both livestock and domestic purposes. Land use is primarily grazing for sheep, cattle, and horses. Contaminants in the Alluvial Aquifer and/or deeper aquifers at concentrations exceeding clean-up standards include aluminum, arsenic, cadmium, cobalt, manganese, molybdenum, nickel, selenium, nitrate, Total Dissolved Solids (TDS), radium 226 and radium 228, and gross alpha.

A Risk Assessment, based on ingestion of groundwater contaminated at 1985 levels, estimated excess lifetime cancer risks for arsenic and radionuclides (the only carcinogens among the contaminants). The excess lifetime cancer risk from arsenic ingestion was estimated as 1×10^{-1} (based on a maximum arsenic concentration) to 1.2×10^{-3} (average concentrations).

For radionuclides, the excess cancer risks was estimated to be 1.8×10^{-1} to 6.5×10^{-5}. In addition, estimated daily intakes of cadmium, manganese, and nickel were estimated to exceed health-based standards for noncarcinogens. These estimates were all based on a "future-use scenario," in which it was assumed that wells would be constructed for domestic use in each of the clean-up target areas. However, EPA has found no current exposure from ground-water ingestion from currently operating domestic and livestock wells within 4 miles of the site.

APPENDIX B

ACRONYM LIST

Acronym List

AMD	acid mine drainage
BAT/BPJ	best available technology/best professional judgment
BLM	Bureau of Land Management
BMP	best management practice
BPJ	best professional judgment
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIP	carbon-in-pulp
CWA	Clean Water Act
FLPMA	Federal Land Policy and Management Act
FS	Forest Service
GPM	gallons per minute
FWS	Fish and Wildlife Service
HRS	Hazard Ranking System
ICSs	individual control strategies
IM	instruction memorandum
kg	kilogram
MCL	maximum contaminant level
mg/l	milligrams per liter
MSHA	Mine Safety and Health Administration
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIOSH	National Institute for Occupational Safety and Health
NMEID	New Mexico Environmental Improvement Division
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPS	National Park Service
NSPSs	new source performance standards
NTIS	National Technical Information Service
oz/t	troy ounces per ton
ppm	parts per million
PSD	prevention of significant deterioration
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation and feasibility study
RIP	resin-in-pulp
ROD	record of decision
SIPs	State implementation plans
TSCA	Toxic Substance Control Act
TDS	total dissolved solids
TSS	total suspended solids
UCL	upper control limit
USC	United States Code
US DOI	United States Department of the Interior
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UMTRCA	Uranium Mill Tailings Remediation Control Act

APPENDIX C

GROUNDWATER STANDARDS FOR REMEDIAL ACTIONS AT INACTIVE URANIUM PROCESSING SITES (60 *FEDERAL REGISTER* 2854, JANUARY 11, 1995)

FEDERAL REGISTER
Vol. 60, No. 7

Rules and Regulations

ENVIRONMENTAL PROTECTION AGENCY (EPA)

40 CFR Part 192

[FRL-3510-1]
RIN 2060-AC03

Groundwater Standards for Remedial Actions at Inactive Uranium Processing Sites

Part IV

60 FR 2854

DATE: Wednesday, January 11, 1995

ACTION: Final rule.

To view the next page, type .np* TRANSMIT.
To view a specific page, transmit p* and the page number, e.g. p*1

SUMMARY: The Environmental Protection Agency is issuing In 1994, EPA issued final regulations to correct and prevent contamination of groundwater beneath and in the vicinity of
inactive uranium processing sites by uranium tailings. EPA first issued regulations (40 CFR part 192, subparts A, B, and C) for cleanup and disposal of tailings from these sites on January 5, 1983. These new regulations replace existing provisions at 40 CFR 192.20(a)(2) and (3) that were remanded by the U.S. Court of Appeals for the Tenth Circuit on September 3, 1985. They are promulgated pursuant to Section 275 of the Atomic Energy Act, as amended by Section 206 of the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604).

The regulations apply to tailings at the 24 locations that qualify for remedial action under Title I of Public Law 95-604. They provide that tailings must be stabilized and controlled in a manner that permanently eliminates or minimizes contamination of groundwater beneath stabilized tailings, so as to protect human health and the environment. They also provide for cleanup of contamination that occurred before the tailings are stabilized.

EFFECTIVE DATE: February 10, 1995.

ADDRESSES: Background Documents. A report ("Groundwater Protection Standards for Inactive Uranium Tailings Sites, Background Information for Final Rule," EPA 520/1-88-023) has been prepared in support of these regulations. Another report ("Groundwater Protection Standards for Inactive Uranium Tailings Sites, Response to Comments," EPA 520/1-88-055) contains the detailed responses of the Environmental Protection Agency to comments on the standard by the reviewing public. Single copies of these documents may be obtained from the Program Management Office (6601J), Office of Radiation and Indoor Air, U.S.

Environmental Protection Agency, Washington, DC 20460; (202) 233-9354.

Docket. Docket Number R-87-01 contains the rulemaking record. The docket is available for public inspection between 8 a.m.-4 p.m., weekdays, at EPA's Central Docket Section (LE-131), Room M-1500, 401 M Street SW., Washington, DC 20460. A reasonable fee may be charged for copying.

FOR FURTHER INFORMATION CONTACT: Allan C.B. Richardson, Criteria and Standards Division (6602J), Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, DC 20460; telephone (202) 233-9213.

SUPPLEMENTARY INFORMATION:

I. Introduction

On November 8, 1978, Congress enacted the Uranium Mill Tailings Radiation Control Act of 1978 (henceforth called "UMTRCA"). In UMTRCA, Congress found that uranium mill tailings "* * * may pose a potential and significant radiation health hazard to the public, and * * * that every reasonable effort should be made to provide for stabilization, disposal, and control in a safe and environmentally sound manner of such tailings in order to prevent or minimize radon diffusion into the environment and to prevent or minimize other environmental hazards from such tailings." The Act directs the Administrator of the Environmental Protection Agency (EPA) to set "* * * standards of general application for the protection of the public health, safety, and the environment * * *" to govern this process of stabilization, disposal, and control.

UMTRCA directs the Department of Energy (DOE) to conduct such remedial actions at the inactive uranium processing sites as will insure compliance with the standards established by EPA. This remedial action is to be selected and performed with the concurrence of the Nuclear Regulatory Commission (NRC). Upon completion of the remedial action program, the depository sites will remain in the custody of the Federal government under an NRC license.

The standards apply to residual radioactive material at the 24 processing sites designated, as provided in the Act, by DOE. Residual radioactive material is defined as any wastes which DOE determine to be radioactive, either in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores, or in other forms which relate to such processing, such as sludges and captured contaminated water from these sites. (Additional wastes that do not meet this definition may be subject to regulation as hazardous waste under the Solid Waste Disposal Act (SWDA) as amended by the Resource Conservation and Recovery Act of 1976 (RCRA).)

Standards are required for two types of remedial actions: disposal and cleanup of residual radioactive material. Disposal is here used to mean the operation that places tailings in a permanent condition which will minimize risk of harmful effects to the health of people and harm to the environment. Cleanup is the operation that eliminates, or reduces to acceptable levels, the potential health and environmental consequences of tailings or their constituents that have been dispersed from tailings piles or disposal areas by natural forces or by human activity, through removal of residual radioactive materials from land, buildings, and groundwater.

On January 5, 1983, EPA promulgated final standards for the disposal and cleanup of the inactive mill tailings sites under UMTRCA (48 FR 590). These standards were challenged in the Tenth Circuit Court of Appeals by several parties (Case Nos. 83-1014, 83-1041, 83-1206, and 83-1300). On September 3, 1985, the court dismissed all challenges except one: it set aside the groundwater provisions of the regulations at 40 CFR 192.20(a)(2) and (3) and remanded them to EPA "* * * to treat these toxic chemicals that pose a groundwater risk as it did in the active mill site regulations." On September 24, 1987, EPA proposed new standards to replace those remanded. A public hearing was held in Durango, Colorado, on October 29, 1987. In response to requests from several commenters at the public hearing and a later request by the American Mining Congress, the public record for comments on the proposed standard was not closed until January 29, 1988. With this notice, EPA is establishing final standards to replace those set aside.

II. Summary of Background Information

Beginning in the 1940's, the U.S. Government purchased large quantities of uranium for defense purposes. As a result, large piles of tailings were created by the uranium milling industry. Tailings piles pose a hazard to public health and the environment because they contain radioactive and toxic constituents which emanate radon to the atmosphere and may leach into groundwater. Tailings, which are a sand-like material, have also been removed from tailings piles in the past for use in construction and for soil [*2855] conditioning. These uses are inappropriate, because the radioactive and toxic constituents of tailings may elevate indoor radon levels, expose people to gamma radiation, and leach into ground and surface waters.

Most of the mills are now inactive and many of the sites were abandoned. These abandoned sites are being remediated under Title I of UMTRCA. Congress designated 22 specific inactive sites in Title I of UMTRCA, and the DOE subsequently added two more. Most remaining uranium mill tailings sites are regulated by the NRC or States and will be reclamated under Title II of UMTRCA. (DOE also owns one inactive site at Monticello, Utah, that is not included under UMTRCA). The Title I sites are located in the West, predominantly in arid areas, except for a single site at Canonsburg, Pennsylvania. Before disposal operations began, tailings piles at the inactive sites ranged in area from 5 to 150 acres and in height from only a few feet to as much as 230 feet. The amount at each site ranges from residual contamination to 2.7 million tons of tailings. The 24 designated Title I sites combined contain about 26 million tons of tailings covering a total of about 1000 acres.

Under the provisions of Title I of UMTRCA, the DOE is responsible for the disposal of tailings at these sites, which will then be licensed to DOE by NRC for long term surveillance and maintenance, following NRC approval of the remediation. In addition, tailings that were dispersed from the piles by natural forces or that have been removed for use in or around buildings or on land are being retrieved and replaced on the tailings piles prior to their disposal.

UMTRCA, as originally enacted, required that DOE complete all these remedial actions within 7 years of the effective date of EPA's standards, that is, by March 5, 1990. At the end of 1993 disposal actions had been completed at ten sites: Canonsburg, Pennsylvania, one of two sites in areas of high precipitation (Falls City, Texas is the other); Shiprock, New Mexico; Salt Lake City, Utah; Lakeview, Oregon; Green River, Utah; Spook and Riverton, Wyoming; Lowman,

Idaho; Tuba City, Arizona; and Durango, Colorado. Disposal actions were well advanced at eight other sites: Rifle (two piles), Grand Junction, and Gunnison, Colorado; Monument Valley, Arizona; Mexican Hat, Utah; Falls City, Texas; and Ambrosia Lake, New Mexico. The remaining sites are in the advanced stages of planning and should be under construction within the next two years. In view of the rate of progress with remedial work, Congress in 1988 extended the completion date for disposal and most cleanup activities until September 30, 1994, and provided further "* * * that the authority of the Secretary to perform groundwater restoration activities under this title is without limitation." (Uranium Mill Tailings Remedial Action Amendments Act of 1988, P.L. 100-616, November 5, 1988; 42 U.S.C. 7916). Section 1031 of the Energy Policy Act of 1992 further extended the completion date for UMTRCA surface stabilization (disposal) activities to September 30, 1996.

The most important hazardous constituent of uranium mill tailings is radium, which is radioactive. Other potentially hazardous substances in tailings piles include arsenic, molybdenum, selenium, uranium, and, usually in lesser amounts, a variety of other toxic substances. The concentrations of these materials in tailings vary from pile to pile, ranging from 2 to more than 100 times local background soil concentrations. A variety of organics is also known to have been used at these sites.

Exposure to radioactive and toxic substances may cause cancer and other diseases, as well as genetic damage and teratogenic effects. Tailings pose a risk to health because: (1) Radium in tailings decays into radon, a gaseous radioactive element which is easily transported in air and the radioactive decay products of which may lodge in the lungs; (2) individuals may be directly exposed to gamma radiation from the radioactivity in tailings; and (3) radioactive and toxic substances from tailings may leach into water and then be ingested with food or water, or inhaled following aeration. It is the last of these hazards that is primarily addressed here. (Although radon from radium in groundwater is unlikely to pose a substantial hazard at these locations, these standards also address that potential hazard.) The other hazards are covered by existing provisions of 40 CFR part 192.

EPA's technical analysis was based on detailed reports for 14 of the 24 inactive uranium mill tailings sites that had been developed by late 1988 for the Department of Energy by its contractors. Preliminary data for the balance of the sites were also examined. Those data showed that the volumes of contaminated water in aquifers at the 24 sites range from a few tens of millions of gallons to 4 billion gallons. In a few instances mill effluent was apparently the sole source of this groundwater. Each of the 14 sites examined in detail had at least some groundwater contamination beneath and/or beyond the site. In some cases the groundwater upgradient of the pile already exceeded EPA drinking water standards for one or more contaminants due to mineralization sources or due to anthropogenic sources other than the uranium milling activities, thus making it unsuitable for use as drinking water without treatment and, in some extreme cases, for most other purposes before it was contaminated by effluent from the mill. Some contaminants from the tailings piles are moving offsite quickly and others are moving slowly. The time for natural flushing of the contaminated portions of these aquifers was estimated to vary from a couple of years to many hundreds of years. Active restoration was estimated to take from less than 5 years at most sites to approximately 50 years at one site.

DOE currently estimates that there is approximately 4.7 billion gallons of contaminated water, but this estimate does not include all sites. One site, Lowman, Idaho, shows no sign of contamination related to the processing activities, while the site with the largest amount of contamination, Monument Valley, Arizona, has an estimated 0.75 billion gallons of contaminated water. The DOE estimate does not include those sites where current assessments indicate that supplemental standards should be applied, because contamination at these sites has been hard to quantify.

Contaminants that have been identified in the groundwater downgradient from a majority of the sites include uranium, sulfate, iron, manganese, nitrate, chloride, molybdenum, selenium, and total dissolved solids. Radium, arsenic, fluoride, sulfide, chromium, cadmium, vanadium, lead, and copper have also been found in the groundwater at one or more sites.

UMTRCA requires that the standards established under Title I provide protection that is consistent, to the maximum extent practicable, with the requirements of RCRA. In this regard, regulations established by EPA for hazardous waste disposal sites under RCRA provide for the specification of a groundwater protection standard for each waste management area in the facility permit (see 40 CFR part 264, subpart F). The groundwater protection standard includes a list of specific hazardous constituents relevant to each waste management area, a concentration limit for each hazardous constituent, the point of compliance, and the compliance period. The subpart F regulations specify that the concentration limits may be set at [*2856] general numerical limits (maximum concentration limits (MCLs)) for some hazardous constituents or at their background level in groundwater unless alternate concentration limits (ACLs) are requested and approved. ACLs may be requested based upon data which would support a determination that, if the ACL is satisfied, the constituent would not present a current or potential threat to human health and the environment. This standard incorporates many of these provisions into the regulations for the Title I sites.

III. Changes and Clarifications in Response to Comments

These final standards modify and clarify some of the provisions of the proposed standards as a result of information and views submitted during the comment period and at the public hearing. EPA received many comments on the proposed standards. Twenty-three letters were received and eight individuals testified at the public hearing. Comments were submitted from private citizens, public interest groups, members of the scientific community, and representatives of industry and of State and Federal agencies. EPA has carefully reviewed and considered these comments in preparing its detailed Response to Comments and the final Background Information Document and in developing the final standards. EPA's responses to major comments are summarized below.

Uranium Concentration Limit

Several commenters pointed out that the Agency used inappropriate dose conversion values (nonstochastic) for uranium and radium (instead of the more appropriate stochastic values) in developing the proposed concentration limit for uranium. These comments were correct. We have reevaluated the risks associated with ingestion of uranium, using current risk factors for radiocarcinogenicity of uranium, and have also considered the chemical toxicity of uranium. We have concluded that the level proposed, 30 pCi/liter, provides

an adequate margin of safety against both carcinogenic and toxic effects of uranium, and that the level should be expressed in terms of the concentration of radioactivity, because it is related to the principal health risk, and can accommodate different levels of radioactive disequilibrium between uranium-234 and uranium-238.

EPA's Office of Groundwater and Drinking Water has also examined these factors, and, on July 18, 1991, proposed the MCL for uranium in drinking water be set at a chemical concentration comparable to the limit on radioactivity promulgated in this regulation. Should the MCL for drinking water, as finally promulgated, provide a level of health protection different from that provided by the limit in this regulation, EPA will reconsider the limit at that time. On the basis of the above considerations, the limit for uranium has been established at 30 pCi/liter for this regulation.

Molybdenum Concentration Limit

Several reviewers objected to the proposed inclusion of a limit on molybdenum. They pointed out that EPA has not established a drinking water standard for this element. While this is true, the drinking water regulations also make provision for health advisories in the case of contaminants that are problems only in special situations. Molybdenum in the vicinity of uranium mill tailings is such a special case. Uranium mill tailings often contain high concentrations of molybdenum that can leach into groundwater in concentrations that may cause toxic effects in humans and cattle. This rule therefore continues to contain a limit on the concentration of molybdenum in groundwater. The value chosen remains the same as that proposed, as discussed in Section IV below.

Other Groundwater Limits

These groundwater limits incorporate MCLs issued under the Safe Drinking Water Act (SDWA) (42 USC 300f, et seq.) and in effect for sites regulated under RCRA from the time these limits were proposed on September 24, 1987, to the present. However, on January 30, 1991, EPA issued new MCLs for some of the inorganic constituents included in the present limits, and proposed new drinking water standards for radioactive constituents were published on July 18, 1991 (56 FR 3526 and 33050). Following publication of final drinking water standards for radioactive constituents, EPA will consider whether the benefits and costs implied by differences between these limits and the new drinking water standards warrant proposing to incorporate the new values into both the Title I and the Title II limits for groundwater.

Application of These Regulations to Vicinity Properties

Several commenters questioned the wisdom of applying these regulations to vicinity properties. (Vicinity properties are real properties or improvements in the vicinity of a tailings pile that are determined by DOE, in consultation with the NRC, to be contaminated with residual radioactive materials.) They indicated that if the portion of the proposed rule requiring detailed assessment and monitoring were applied to all vicinity properties, it would greatly expand the cost of the program without providing additional benefits. Since only a few vicinity properties contain sufficient tailings to constitute a significant threat of groundwater contamination, we have concluded that detailed assessment and monitoring, followed by identification of listed constituents and groundwater standards, is not required at all vicinity properties. It is

necessary only at those vicinity properties with a significant potential for groundwater contamination, as determined by the DOE (with the concurrence of NRC) using factors such as those in EPA's RCRA Facility Assessment Guidance document. It should be noted that this modification applies to the requirement for detailed assessment and monitoring only; the standards for cleanup of groundwater contamination are not changed. In addition, we note that the minimal quantities of residual radioactive materials left behind at vicinity properties after compliance with subpart B do not constitute disposal sites under subpart A.

Application of State Regulations to These Sites

Some commenters expressed the view that these regulations should require consistency with State laws and regulations. EPA's regulations for licensed mill tailings sites under Title II of this Act do not contain such a provision. (Although NRC Agreement States may, under the Atomic Energy Act, adopt standards which "* * * are equivalent to the extent practicable or more stringent * * *," they have not done so under UMTRCA.) We have decided that decisions regarding consistency with State laws and regulations should be made by DOE in consultation with the States, as provided by Section 103 of the Act. In making these decisions in cases where an approved Wellhead Protection Area, under the Safe Drinking Water Act, is associated with the site, however, DOE must comply with the provisions of that program, unless an exemption is granted by the President of the United States. In addition, contamination on the site that is not covered by UMTRCA (because it is not related to the processing operation) may be covered by Federal or State RCRA programs.

Application of Institutional Controls During an Extended Remedial Period

Several comments were received concerning the effectiveness, reliability, [*2857] and enforceability of institutional controls to be applied during a remedial period that has been extended to take advantage of natural flushing. EPA recognizes that some institutional controls, such as advisories or signs, although desirable as secondary measures, are not appropriate as primary measures for preventing human exposure to contaminated water. For this reason, the regulations permit institutional controls to be used in place of remediation only when DOE is able to ensure their effectiveness will be maintained during their use. The standards require that institutional controls "* * * effectively protect public health and the environment and satisfy beneficial uses of groundwater * * *" during their period of application. In this regard, we note that tribal, state, and local governments can also play a key role in assuring the effectiveness of institutional controls. In some cases this may be effected through changes in tribal, state, or local laws to ensure the enforceability of institutional controls by the administrative or judicial branches of government entities. One State indicated that some institutional controls, such as deed restrictions, should not be viewed as restrictions since they do not empower any agency to prohibit access to contaminated water. However, judicial enforcement of deed restrictions can be as effective as administrative enforcement of other institutional controls by a government agency. Therefore, deed restrictions are an acceptable institutional control if they are enforceable by a court with jurisdiction over the site at which they are used, and if the implementing agency will take appropriate steps to assure their effective application.

Some commenters expressed the view that, if institutional controls are used, this use must be restricted to the 7-year period for remediation authorized in

Section 112(a) of UMTRCA. EPA believes that it is not possible to achieve cleanup of groundwater at all of the sites within 7 years, no matter what reclamation scheme is employed. It is therefore necessary to consider time frames other than that originally contemplated in UMTRCA for completion of remedial actions. Congress, in granting an extension of the authorization in Section 112(a) of UMTRCA for disposal and cleanup actions from March 5, 1990 to September 30, 1994, provided further "* * * that the authority of the Secretary to perform groundwater restoration activities under this title is without limitation." (Uranium Mill Tailings Remedial Action Amendments Act of 1988 (42 U.S.C. 7916)). In addition, under Section 104(f)(2) of the Act (42 U.S.C. 7919(f)(2)), the NRC may require maintenance of corrective and institutional measures that are already in place at the time authorization under Section 112(a) expires, without time limitation.

The provisions for use of natural flushing when appropriate institutional controls are in place are consistent with existing regulations under Title II, although they are not explicit in those regulations. In cases where groundwater contamination is detected, the Title II regulations specify when corrective actions must begin, but do not specify a time when corrective actions must be completed. These provisions under Title I provide additional guidance on the length of time over which institutional control may reasonably be relied upon, and further guidance on the kinds of institutional provisions that would be appropriate at any uranium tailings site. In addition, use of institutional controls is not limited to extended remedial periods. Interim institutional controls may also be used to protect public health or the environment, when DOE finds them necessary and appropriate, prior to commencing active remedial action, during active remedial action, or during implementation of other compliance strategies.

Other comments addressed a variety of matters, including the monitoring of institutional controls, the relationship between long-term maintenance responsibilities and the 100-year limit on use of institutional controls, types of institutional controls, longer or shorter extended remedial periods, and the legality of institutional controls under UMTRCA. These matters are addressed in the Response to Comments, published separately as a background document.

Point of Compliance

Several commenters objected to the definition of the point of compliance in the disposal standards (subpart A), and suggested that it be defined at some finite distance from the edge of the remediated tailings instead of at the downgradient edge of the pile, as in regulations established under RCRA. They indicated that the remediated tailings may seep a minor amount of contamination, which may cause the standards to be exceeded at the proposed point of compliance, under conditions where there would be no detriment to human health or the environment at small distances away. This difficulty can be solved, as proposed, by moving the point of compliance or, alternatively, by granting an ACL if it can be shown that such levels of contamination will not impair human health or damage the environment. We have concluded the latter is more in keeping with the regulations established under RCRA. The standards provide that DOE may request an ACL under such circumstances and NRC may approve such a request if contamination of groundwater will not endanger human health or degrade the environment. It is our view that this requirement would usually be satisfied at any site where the minor seepage noted above is not projected to extend beyond a few hundred meters from the waste management area and will not

extend outside the site boundary. This could occur under a variety of circumstances where important roles are played by attenuation, dilution, or by vapor transport in unsaturated zones.

Under the cleanup standard (subpart B), the DOE is required to characterize the extent of contamination from the site and clean it up wherever it exceeds the standards. This characterization and confirmation of cleanup will be carried out through the monitoring program established under @ 192.12(c)(3). Although the DOE is not required to clean up preexisting contamination that is located beneath a remediated tailings pile, they are required to consider this contamination when developing their plan(s) for remedial action and will have to clean up any contamination that will migrate from beneath the pile and exceed the concentration limits established in accordance with @ 192.02(c)(3).

Alternate Concentration Limits

Several reviewers commented that EPA should not, for a variety of reasons, delegate the responsibility for approving ACLs to the NRC. Others stated that the standards were so strict that ACLs would be needed at every site. EPA considered a number of approaches to the provision for granting ACLs. These included deleting the ACL provision, establishing (by regulation) generic criteria for ACLs to be implemented by NRC, providing for some form of EPA review or oversight of ACL implementation, and (as in the proposed regulation) providing for no EPA role in setting ACLs at individual sites.

EPA has decided not to delete the ACL provision because it is clearly needed, if for no other reason than to deal with the possibilities of unavoidable minor projected seepage over the extremely long-term design life (1000 years) of the disposal required, in most cases, by these standards, and of [*2858] cleanup situations involving pollutants for which no MCLs exist. Establishment of a complete set of regulations specifying generic criteria for granting ACLs presents difficulties for rulemaking, since ACL determinations often involve complex judgments that are not amenable to being reduced to simple regulatory requirements. In this regard we note that such regulations do not yet exist in final form for sites directly regulated under RCRA. However, the Agency has issued interim final Alternate Concentration Limit Guidance (OSWER Directive 9481.00; EPA/SW-87-017), and has proposed several relevant rules, e.g., under 40 CFR parts 264, 265, 270, and 271, for Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities (55 FR 30798; July 27, 1990). In addition, the NRC proposed a draft Technical Position on Alternate Concentration Limits for Uranium Mills at Title II sites on March 21, 1994 (59 FR 13345). EPA has reviewed the NRC draft Technical position, and we find that it is consistent, in general, with EPA's own guidance and proposed rules. The NRC draft position does not, however, specify an upper limit on risks to humans from carcinogens. We have reconsidered the issue of EPA review or oversight of ACLs at Title I sites in light of this review, and concluded that, in the interests of assuring that public health is adequately protected while at the same time minimizing the regulatory burden on DOE, the best course of action is to specify that upper limit in this regulation and assign the responsibility for making determinations for ACLs at individual sites to NRC. Accordingly, in this rule, in the implementing guidance contained in subpart C, @ 192.20(a)(2), we now specify that the criterion for known or suspected carcinogens contained in the above-referenced RCRA documents should be applied in granting ACLs. That criterion specifies that ACLs should be established at levels which represent an excess lifetime risk, at a point of exposure, no greater than 10 supra -4 to

10 supra -6 to an average individual.

EPA is required by UMTRCA (Section 206) to be consistent, to the maximum extent practicable, with RCRA. For this reason, relevant portions of the RCRA regulations have been incorporated. For example, these regulations provide for the use of ACLs when it can be shown that the criteria specified in @ 192.02(c)(3)(ii) are satisfied. It remains the view of the Agency that, as at the Title II sites, an ACL is appropriate if the NRC has determined that these criteria are satisfied when the otherwise applicable standard will be met within the site boundary (or at a distance of 500 meters, if this is closer). It is clear that ACLs will usually be appropriate to accommodate the controlled minor seepage anticipated from properly designed tailings disposal within such distances, when public use is not possible.

Cost

Greater consideration of cost and cost-benefit analysis was requested by several commenters. In 1983, Congress amended UMTRCA to provide that when establishing standards the Administrator should consider, among other factors, the economic costs of compliance. We have considered these costs in two ways. First, we compared them to the benefit, expressed in terms of the value of the product-processed uranium ore-which has led to contamination of groundwater at these sites. We estimate the present value of the processed uranium ore from these sites as approximately 3.9 billion dollars (1989 dollars). The estimated cost of compliance is approximately 5.5% of this value, and we judge this to be a not unreasonable incremental cost for the remediation of contamination from the operations which produced this uranium. As a second way of considering the economic costs of compliance, we examined the cost of alternative ways to supply the resources for future use represented by these groundwaters. As noted earlier, water is a scarce resource in the Western States where this cleanup would occur. When other resources have been exhausted, the only remaining alternative to cleaning up groundwater in the vicinity of these sites is to replace this water by transporting water from the nearest alternative source. Our analysis of the costs of doing this indicates that it is significantly more costly to supply water from alternative sources than it would be to clean up the groundwater at these sites. We have concluded, therefore, that this final rule involves a reasonable relationship between the overall costs and benefits of compliance.

The RCRA subpart F regulations do not include cost as a consideration for the degree of cleanup of groundwater, and these regulations also do not provide for site-specific standards based on site-specific costs. Nonetheless, it is clearly desirable and appropriate to apply the most cost-effective remedies available to meet these standards at each site, and we anticipate that DOE will make such choices in choosing the remedies it applies to satisfy these standards. Further, once the basic criteria for establishing ACLs set forth in @ 192.02(c)(3)(ii)(B) have been satisfied, if a higher level of protection is reasonably achievable, this should be carried out. However, we do not believe it is appropriate to apply detailed cost/benefit balancing judgments to justify lesser levels of protection for ground water. The benefits of cleaning up groundwater are often not quantifiable and may not become known for many years; therefore, site-specific cost-benefit analyses are difficult to apply in such situations. Moreover, Congress provided no authority that protection of ground water at each site should be limited by cost/benefit considerations, even after reconsidering the question in the 1984 amendments.

Some reviewers raised the issue of additional costs arising from use of these standards in other applications, such as CERCLA cleanups. We recognize that there may be costs associated with using these standards as precedents for other waste cleanup projects. However, the reasonableness of incurring such costs should be assessed when it is possible to do so with complete information, that is, at the time of application of these standards as precedents for situations other than the one for which they were developed.

Natural Restoration

The use of natural restoration of an aquifer was discussed by several reviewers. Some felt that it was a viable and desirable alternative, because it is easy and inexpensive to apply, for groundwaters that are not expected to be used for drinking or other purposes during the cleanup period. Others felt that it should be prohibited because it required a reliance on institutional controls and would circumvent active cleanup of groundwater. EPA believes that the use of natural restoration can be a viable alternative in situations where water use and ecological considerations are not affected, and cleanup will occur within a reasonable time. We have concluded that institutional controls, when enforced by government entities, or that otherwise have a high degree of permanence, can be relied on for periods of time up to 100 years, and that adequate safeguards are provided through NRC oversight of the implementation of these standards to prevent this alternative from being used to circumvent active cleanup of water that will be used by nearby populations.

Commenters suggested that natural restoration was not adequate to restore water quality at these sites. DOE has indicated that they expect that natural restoration may be all that is necessary at up to eight sites and could be used [*2859] in conjunction with active remedial measures at several other sites. Natural restoration is most valuable when the contaminated aquifer discharges into a surface water body that will not be adversely affected by the contamination.

Pile and Liner Design

The design of the remediated pile and the use of a liner was of concern to several commenters, and recommendations were given for suitable designs. These commenters feared that water would continually infiltrate the remediated piles and contaminate groundwater.

These EPA standards would not be satisfied by designs which allow contamination that would adversely affect human health or the environment. Further, current engineering designs for covers incorporate a number of features that control infiltration to extremely low levels. These may include an erosion barrier (with vegetation, where feasible) to transpire moisture and reduce infiltration; rock filters and drains to drain and laterally disperse any episodic infiltration; very low permeability infiltration barriers to intercept residual infiltration; and finally, the thick radon barrier, which further inhibits infiltration. The combined effect of these features is to reduce the overall hydrological transmission of covers to levels on the order of one part in a billion, with a resulting high probability that there will be no saturated zone of leachate in or below the tailings. EPA expects DOE to use such state-of-the-art designs wherever it is appropriate to do so because of the proximity of groundwater.

Under the provisions of UMTRCA, the detailed design of the pile and its cover is the responsibility of DOE, and confirmation of the viability of the design to satisfy EPA's standards is the responsibility of NRC. EPA's responsibility is to promulgate the standards to which the disposal must conform. It would be inconsistent with the division of responsibilities set forth in UMTRCA to specify actual designs for the piles in these regulations. In this connection, the requirement to provide a liner when tailings are moved to a new location in a wet state is properly seen as a generic management requirement. Any liner for this purpose would only serve a useful purpose for the relatively short time over which the moisture content of the pile adjusts to its long-term equilibrium value, after which the cover design would determine the groundwater protection capability of the disposal.

Restricted List of Constituents

Commenters were overwhelmingly opposed to a restricted list of radioactive or toxic constituents and recommended that the entire list of constituents be relied upon. It is the Agency's experience that, under RCRA, no changes in this list have been requested based on the criteria provided in @ 264.93(b). These criteria allow for hazardous constituents to be excluded based on a determination that the constituent does not pose a substantial present or potential hazard to human health or the environment. Therefore, that portion of the RCRA standards which specify conditions for the exclusion of constituents from the RCRA list of hazardous constituents has been excluded as unnecessary.

However, a short list of compounds has been developed by EPA for use in monitoring groundwater under RCRA. This rule incorporates that list of constituents (Appendix IX of part 264) in place of the complete list in Appendix I for the monitoring programs required at @@ 192.02(c)(1), 192.03, and 192.12(c)(1). However, the rule still requires that all hazardous constituents listed in Appendix I be considered when corrective action is necessary.

IV. Summary of the Final Standard

These final standards consist of three parts: a first part governing protection against future groundwater contamination from tailings piles after disposal; a second part that applies to the cleanup of contamination that occurred before disposal of the tailings piles; and a third part that provides guidance on implementation and specifies conditions under which supplemental standards may be applied.

A. The Groundwater Standard for Disposal

The standard for protection of groundwater after disposal (subpart A) is divided into two parts that separately address actions to be carried out during periods of time designated as the disposal and post-disposal periods. The disposal and post-disposal periods are defined in a manner analogous to the closure and post-closure periods, respectively, in RCRA regulations. However, there are some differences regarding their duration and the timing of any corrective actions that may become necessary due to failure of disposal systems to perform as designed. (Because there are no mineral processing activities currently at these inactive sites, standards are not needed for an operational period.) The disposal period, for the purpose of this regulation, is defined as that period of time beginning on the effective date of the original Title I part 192 standard for the inactive sites (March 7, 1983) and ending with completion

of all actions related to disposal except post-disposal monitoring and any corrective actions that might become needed as a result of failure of completed disposal. The post-disposal period begins with completion of disposal actions and ends after an appropriate period for the monitoring of groundwater to confirm the adequacy of the disposal. The groundwater standard governing the actions to be carried out during the disposal period incorporates relevant requirements from subpart F of part 264 of this chapter (@@ 264.92-264.95). The standard for the post-disposal period reflects relevant requirements of @ 264.111 of this Chapter. The disposal standard also includes provisions for monitoring and any necessary corrective action during both disposal and post-disposal periods. These provisions are essentially the same as those governing the licensed (Title II) uranium mill tailings sites (40 CFR 192, subparts D and E; see also the Federal Register notices for those standards published on April 29, 1983 and on October 7, 1983). Several additional constituents are regulated, however, in these final Title I regulations.

These regulations do not change existing requirements at Title I sites for the period of time disposal must be designed to comply with the standards, and therefore remain identical to the requirements for licensed (Title II) sites in this respect. The Agency also recently promulgated final regulations for spent nuclear fuel, and high level and transuranic radioactive wastes (40 CFR part 191; 58 FR 66398, December 20, 1993). Those standards specify a different design period for compliance (10,000 years versus 1000 years) for two principle reasons: (1) The level of radioactivity, and therefore the level of health risk, in the wastes addressed under 40 CFR part 191 is many orders of magnitude greater than those addressed here. (The radioactivity of tailings is typically 0.4 to 1.0 nCi/g, 40 CFR part 191 wastes are always greater than 100 nCi/g, and are typically far higher.) (2) The volume of uranium mill tailings is far greater than the waste volumes addressed under 40 CFR part 191. The containment that would be required to meet a 10,000 year requirement is simply not feasible for the volumes of tailings involved (the option of underground disposal was addressed and rejected in the original [*2860] rulemakings for the Title I and Title II sites).

These regulations require installation of monitoring systems upgradient of the point of compliance (i.e., in the uppermost aquifer upgradient of the edge of the tailings disposal site) or at some other point adequate to determine background levels of any listed constituents that occur naturally at the site. The disposal should be designed to control, to the extent reasonably achievable for 1000 years and, in any case, for at least 200 years, all listed constituents identified in residual radioactive materials at the site to levels for each constituent derived in accordance with @ 192.02(c)(3). Accordingly, the elements of the groundwater protection standard to be specified for each disposal site include a list of relevant constituents, the concentration limits for each such constituent, and the compliance point.

These standards provide for consideration of ACLs if the disposal cannot reasonably be designed to assure conformance to background levels (or those in Table 1) over the required term. ACLs can be granted provided that, after considering practicable corrective actions, a determination can be made that it satisfies the values given by implementing the conditions for ACLs under @ 192.02(c)(3)(ii).

The standards for Title II sites require use of a liner under new tailings piles or lateral extensions of existing piles. These standards for remedial

action at the inactive Title I sites do not contain a similar provision. EPA assumes that the inactive piles will not need to be enlarged. Several, however, will be relocated. However, unlike tailings at the Title II sites, which generally may contain large amounts of process water, the inactive tailings contain little or no free water. Such tailings, if properly located and stabilized with a cover adequate to ensure an unsaturated zone, are not likely to require a liner in order to protect groundwater.

However, a liner would be needed for an initial drying-out period to meet these groundwater standards if a situation arose where the tailings initially contained water above the level of specific retention. For example, tailings to which water was added to facilitate their removal to a new site (i.e., through slurrying), or for compaction during disposal. (It is anticipated that piles will never be moved to areas of high precipitation or situated within a zone of water table fluctuation.) Section 192.20(a)(3) requires the remedial plan to address how any such excess water in tailings would be dealt with. In such circumstances it will normally be necessary to use a liner or equivalent to assure that groundwater will not be contaminated while the moisture level in the tailings adjusts to its long-term equilibrium value. Currently, however, DOE plans do not include slurrying any tailings to move them to new locations. Further, for all but two sites, of which one has already been closed (Canonsburg) and at the other (Falls City) disposal actions are well advanced, the tailings are located in arid areas where annual precipitation is low.

Disposal designs which prevent migration of listed constituents in the groundwater for only a short period of time would not provide appropriate protection. Such approaches simply defer adverse groundwater effects. Therefore, measures which only modify the gradient in an aquifer or create barriers (e.g., slurry walls) would not of themselves provide an adequate disposal.

Section 192.02(d) requires that a site be closed in a manner that minimizes further maintenance. Depending on the physical properties of the sites, candidate disposal systems, and the effects of natural processes over time, measures required to satisfy these standards will vary from site to site. Actual site data, computational models, and prevalent expert judgment may be used in deciding that proposed measures will satisfy the standards. Under the provisions of Section 108(a) of UMTRCA, the adequacy of these judgments is determined by the NRC.

For the post-disposal period, a groundwater monitoring plan is required to be developed and implemented. The plan will require monitoring for a period of time deemed sufficient to verify, with reasonable assurance, the adequacy of the disposal to achieve its design objectives for containment of listed constituents. EPA expects this period of time to be comparable, in most cases, to that required under @ 264.117 of Title 40 for waste sites regulated under RCRA (i.e., a few decades). However, there may be situations where longer or shorter periods are appropriate. Installation and commencement of the monitoring required under @ 192.03 will satisfy this EPA standard, for the purposes of licensing of the site by the NRC.

With regard to this monitoring, UMTRCA provides that, after remediation is completed and custody is transferred to a Federal agency, NRC may require that the Federal agency having custody of each remediated tailings site "* * * undertake such monitoring, maintenance, and emergency measures * * *and other actions as [NRC] deems necessary to comply with [EPA's standards]" (UMTRCA,

Section 104(f)(2)). Although it is not intended that routine monitoring be carried out as a requirement for conformance to these standards for the 200- to 1000-year period over which the disposal is designed to be effective, NRC may require more extensive monitoring to comply with EPA's standards, as NRC deems necessary under @ 104(f)(2) of the Act.

During the post-disposal period, if listed constituents from a disposal site are detected in excess of the groundwater standards, these regulations require a corrective action program designed to bring the disposal and the groundwater into compliance with the provisions of @ 192.02(c)(3) and subpart B, respectively. In designing such a corrective action program, the implementing agencies may consider all of the provisions available under subparts A, B, and C. A modification of the monitoring program sufficient to demonstrate that the corrective measures will be successful is also required. In designing future corrective action programs, the implementing agencies may also wish to consider the guidance provided by new regulations now being developed for the RCRA program that will be proposed as subpart S to Title 40. However, the requirements of Part 192 will still govern regulatory determinations of acceptability.

Additional Regulated Constituents

For the purpose of this regulation only, the Agency is regulating, in addition to the hazardous constituents referenced by @ 264.93, molybdenum, nitrate, combined radium-226 and radium-228, and combined uranium-234 and uranium-238. Molybdenum, radium, and uranium were addressed by the Title II standards because these radioactive and/or toxic constituents are found in high concentrations at many mill tailings sites. These regulations add numerical limits for these constituents. Nitrate was added because it had been identified in concentrations far in excess of drinking water standards in groundwater at a number of the inactive sites.

The concentration limit for molybdenum in groundwater from uranium tailings is set at 0.1 milligram per liter. This is the value of the provisional Adjusted Acceptable Daily Intake (AADI) for drinking water developed by EPA under the Safe Drinking Water Act (50 FR 46958). The Agency has established neither a maximum concentration limit goal [*2861] (MCLG) nor a maximum concentration limit (MCL) for molybdenum because it occurs only infrequently in water. According to the most recent relevant report of the National Academy of Sciences (Drinking Water and Health, 1980, Vol. III), molybdenum from drinking water, except for highly contaminated sources, is not likely to constitute a significant portion of the total human intake of this element. However, as noted above, uranium tailings are often a highly concentrated source of molybdenum, and it is therefore appropriate to include a standard for molybdenum in this rule. In addition to the hazard to humans, our analysis of toxic substances in tailings in the Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (EPA 520/4-82-013-1) found that, for ruminants, molybdenum in concentrations greater than 0.05 ppm in drinking water would lead to chronic toxicity. This concentration included a safety factor of 10; the standard provides for a safety factor of 5, which we consider adequately protective for ruminants.

The standard for combined uranium-234 and uranium-238 due to contamination from uranium tailings is 30 pCi per liter. The level of health risk associated with this standard is equivalent to the level proposed as the MCL for uranium

in drinking water by EPA (56 FR 33050, July 18, 1991). The standard promulgated here applies to remedial actions for uranium tailings only. When the Agency has established a final MCL for isotopes of uranium in drinking water, we will consider whether this standard needs to be reviewed.

The limit for nitrate (as nitrogen) is 10 mg per liter. This is the value of the drinking water standard for nitrate.

B. The Cleanup Standard

With the exception of the point of compliance provision, the standard (subpart B) for cleanup of contaminated groundwater contains the same basic provisions as the standard for disposal in subpart A. In addition, it provides for the establishment of supplemental standards under certain conditions, and for use of institutional control to permit passive restoration through natural flushing when no public water system is involved.

Although the standards specify a single point of compliance for conformance to the groundwater standards for disposal, this does not suffice for the cleanup of groundwater that has been contaminated before final disposal. Instead, in this case compliance must be achieved anywhere contamination above the levels established by these standards is found or is projected to be found in groundwater outside the disposal area and its cover. The standards require DOE to establish a monitoring program adequate to determine the extent of contamination (@ 192.12(c)(1)) in groundwater around each processing site. The possible presence of any of the inorganic or organic hazardous constituents identified in tailings or used in the processing operation should be assessed. The plan for remedial action referenced under @ 192.20(b)(4) should document the extent of contamination, the rate and direction of movement of contaminants, and consider future movement of the plume. The cleanup standards normally require restoration of all contaminated groundwater to the levels provided for under @ 192.02(c)(3). These levels are either background concentrations, the levels specified in Table 1 in the rule, or ACLs. In cases where the groundwater is not classified as of limited use, any ACL should be determined under the assumption that the groundwater may be used for drinking purposes. In certain circumstances, however, supplemental standards set at levels that would be achieved by remedial actions that come as close to meeting the otherwise applicable standards as is reasonably achievable under the circumstances may be appropriate. Such supplemental standards and ACLs are distinct regulatory provisions and may be considered independently. The regulations provide that supplemental standards may be granted if:

. Groundwater at the site is of limited use (@ 192.11(e)) in the absence of contamination from residual radioactive materials; or

. Complete restoration would cause more environmental harm than it would prevent; or

. Complete restoration is technically impracticable from an engineering perspective.

The use of supplemental standards for limited use groundwater applies the groundwater classification system proposed in EPA's 1984 Groundwater Protection Strategy. As proposed for use in these standards (52 FR 36003, September 24, 1987), Class III encompasses groundwaters that are not a current or potential

source of drinking water because of widespread, ambient contamination caused by natural or human-induced conditions, or cannot provide enough water to meet the needs of an average household. These standards adopt the proposed definition of limited use groundwater. However, for the purpose of qualifying for supplemental standards, human-induced conditions exclude contributions from residual radioactive materials.

Water which meets the definition of limited use groundwater may, nevertheless, reasonably be or be projected to be useful for domestic, agricultural, or industrial purposes. For example, in some locations higher quality water may be scarce or absent. Therefore, @ 192.22(d) requires the implementing agencies to remove any additional contamination that has been contributed by residual radioactive materials to the extent that is necessary to preserve existing or reasonably projected beneficial uses in areas of limited water supplies. At a minimum, at sites with limited use groundwater, the supplemental standards require such management of contamination due to tailings as is required to assure protection of human health and the environment from that contamination. For example, if the additional contamination from the tailings would cause an adverse effect on drinkable groundwater that has a significant interconnection with limited use groundwater over which the tailings reside, then the additional contamination from the tailings will have to be abated.

Supplemental standards are also appropriate in certain other cases similar to those addressed in Section 121(d)(4) of the Superfund Amendments and Reauthorization Act of 1986 (SARA). SARA recognizes that cleanup of contamination could sometimes cause environmental harm disproportionate to the effects it would alleviate. For example, if fragile ecosystems would be impaired by any reasonable restoration process (or by carrying a restoration process to extreme lengths to remove small amounts of residual contamination), then it might be prudent not to completely restore groundwater quality. Such a situation might occur, for example, if the quantity of water that would be lost during remediation is a significant fraction of that available in an aquifer that recharges very slowly. Decisions regarding tradeoffs of environmental damage can only be based on characteristics peculiar to the specific location of the site. We do not yet know whether such situations exist in the UMTRCA program, but EPA believes that use of supplemental standards should be possible in such situations, after thorough investigation and consideration of all reasonable restoration alternatives. [*2862]

Based on currently available information, we are not aware that at least substantial restoration of groundwater quality is technically impracticable from an engineering perspective at any of the designated sites. However, our information is incomplete. For example, there may not be enough water available in a very small aquifer to carry out remediation and retain the groundwater resource, or, in other cases, some contaminants may not be removable without destroying the aquifer. EPA believes that DOE should not be required to institute active measures that would completely restore groundwater at these sites if such restoration is technically impracticable from an engineering perspective, and if, at a minimum, protection of human health and the environment is assured. Consistent with the provisions of SARA for remediation of waste sites generally, the standards therefore permit supplemental standards in such situations at levels achievable by site-specific alternate remedial actions. A finding of technical impracticability from an engineering perspective requires careful and extensive documentation, including an analysis of the

degree to which remediation is practicable. It should be noted that the phrase "technically impracticable from an engineering perspective" means that the remedial action cannot reasonably be put into practice; it does not mean a conclusion derived from the balancing of costs and benefits. In addition to documentation of technical matters related to cleanup technology, DOE should also include a detailed assessment of such site-specific matters as transmissivity of the geologic formation, aquifer recharge and storage, contaminant properties (e.g., withdrawal and treatability potential), and the extent of contamination.

Finally, for aquifers where compliance with the groundwater standards can be projected to occur naturally within a period of less than 100 years, and where the groundwater is not now used for a public water system and is not now projected to be so used within this period, this rule permits extension of the remedial period to that time, provided institutional control and an adequate verification plan which assures satisfaction of beneficial uses is established and maintained throughout this extended remedial period.

Active restoration should be carefully considered when evaluating the use of such passive restoration. The provision to permit reliance on natural restoration is based on the judgment that sole reliance on active cleanup may not always be warranted under these standards promulgated pursuant to UMTRCA. This may be the case for situations where active cleansing to completely achieve the standards is impracticable, environmentally damaging, or excessively costly, if groundwater can reach the levels required by the standards through natural flushing within an acceptable period of time. This mechanism may be considered where groundwater concentration limits can be met through partial (or complete) reliance on natural processes and no use of the water as a source for a public water system exists or is projected. Any institutional control that may be required to effectively protect public health and the environment and assure that beneficial uses that the water could have satisfied are provided for in the interim must be verified for effectiveness and modified as necessary. Alternate standards are not required where final cleanup is to be accomplished through natural flushing, since those established under @ 192.02(c)(3) must be met at the end of the remedial period.

The regulations establish a time limit on such extension of the remedial period to limit reliance on extended use of institutional controls to manage public access to contaminated groundwater. Following the precedent established by our rule for high-level radioactive wastes (40 CFR 191.14(a)), use of institutional controls is permitted for this purpose only when they will be needed for periods of less than 100 years.

The effectiveness of institutional controls must be verified and maintained over the entire period of time that they are in use. Examples of acceptable measures include use restrictions enforceable by the administrative or judicial branches of government entities, and measures with a high degree of permanence, such as Federal or State ownership of the land containing the contaminated water. In some instances, a combination of institutional controls may be needed to provide adequate protection, such as providing an alternate source of water for drinking or other beneficial uses and restricting inappropriate use of contaminated groundwater. However, institutional control provisions are not intended to require DOE to provide water for uses that the groundwater would not have been available or suitable for in the absence of contamination from residual radioactive materials. Institutional controls that are not adequate

by themselves include such measures as health advisories, signs, posts, admonitions, or any other measure that requires the voluntary cooperation of private parties. However, such measures may be used to complement other enforceable institutional controls.

Restoration of groundwater may be carried out by removal, wherein the contaminated water is removed from the aquifer, treated, and either disposed of, used, or re-injected into the aquifer, and in situ , through the addition of chemical or biological agents to fix, reduce, or eliminate the contamination in place. Appropriate restoration will depend on characteristics of specific sites and may involve use of a combination of methods. Water can be removed from an aquifer by pumping it out through wells or by collecting the water from intercept trenches. Slurry walls can sometimes be put in place to contain contamination and prevent further migration of contaminants, so that the volume of contaminated water that must be treated is reduced. The background information document contains a more extensive discussion of candidate restoration methods.

Previously EPA reviewed preliminary information for all 24 sites and detailed information for 14 to make a preliminary assessment of the extent of the potential applicability of supplemental standards and the use of passive remediation. Approximately two-thirds of the sites appear to be located over potable (or otherwise useful) groundwater and the balance over limited use groundwaters. DOE, based on more recent information, feels that up to ten sites are candidates for supplemental standards, and that the rate at which natural flushing is occurring at up to eight of the sites permits consideration of passive remediation under institutional control as the sole remedial method. Some sites exhibit conditions that could be amenable to a combination of strategies. Further, EPA is not able to predict the applicability of provisions regarding technical impracticability or excess environmental harm, since this requires detailed analysis of specific sites, but anticipates that wide application is unlikely. It is emphasized that the above assessment is not based on final results for the vast majority of these sites, and is, therefore, subject to change.

RCRA regulations, for hazardous waste disposal units regulated by EPA, provide that acceptable concentrations of constituents in groundwater (including ACLs) are determined by the Regional Administrator (or an authorized State). EPA's regulations under Title II of UMTRCA provide that the NRC, which regulates active sites, replace the EPA Regional Administrator for the above functions when any [*2863] contamination permitted by an ACL will remain on the licensed site or within 500 meters of the disposal area, whichever is closer. Because Section 108(a) of UMTRCA requires the Commission's concurrence with DOE's selection and performance of remedial actions to conform to EPA's standards, this rule makes the same provision for administration by the NRC of those functions for Title I as it did in the case of the Title II standards, and also provides for NRC concurrence on supplemental standards.

V. Implementation

UMTRCA requires the Secretary of Energy to select and perform the remedial actions needed to implement these standards, with the full participation of any State that shares the cost. The NRC must concur with these actions and, when appropriate, the Secretary of Energy must also consult with affected Indian tribes and the Secretary of the Interior.

The cost of remedial actions is being borne by the Federal Government and the States as prescribed by UMTRCA. The clean-up of groundwater is a large-scale undertaking for which there is relatively little long-term experience. Groundwater conditions at the inactive processing sites vary greatly, and, as noted above, engineering experience with some of the required remedial actions is limited. Although preliminary engineering assessments have been performed, specific engineering requirements and detailed costs to meet the groundwater standards at each site have yet to be determined. We believe that costs averaging about 10-15 million (1993) dollars for each of the approximately fourteen tailings sites at which remedial action may be required are most likely.

The benefits from the cleanup of this groundwater are difficult to quantify. In some instances, groundwater that is contaminated by tailings is now in use and will be restored. Future uses that will be preserved by cleanup are difficult to project. In the areas where the tailings were processed, groundwater is an important resource due to the arid condition of the land. However, much of the contamination at these sites occurs in shallow alluvial aquifers. At some of these sites such aquifers have limited use because of their generally poor quality and the availability of better quality water from deeper aquifers.

Implementation of the disposal standard for protection of groundwater will require a judgment that the method chosen provides a reasonable expectation that the provisions of the standard will be met, to the extent reasonably achievable, for up to 1000 years and, in any case, for at least 200 years. This judgment will necessarily be based on site-specific analyses of the properties of the sites, candidate disposal systems, and the potential effects of natural processes over time. Therefore, the measures required to satisfy the standard will vary from site to site. Actual site data, computational models, and expert judgment will be the major tools in deciding that a proposed disposal system will satisfy the standard.

The purpose of the groundwater cleanup standard is to provide the maximum reasonable protection of public health and the environment. Costs incurred by remedial actions should be directed toward this purpose. We intend the standards to be implemented using verification procedures whose cost and technical requirements are reasonable. Procedures that provide a reasonable assurance of compliance with the standards will be adequate. Measurements to assess existing contamination and to determine compliance with the cleanup standards should be performed with 1 reasonable survey and sampling procedures designed to minimize the cost of verification.

The explanations regarding implementation of these regulations in @@ 192.20(a)(2) and (3) have been revised to remove those provisions that the Court remanded and to reflect these new requirements.

These standards are not expected to affect the disposal work DOE has already performed on tailings. On the basis of consultations with DOE and NRC, we expect, in general, that a pile designed to comply with the disposal standards proposed on September 24, 1987, will also comply with these disposal standards for the control of groundwater contamination. DOE will have to determine, with the concurrence of the NRC, what additional work may be needed to comply with the groundwater cleanup requirements. However, any such cleanup work should not adversely affect the control systems for tailings piles that have already been

or are currently being installed.

However, at three sites (Canonsburg, PA; Shiprock, NM; and Salt Lake City, UT) the disposal design was based on standards remanded in part on September 3, 1985. We have considered these sites separately, based on information supplied by DOE, and reached the tentative conclusion that modification of the existing disposal cells is not warranted at any of them. Final determinations will be made by DOE, with the concurrence of NRC.

The disposal site at Canonsburg, PA, is located above the banks of Chartiers Creek. Contamination that might seep from the encapsulated tailings will reach the surface within the site boundary, and is then diluted by water in the creek to insignificant levels. Under these circumstances, this site qualifies for an ACL under @ 192.02(c)(3)(ii), and modification of the existing disposal cell is not warranted.

The site at Shiprock, NM, which is located above the floodplain of the San Juan River, is over an aquifer that may not be useful as a source of water for drinking or other beneficial purpose because of its quality, areal extent, and yield. Most of the groundwater in this aquifer appears to have originated from seepage of tailings liquor from mill impoundments and not to be contributing to contamination of any currently or potentially useful aquifer. Additionally, the quality of this water may be degraded by uncontrolled disposal of municipal refuse north and south of the site. DOE is currently in the process of completing its characterization of this groundwater, and may or may not recommend use of a supplemental standard under @ 192.21(g). In any case, however, it appears unlikely that modification of the existing disposal cell will be necessary.

The site containing the tailings from the Salt Lake City mill is located at Clive, Utah, over groundwater that contains dissolved solids in excess of 10,000 mg/l and is not contributing to contamination of any currently or potentially useful aquifer. Under these circumstances, this site also qualifies for a supplemental standard under @ 192.21(g), and modification of the existing disposal cell is not warranted.

VI. Relationship to Other Policy and Requirements 1In July 1991 EPA completed development of a strategy to guide future EPA and State activities in groundwater protection and cleanup. A key element of this strategy is a statement of EPA Groundwater Protection Principles' n1 that has as its overall goals the prevention of adverse effects on human health and the environment and protection of the environmental integrity of the nation's groundwater resources. To achieve these [*2864] goals, EPA developed principles regarding prevention; remediation; and Federal, State, and local responsibilities. These principles are set forth and their implementation by this rule summarized below.

n1 Protecting the Nation's Groundwater: EPA's Strategy for the 1990s, The Final Report of the EPA Groundwater Task Force, U.S. Environmental Protection Agency, Washington, (Report 21Z-1020), July 1991.

(1) With respect to prevention: groundwater should be protected to ensure that the nation's currently used and reasonably expected drinking water supplies, both public and private, do not present adverse health risks and are preserved for present and future generations. Groundwater should also be protected to ensure that groundwater that is closely hydrologically connected

to surface waters does not interfere with the attainment of surface water quality standards, which is necessary to protect the integrity of associated ecosystems. Groundwater protection can be achieved through a variety of means including: pollution prevention programs; source controls; siting controls; the designation of wellhead protection areas and future public water supply areas; and the protection of aquifer recharge areas. Efforts to protect groundwater must also consider the use, value, and vulnerability of the resource, as well as social and economic values.

This rule for uranium mill tailings protects groundwater by requiring that disposal piles be designed to avoid any new contamination of groundwater that would threaten human health or the environment in the future. Water is scarce in the Western States where these disposal sites occur. Currently almost half of the water consumed in Arizona and New Mexico and 20 to 30 percent of the water consumed in Utah, Colorado, Idaho, and Texas is groundwater. The population in the Mountain States is expected to increase more than that of any other region between now and the year 2010. In particular, the population in Colorado, New Mexico, Arizona, and Utah is expected to increase dramatically. Thus, in order to ensure that all currently used and reasonably expected drinking water supplies near these sites, both public and private, are adequately protected for use by present and future generations, these rules apply drinking water standards to all potable groundwater. The rule also requires that hydrologically-connected aquifers and surface waters, including designated wellhead protection areas and future public water supply areas, be identified and protected, and that other beneficial uses of groundwater besides drinking be identified and protected, including the integrity of associated ecosystems. In this regard we note that DOE has not identified any critical aquatic habitats that have been or could be adversely affected by contamination from these sites.

(2) With respect to remediation: groundwater remediation activities must be prioritized to limit the risk of adverse effects to human health risks first and then to restore currently used and reasonably expected sources of drinking water and groundwater closely hydrologically connected to surface waters, whenever such restorations are practicable and attainable.

Pursuant to our responsibilities under Section 102(b) of UMTRCA, EPA advised DOE in 1979 concerning the criteria which should govern the order in which these sites should be cleaned up. Those criteria specified, in essence, that sites capable of affecting the health of human populations the most should be remediated first. As a result DOE has divided the 24 sites into three levels of priority, based on the populations affected. In order to facilitate implementation of these principles, we have, in this rule, provided DOE with flexibility to prioritize their cleanup activities so as to first minimize human exposure, then restore reasonably expected drinking water sources, and finally to clean up groundwater only when restoration is practicable and attainable. This has been done by relaxing the requirements for cleanup of water:

(a) If it is not a current or potential source of drinking water (i.e., it meets the definition of limited use),

(b) Where natural processes will achieve the standards and there is no current or planned use,

(c) Where adverse environmental impact will occur, and (d) where cleanup is technologically impracticable.

(3) With respect to Federal, State, and local responsibilities: the primary responsibility for coordinating and implementing groundwater protection programs has always been and should continue to be vested with the States. An effective groundwater protection program should link Federal, State, and local activities into a coherent and coordinated plan of action. EPA should continue to improve coordination of groundwater protection efforts within the Agency and with other Federal agencies with groundwater responsibilities.

In the case of the sites covered by these regulations, UMTRCA specifies a primary role for Federal rather than State agencies. However, since these regulations are modeled after existing RCRA regulations, this will serve to insure coherence and coordination with similar prevention and remediation actions by EPA, the States, and other Federal agencies. For example, the concentration limits in groundwater for listed constituents at the sites covered by this rule are the same as those specified for cleanup and disposal at RCRA sites by EPA and the States and at uranium mill sites licensed by NRC.

Executive Order 12866

Under Executive Order 12866 (58 FR 51735; October 4, 1993), EPA must determine whether a rule is "significant" and therefore subject to review by the Office of Management and Budget (OMB) and the requirements of the Executive Order. The Order defines "significant regulatory action" as one that is likely to result in a rule that may:

(1) Have an annual effect on the economy of $ 100 million or more or adversely effect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local or tribal governments or communities;

(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;

(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of the recipients thereof; or

(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the Executive Order.

Pursuant to the terms of Executive Order 12866, it has been determined that this rule is may be a "significant regulatory action," because it may qualify under criterion #4 above on the basis of comments submitted to EPA by letter on January 15, 1993, as a result of OMB review under the previous Executive Order 12291. This action was therefore resubmitted to OMB for review. Comments from OMB to EPA for their review under the previous Executive Order and EPA's response to those comments are included in the docket. Any changes made in response to OMB suggestions or recommendations as a result of the current review will be documented in the public record.

Paperwork Reduction Act

Under the Paperwork Reduction Act of 1986, the Agency is required to state the information collection requirements of any standard published on or after July 1, 1988. In response to this requirement, this standard contains no information collection requirements and imposes no reporting burden on the

public.

List of Subjects in 40 CFR Part 192

Environmental protection, Groundwater, Radiation protection, Uranium.
[*2865]

Dated: December 14, 1994.

Carol M. Browner,

Administrator, Environmental Protection Agency.

For the reasons set forth in the preamble, 40 CFR part 192 is amended as follows:

PART 192--HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM AND THORIUM MILL TAILINGS

1. The authority citation for part 192 continues to read as follows:

Authority: Section 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as added by the Uranium Mill Tailings Radiation Control Act of 1978, Pub. L. 95-604, as amended.

Subpart A--Standards for the Control of Residual Radioactive Materials From Inactive Uranium Processing Sites

2. Section 192.01 is amended by revising paragraphs (a) and (e) and adding paragraphs (g) through (r) to read as follows:

@ 192.01 -- Definitions.

(a) Residual radioactive material means:

(1) Waste (which the Secretary determines to be radioactive) in the form of tailings resulting from the processing of ores for the extraction of uranium and other valuable constituents of the ores; and

(2) Other wastes (which the Secretary determines to be radioactive) at a processing site which relate to such processing, including any residual stock of unprocessed ores or low-grade materials.

* * * * *

(e) Depository site means a site (other than a processing site) selected under Section 104(b) or 105(b) of the Act.

* * * * *

(g) Act means the Uranium Mill Tailings Radiation Control Act of 1978, as amended.

(h) Administrator means the Administrator of the Environmental Protection Agency.

(i) Secretary means the Secretary of Energy.

(j) Commission means the Nuclear Regulatory Commission.

(k) Indian tribe means any tribe, band, clan, group, pueblo, or community of Indians recognized as eligible for services provided by the Secretary of the Interior to Indians.

(l) Processing site means:

(1) Any site, including the mill, designated by the Secretary under Section 102(a)(1) of the Act; and

(2) Any other real property or improvement thereon which is in the vicinity of such site, and is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

(m) Tailings means the remaining portion of a metal-bearing ore after some or all of such metal, such as uranium, has been extracted.

(n) Disposal period means the period of time beginning March 7, 1983 and ending with the completion of all subpart A requirements specified under a plan for remedial action except those specified in @ 192.03 and @ 192.04.

(o) Plan for remedial action means a written plan (or plans) for disposal and cleanup of residual radioactive materials associated with a processing site that incorporates the results of site characterization studies, environmental assessments or impact statements, and engineering assessments so as to satisfy the requirements of subparts A and B of this part. The plan(s) shall be developed in accordance with the provisions of Section 108(a) of the Act with the concurrence of the Commission and in consultation, as appropriate, with the Indian Tribe and the Secretary of Interior.

(p) Post-disposal period means the period of time beginning immediately after the disposal period and ending at termination of the monitoring period established under @ 192.03.

(q) Groundwater means water below the ground surface in a zone of saturation.

(r) Underground source of drinking water means an aquifer or its portion:

(1)(i) Which supplies any public water system as defined in @ 141.2 of this chapter; or

(ii) Which contains a sufficient quantity of groundwater to supply a public water system; and

(A) Currently supplies drinking water for human consumption; or

(B) Contains fewer than 10,000 mg/l total dissolved solids; and

(2) Which is not an exempted aquifer as defined in @ 144.7 of this chapter.

3. Section 192.02 is revised to read as follows:

@ 192.02 -- Standards.

Control of residual radioactive materials and their listed constituents shall be designed n1 to:

n1 Because the standard applies to design, monitoring after disposal is not required to demonstrate compliance with respect to @ 192.02(a) and (b).

(a) Be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,

(b) Provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not:

(1) Exceed an average n2 release rate of 20 picocuries per square meter per second, or

n2 This average shall apply over the entire surface of the disposal site and over at least a one-year period. Radon will come from both residual radioactive materials and from materials covering them. Radon emissions from the covering materials should be estimated as part of developing a remedial action plan for each site. The standard, however, applies only to emissions from residual radioactive materials to the atmosphere.

(2) Increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

(c) Provide reasonable assurance of conformance with the following groundwater protection provisions:

(1) The Secretary shall, on a site-specific basis, determine which of the constituents listed in Appendix I to Part 192 are present in or reasonably derived from residual radioactive materials and shall establish a monitoring program adequate to determine background levels of each such constituent in groundwater at each disposal site.

(2) The Secretary shall comply with conditions specified in a plan for remedial action which includes engineering specifications for a system of disposal designed to ensure that constituents identified under paragraph (c)(1) of this section entering the groundwater from a depository site (or a processing site, if residual radioactive materials are retained on the site) will not exceed the concentration limits established under paragraph (c)(3) of this section (or the supplemental standards established under @ 192.22) in the uppermost aquifer underlying the site beyond the point of compliance established under paragraph (c)(4) of this section.

(3) Concentration limits:

(i) Concentration limits shall be determined in the groundwater for listed constituents identified under paragraph (c)(1) of this section. The

concentration of a listed constituent in groundwater must not exceed:

(A) The background level of that constituent in the groundwater; or

(B) For any of the constituents listed in Table 1 to subpart A, the respective value given in that Table if the background level of the constituent is below the value given in the Table; or

(C) An alternate concentration limit established pursuant to paragraph (c)(3)(ii) of this section.

(ii)(A) The Secretary may apply an alternate concentration limit if, after [*2866] considering remedial or corrective actions to achieve the levels specified in paragraphs (c)(3)(i)(A) and (B) of this section, he has determined that the constituent will not pose a substantial present or potential hazard to human health and the environment as long as the alternate concentration limit is not exceeded, and the Commission has concurred.

(B) In considering the present or potential hazard to human health and the environment of alternate concentration limits, the following factors shall be considered:

(1) Potential adverse effects on groundwater quality, considering:

(i) The physical and chemical characteristics of constituents in the residual radioactive material at the site, including their potential for migration;

(ii) The hydrogeological characteristics of the site and surrounding land;

(iii) The quantity of groundwater and the direction of groundwater flow;

(iv) The proximity and withdrawal rates of groundwater users;

(v) The current and future uses of groundwater in the region surrounding the site;

(vi) The existing quality of groundwater, including other sources of contamination and their cumulative impact on the groundwater quality;

(vii) The potential for health risks caused by human exposure to constituents;

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

(ix) The persistence and permanence of the potential adverse effects;

(x) The presence of underground sources of drinking water and exempted aquifers identified under @ 144.7 of this chapter; and

(2) Potential adverse effects on hydraulically-connected surface-water quality, considering:

(i) The volume and physical and chemical characteristics of the residual radioactive material at the site;

(ii) The hydrogeological characteristics of the site and surrounding land;

(iii) The quantity and quality of groundwater, and the direction of groundwater flow;

(iv) The patterns of rainfall in the region;

(v) The proximity of the site to surface waters;

(vi) The current and future uses of surface waters in the region surrounding the site and any water quality standards established for those surface waters;

(vii) The existing quality of surface water, including other sources of contamination and their cumulative impact on surface water quality;

(viii) The potential for health risks caused by human exposure to constituents;

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

(x) The persistence and permanence of the potential adverse effects.

(4) Point of compliance: The point of compliance is the location at which the groundwater concentration limits of paragraph (c)(3) of this section apply. The point of compliance is the intersection of a vertical plane with the uppermost aquifer underlying the site, located at the hydraulically downgradient limit of the disposal area plus the area taken up by any liner, dike, or other barrier designed to contain the residual radioactive material.

(d) Each site on which disposal occurs shall be designed and stabilized in a manner that minimizes the need for future maintenance.

4. Section 192.03 is added to read as follows:

@ 192.03 -- Monitoring.

A groundwater monitoring plan shall be implemented, to be carried out over a period of time commencing upon completion of remedial actions taken to comply with the standards in @ 192.02, and of a duration which is adequate to demonstrate that future performance of the system of disposal can reasonably be expected to be in accordance with the design requirements of @ 192.02(c). This plan and the length of the monitoring period shall be modified to incorporate any corrective actions required under @ 192.04 or @ 192.12(c).

5. Section 192.04 is added to read as follows:

@ 192.04 -- Corrective Action.

If the groundwater concentration limits established for disposal sites under provisions of @ 192.02(c) are found or projected to be exceeded, a corrective action program shall be placed into operation as soon as is practicable, and in no event later than eighteen (18) months after a finding of exceedance. This corrective action program will restore the performance of the system of disposal to the original concentration limits established under @ 192.02(c)(3), to the

extent reasonably achievable, and, in any case, as a minimum shall:

(a) Conform with the groundwater provisions of @ 192.02(c)(3), and

(b) Clean up groundwater in conformance with subpart B, modified as appropriate to apply to the disposal site.

6. Table 1 is added to subpart A to read as follows:

Table 1 to Subpart A.--Maximum Concentration of Constituents for Groundwater Protection

Constituent concentration fn 1	Maximum
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Nitrate (as N)	10.
Molybdenum	0.1
Combined radium-226 and radium-228	5 pCi/liter
Combined uranium-234 and uranium-238 fn 2	30 pCi/liter
Gross alpha-particle activity (excluding radon and uranium)	15 pCi/liter
Endrin (1,2,3,4,10,10-hexachloro-6,7-exposy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo,endo-5,8-dimethanonaphthalene)	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma insomer)	0.004
Methoxychlor (1,1,1-trichloro-2,2'-bis(p-methoxyphenylethane))	0.1
Toxaphene (C10H10Cl6, technical chlorinated camphene, 67-69 percent chlorine)	0.005
2,4-D (2,4-dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-trichlorophenoxypropionic acid)	0.01

fn 1 Milligrams per liter, unless stated otherwise.

fn 2 Where secular equilibrium obtains, this criterion will be satisfied by a concentration of 0.044 milligrams per liter (0.044 mg/l). For conditions of other than secular equilibrium, a corresponding value may be derived and applied, based on the measured site-specific ratio of the two isotopes of uranium.

Subpart B--Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

7. Section 192.11 is amended by revising paragraph (a) and adding paragraph (e) to read as follows:

192.11 -- Definitions.

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in subpart A.

* * * * * [*2867]

(e) Limited use groundwater means groundwater that is not a current or potential source of drinking water because (1) the concentration of total dissolved solids is in excess of 10,000 mg/l, or (2) widespread, ambient contamination not due to activities involving residual radioactive materials from a designated processing site exists that cannot be cleaned up using treatment methods reasonably employed in public water systems, or (3) the quantity of water reasonably available for sustained continuous use is less than 150 gallons per day. The parameters for determining the quantity of water reasonably available shall be determined by the Secretary with the concurrence of the Commission.

8. In @ 192.12, the introductory text is republished without change and paragraph (c) is added to read as follows:

192.12 -- Standards.

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

* * * * *

(c) The Secretary shall comply with conditions specified in a plan for remedial action which provides that contamination of groundwater by listed constituents from residual radioactive material at any designated processing site (@ 192.01(1)) shall be brought into compliance as promptly as is reasonably achievable with the provisions of @ 192.02(c)(3) or any supplemental standards established under @ 192.22. For the purposes of this subpart:

(1) A monitoring program shall be carried out that is adequate to define backgroundwater quality and the areal extent and magnitude of groundwater contamination by listed constituents from residual radioactive materials (@ 192.02(c)(1)) and to monitor compliance with this subpart. The Secretary shall determine which of the constituents listed in Appendix I to part 192 are present in or could reasonably be derived from residual radioactive material at the site, and concentration limits shall be established in accordance with @ 192.02(c)(3).

(2) (i) If the Secretary determines that sole reliance on active remedial procedures is not appropriate and that cleanup of the groundwater can be more reasonably accomplished in full or in part through natural flushing, then the period for remedial procedures may be extended. Such an extended period may extend to a term not to exceed 100 years if:

(A) The concentration limits established under this subpart are projected to be satisfied at the end of this extended period,

(B) Institutional control, having a high degree of permanence and which will effectively protect public health and the environment and satisfy beneficial uses of groundwater during the extended period and which is enforceable by the

administrative or judicial branches of government entities, is instituted and maintained, as part of the remedial action, at the processing site and wherever contamination by listed constituents from residual radioactive materials is found in groundwater, or is projected to be found, and

(C) The groundwater is not currently and is not now projected to become a source for a public water system subject to provisions of the Safe Drinking Water Act during the extended period.

(ii) Remedial actions on groundwater conducted under this subpart may occur before or after actions under Section 104(f)(2) of the Act are initiated.

(3) Compliance with this subpart shall be demonstrated through the monitoring program established under paragraph (c)(1) of this section at those locations not beneath a disposal site and its cover where groundwater contains listed constituents from residual radioactive material.

Subpart C--Implementation

9. In @ 192.20, paragraphs (a)(2) and (a)(3) and the first sentence of paragraph (b)(l) are revised and paragraphs (a)(4) and (b)(4) are added to read as follows:

192.20 -- Guidance for implementation.

* * * * *

(a)(1) * * *

(2) Protection of water should be considered on a case-specific basis, drawing on hydrological and geochemical surveys and all other relevant data. The hydrologic and geologic assessment to be conducted at each site should include a monitoring program sufficient to establish background groundwater quality through one or more upgradient or other appropriately located wells. The groundwater monitoring list in Appendix IX of part 264 of this chapter (plus the additional constituents in Table A of this paragraph) may be used for screening purposes in place of Appendix I of part 192 in the monitoring program. New depository sites for tailings that contain water at greater than the level of "specific retention" should use aliner or equivalent. In considering design objectives for groundwater protection, the implementing agencies should give priority to concentration levels in the order listed under @ 192.02(c)(3)(i). When considering the potential for health risks caused by human exposure to known or suspected carcinogens, alternate concentration limits pursuant to paragraph 192.02(c)(3)(ii) should be established at concentration levels which represent an excess lifetime risk, at a point of exposure, to an average individual no greater than between 10-4 and 10-6.

Table A to @ 192.20(a)(2)--Additional Listed Constituents

Nitrate (as N)
Molybdenum
Combined radium-226 and radium-228
Combined uranium-234 and uranium-238
Gross alpha-particle activity (excluding radon and uranium)

(3) The plan for remedial action, concurred in by the Commission, will specify how applicable requirements of subpart A are to be satisfied. The plan should include the schedule and steps necessary to complete disposal operations at the site. It should include an estimate of the inventory of wastes to be disposed of in the pile and their listed constituents and address any need to eliminate free liquids; stabilization of the wastes to a bearing capacity sufficient to support the final cover; and the design and engineering specifications for a cover to manage the migration of liquids through the stabilized pile, function without maintenance, promote drainage and minimize erosion or abrasion of the cover, and accommodate settling and subsidence so that cover integrity is maintained. Evaluation of proposed designs to conform to subpart A should be based on realistic technical judgments and include use of available empirical information. The consideration of possible failure modes and related corrective actions should be limited to reasonable failure assumptions, with a demonstration that the disposal design is generally amenable to a range of corrective actions.

(4) The groundwater monitoring list in Appendix IX of part 264 of this chapter (plus the additional constituents in Table A in paragraph (a)(2) of this section) may be used for screening purposes in place of Appendix I of part 192 in monitoring programs. The monitoring plan required under @ 192.03 should be designed to include verification of site-specific assumptions used to project the performance of the disposal system. Prevention of [*2868] contamination of groundwater may be assessed by indirect methods, such as measuring the migration of moisture in the various components of the cover, the tailings, and the area between the tailings and the nearest aquifer, as well as by direct monitoring of groundwater. In the case of vicinity properties (@ 192.01(l)(2)), such assessments may not be necessary, as determined by the Secretary, with the concurrence of the Commission, considering such factors as local geology and the amount of contamination present. Temporary excursions from applicable limits of groundwater concentrations that are attributable to a disposal operation itself shall not constitute a basis for considering corrective action under @ 192.04 during the disposal period, unless the disposal operation is suspended prior to completion for other than seasonal reasons.

(b)(l) Compliance with @ 192.12(a) and (b) of subpart B, to the extent practical, should be demonstrated through radiation surveys. * * *

* * * * *

(4) The plan(s) for remedial action will specify how applicable requirements of subpart B would be satisfied. The plan should include the schedule and steps necessary to complete the cleanup of groundwater at the site. It should document the extent of contamination due to releases prior to final disposal, including the identification and location of listed constituents and the rate and direction of movement of contaminated groundwater, based upon the monitoring carried out under @ 192.12(c)(1). In addition, the assessment should consider future plume movement, including an evaluation of such processes as attenuation and dilution and future contamination from beneath a disposal site. Monitoring for assessment and compliance purposes should be sufficient to establish the extent and magnitude of contamination, with reasonable assurance, through use of a carefully chosen minimal number of sampling locations. The location and number of monitoring wells, the frequency and duration of monitoring, and the selection of indicator analytes for long-term groundwater monitoring, and, more generally, the design and operation of the monitoring system, will depend on the

potential for risk to receptors and upon other factors, including characteristics of the subsurface environment, such as velocity of groundwater flow, contaminant retardation, time of groundwater or contaminant transit to receptors, results of statistical evaluations of data trends, and modeling of the dynamics of the groundwater system. All of these factors should be incorporated into the design of a site-specific monitoring program that will achieve the purpose of the regulations in this subpart in the most cost-effective manner. In the case of vicinity properties (@ 192.01(l)(2)), such assessments will usually not be necessary. The Secretary, with the concurrence of the Commission, may consider such factors as local geology and amount of contamination present in determining criteria to decide when such assessments are needed. In cases where @ 192.12(c)(2) is invoked, the plan should include a monitoring program sufficient to verify projections of plume movement and attenuation periodically during the extended cleanup period. Finally, the plan should specify details of the method to be used for cleanup of groundwater.

10. In @ 192.21, the introductory text and paragraph (b) are revised, paragraph (f) is redesignated as paragraph (h), and new paragraphs (f) and (g) are added to read as follows:

@ 192.21 -- Criteria for applying supplemental standards

Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in subparts A and B. The implementing agencies may (and in the case of paragraph (h) of this section shall) apply standards under @ 192.22 in lieu of the standards of subparts A or B if they determine that any of the following circumstances exists:

* * * * *

(b) Remedial actions to satisfy the cleanup standards for land, @ 192.12(a), and groundwater, @ 192.12(c), or the acquisition of minimum materials required for control to satisfy @@ 192.02(b) and (c), would, notwithstanding reasonable measures to limit damage, directly produce health and environmental harm that is clearly excessive compared to the health and environmental benefits, now or in the future. A clear excess of health and environmental harm is harm that is long-term, manifest, and grossly disproportionate to health and environmental benefits that may reasonably be anticipated.

* * * * *

(f) The restoration of groundwater quality at any designated processing site under @ 192.12(c) is technically impracticable from an engineering perspective.

(g) The groundwater meets the criteria of @ 192.11(e).

* * * * *

11. In @ 192.22, paragraphs (a) and (b) are revised and paragraph (d) is added to read as follows:

192.22 -- Supplemental standards.

* * * * *

(a) When one or more of the criteria of @ 192.21(a) through (g) applies, the Secretary shall select and perform that alternative remedial action that comes as close to meeting the otherwise applicable standard under @ 192.02(c)(3) as is reasonably achievable.

(b) When @ 192.21(h) applies, remedial actions shall reduce other residual radioactivity to levels that are as low as is reasonably achievable and conform to the standards of subparts A and B to the maximum extent practicable.

* * * * *

(d) When @ 192.21(b), (f), or (g) apply, implementing agencies shall apply any remedial actions for the restoration of contamination of groundwater by residual radioactive materials that is required to assure, at a minimum, protection of human health and the environment. In addition, when @ 192.21(g) applies, supplemental standards shall ensure that current and reasonably projected uses of the affected groundwater are preserved.

12. Appendix I is added to part 192 to read as follows:

Appendix I to Part 192--Listed Constituents

Acetonitrile

Acetophenone (Ethanone, 1-phenyl)

2-Acetylaminofluorene (Acetamide, N-9H-fluoren-2-yl-)

Acetyl chloride

1-Acetyl-2-thiourea (Acetamide, N-(aminothioxymethyl)-)

Acrolein (2-Propenal)

Acrylamide (2-Propenamide)

Acrylonitrile (2-Propenenitrile)

Aflatoxins

Aldicarb (Propenal, 2-methyl-2-(methylthio)-,O-[(methylamino)carbonyl]oxime

Aldrin (1,4:5,8-Dimethanonaphthalene,
1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro(1 alpha ,4 alpha ,4a beta ,5 alpha,8 alpha,8 alpha beta)-)

Allyl alcohol (2-Propen-1-ol)

Allyl chloride (1-Propane,3-chloro)

Aluminum phosphide

4-Aminobiphenyl ([1,1'-Biphenyl]-4-amine)

5-(Aminomethyl)-3-isoxazolol (3(2H)-Isoxazolone,5-(aminomethyl)-)

4-Aminopyridine (4-Pyridineamine)

Amitrole (lH-1,2,4-Triazol-3-amine)

Ammonium vanadate (Vanadic acid, ammonium salt)

Aniline (Benzenamine)

Antimony and compounds, N.O.S. n1

n1 The abbreviation N.O.S. (not otherwise specified) signifies those members of the general class not specifically listed by name in this appendix.
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Aramite (Sulfurous acid, 2-chloroethyl
2-[4-(1,1-dimethylethyl)phenoxy]-1-methylethyl ester)

Arsenic and compounds, N.O.S.

Arsenic acid (Arsenic acid H sub 3AsO sub 4)

Arsenic pentoxide (Arsenic oxide As sub 2O sub 5)

Auramine (Benzamine, 4,4'-carbonimidoylbis[N,N-dimethyl-])

Azaserine (L-Serine, diazoacetate (ester))

Barium and compounds, N.O.S.

Barium cyanide

Benz[c]acridine (3,4-Benzacridine)

Benz[a]anthracene (1,2-Benzanthracene)

Benzal chloride (Benzene, dichloromethyl-)

Benzene (Cyclohexatriene)

Benzenearsonic acid (Arsenic acid, phenyl-)

Benzidine ([1,1'-Biphenyl]-4,4'-diamine)

Benzo[b]fluoranthene (Benz[e]acephananthrylene)

Benzo[j]fluoranthene

Benzo[k]fluoranthene

Benzo[a]pyrene

p-Benzoquinone (2,5-Cyclohexadiene-1,4-dione)

Benzotrichloride (Benzene, (trichloro-

methyl)-)

Benzyl chloride (Benzene, (chloromethyl)-)

Beryllium and compounds, N.O.S.

Bromoacetone (2-Propanone, 1-bromo-)

Bromoform (Methane, tribromo-)

4-Bromophenyl phenyl ether (Benzene, l-bromo-4-phenoxy-)

Brucine (Strychnidin-10-one, 2,3-dimeth-

oxy-)

Butyl benzyl phthalate (1,2-Benzenedicarbozylic acid, butyl phenylmethyl ester)

Cacodylic acid (Arsinic acid, dimethyl)

Cadmium and compounds, N.O.S.

Calcium chromate (Chromic acid H sub 2CrO sub 4, calcium salt)

Calcium cyanide (Ca(CN) sub 2)

Carbon disulfide

Carbon oxyfluoride (Carbonic difluoride)

Carbon tetrachloride (Methane, tetrachloro-)

Chloral (Acetaldehyde, trichloro-)

Chlorambucil (Benzenebutanoic acid, 4-[bis(2-chloroethyl)amino]-)

Chlordane
(4,7-Methano-1H-indene,1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-)

Chlorinated benzenes, N.O.S.

Chlorinated ethane, N.O.S.

Chlorinated fluorocarbons, N.O.S.

Chlorinated naphthalene, N.O.S.

Chlorinated phenol, N.O.S.

Chlornaphazin (Naphthalenamine, N,N'-bis(2-chlorethyl)-)

Chloroacetaldehyde (Acetaldehyde, chloro-)

Chloroalkyl ethers, N.O.S.

p-Chloroaniline (Benzenamine, 4-chloro-)

Chlorobenzene (Benzene, chloro-)

Chlorobenzilate (Benzeneacetic acid, 4-chloro- alpha -(4-chlorophenyl)- alpha -hydroxy-, ethyl ester)

p-Chloro-m-cresol (Phenol, 4-chloro-3-methyl)

2-Chloroethyl vinyl ether (Ethene, (2-chloroethoxy)-)

Chloroform (Methane, trichloro-)

Chloromethyl methyl ether (Methane, chloromethoxy-)

beta -Chloronapthalene (Naphthalene, 2-chloro-)

o-Chlorophenol (Phenol, 2-chloro-)

1-(o-Chlorophenyl)thiourea (Thiourea, (2-chlorophenyl-))

3-Chloropropionitrile (Propanenitrile, 3-chloro-)

Chromium and compounds, N.O.S.

Chrysene

Citrus red No. 2 (2-Naphthalenol, 1-[(2,5-dimethoxyphenyl)azo]-)

Coal tar creosote

Copper cyanide (CuCN)

Creosote

Cresol (Chresylic acid) (Phenol, methyl-)

Crotonaldehyde (2-Butenal)

Cyanides (soluble salts and complexes), N.O.S.

Cyanogen (Ethanedinitrile)

Cyanogen bromide ((CN)Br)

Cyanogen chloride ((CN)Cl)

Cycasin (beta-D-Glucopyranoside, (methyl-ONN-azoxy)methyl)

2-Cyclohexyl-4,6-dinitrophenol (Phenol, 2-cyclohexyl-4,6-dinitro-)

Cyclophosphamide (2H-1,3,2-Oxazaphosphorin-2-amine,N,N-bis(2-chloroethyl) tetrahydro-,2-oxide)

2,4-D and salts and esters (Acetic acid, (2,4-dichlorophenoxy)-)

Daunomycin (5,12-Naphthacenedione,8-acetyl-10-[(3-amino-2,3,6-trideoxy- alpha -Llyxo-hexopyranosyl)oxy]-7,8,9,10-tetrahydro-6,8,11-trihydroxy-1-methoxy-,(8S-cis))

DDD (Benzene, 1,1'-(2,2-dichloroethylidene)bis[4-chloro-)

DDE (Benzene, 1,1-(dichloroethylidene)bis[4-chloro-)

DDT (Benzene, 1,1'-(2,2,2-trichloroethlyidene)bis[4-chloro-)

Diallate (Carbomothioic acid, bis(1-methylethyl)-,S-(2,3-dichloro-2-propenyl) ester)

Dibenz[a,h]acridine

Dibenz[a,j]acridine

Dibenz[a,h]anthracene

7H-Dibenzo[c,g]carbazole

Dibenzo[a,e]pyrene (Naphtho[1,2,4,5-def)crysene)

Dibenzo[a,h]pyrene (Dibenzo[b,def]crysene)

Dibenzo[a,i]pyrene (Benzo[rst]pentaphene)

1,2-Dibromo-3-chloropropane (Propane, 1,2-dibromo-3-chloro-)

Dibutylphthalate (1,2-Benzenedicarboxylic acid, dibutyl ester)

o-Dichlorobenzene (Benzene, 1,2-dichloro-)

m-Dichlorobenzene (Benzene, 1,3-dichloro-)

p-Dichlorobenzene (Benzene, 1,4-dichloro-)

Dichlorobenzene, N.O.S. (Benzene; dichloro-, N.O.S.)

3,3'-Dichlorobenzidine ([1,1'-Biphenyl]-4,4'-diamine, 3,3'-dichloro-)

1,4-Dichloro-2-butene (2-Butene, 1,4-dichloro-)

Dichlorodifluoromethane (Methane, dichlorodifluoro-)

Dichloroethylene, N.O.S.

1,1-Dichloroethylene (Ethene, 1,1-dichloro-)

1,2-Dichloroethylene (Ethene, 1,2-dichloro-,(E)-)

Dichloroethyl ether (Ethane, 1,1'-oxybis[2-chloro-)

Dichloroisopropyl ether (Propane, 2,2'-oxybis[2-chloro-)

Dichloromethoxy ethane (Ethane, 1,1'-[methylenebis(oxy)bis[2-chloro-)

Dichloromethyl ether (Methane, oxybis[chloro-)

2,4-Dichlorophenol (Phenol, 2,4-dichloro-)

2,6-Dichlorophenol (Phenol, 2,6-dichloro-)

Dichlorophenylarsine (Arsinous dichloride, phenyl-)

Dichloropropane, N.O.S. (Propane,

dichloro-,)

Dichloropropanol, N.O.S. (Propanol, dichloro-,)

Dichloropropene; N.O.S. (1-Propane, dichloro-,)

1,3-Dichloropropene (1-Propene, 1,3-dichloro-)

Dieldrin
(2,7:3,6-Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,
7,7a,octahydro-,(1a alpha ,2 beta ,2a alpha ,3 beta ,6 beta ,6a alpha ,7 beta
,7a alpha)-)

1,2:3,4-Diepoxybutane (2,2'-Bioxirane)

Diethylarsine (Arsine, diethyl-)

1,4 Diethylene oxide (1,4-Dioxane)

Diethylhexyl phthalate (1,2-Benzenedicarboxlyic acid, bis(2-ethylhexl) ester)

N,N-Diethylhydrazine (Hydrazine, 1,2-diethyl)

O,O-Diethyl S-methyl dithiophosphate (Phosphorodithioic acid, O,O-diethyl
S-methyl ester)

Diethyl-p-nitrophenyl phosphate (Phosphoric acid, diethyl 4-nitrophenyl ester)

Diethyl phthalate (1,2-Benzenedicarboxylic acid, diethyl ester)

O,O-Diethyl O-pyrazinyl phosphorothioate (Phosphorothioic acid, O,O-diethyl
O-pyrazinyl ester)

Diethylstilbesterol (Phenol, 4,4'-(1,2-diethyl-1,2-ethenediyl)bis-,(E)-)

Dihydrosafrole (1,3-Benxodioxole, 5-propyl-)

Diisopropylfluorophosphate (DFP) (Phosphorofluoridic acid, bis(1-methyl ethyl)
ester)

Dimethoate (Phosphorodithioic acid, O,O-dimethyl S-[2-(methylamino) 2-oxoethyl] ester)

3,3'-Dimethoxybenzidine ([1,1'-Biphenyl]-4,4'-diamine, 3,3'-dimethoxy-)

p-Dimethylaminoazobenzene (Benzenamine, N,N-dimethyl-4-(phenylazo)-)

7,12-Dimethylbenz[a]anthracene (Benz[a]anthracene, 7,12-dimethyl-)

3,3'-Dimethylbenzidine ([1,1'-Biphenyl]-4,4'-diamine, 3,3'-dimethyl-)

Dimethylcarbamoyl chloride (carbamic chloride, dimethyl-)

1,1-Dimethylhydrazine (Hydrazine, 1,1-dimethyl-)

1,2-Dimethylhydrazine (Hydrazine, 1,2-dimethyl-)

alpha , alpha -Dimethylphenethylamine (Benzeneethanamine, alpha , alpha -dimethyl-)

2,4-Dimethylphenol (Phenol, 2,4-dimethyl-)

Dimethylphthalate (1,2-Benzenedicarboxylic acid, dimethyl ester)

Dimethyl sulfate (Sulfuric acid, dimethyl ester)

Dinitrobenzene, N.O.S. (Benzene, dinitro-)

4,6-Dinitro-o-cresol and salts (Phenol, 2-methyl-4,6-dinitro-)

2,4-Dinitrophenol (Phenol, 2,4-dinitro-)

2,4-Dinitrotoluene (Benzene, 1-methyl-2,4-dinitro-)

2,6-Dinitrotoluene (Benzene, 2-methyl-1,3-dinitro-)

Dinoseb (Phenol, 2-(1-methylpropyl)-4,6-dinitro-)

Di-n-octyl phthalate (1,2-Benzenedicarboxylic acid, dioctyl ester)

1,4-Dioxane (1,4-Diethyleneoxide)

Diphenylamine (Benzenamine, N-phenyl-) [*2870]

1,2-Diphenylhydrazine (Hydrazine, 1,2-diphenyl-)

Di-n-propylnitrosamine (1-Propanamine,N-nitroso-N-propyl-)

Disulfoton (Phosphorodithioic acid, O,O-diethyl S-[2-(ethylthio)ethyl] ester)

Dithiobiuret (Thioimidodicarbonic diamide [(H sub 2N)C(S)] sub 2NH)

Endosulfan (6,9,Methano-2,4,3-benzodioxathiepin,6,7,8,9,10,10-hexachloro-1,5,5a, 6,9,9ahexahydro,3-oxide)

Endothall (7-Oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid)

Endrin and metabolites
(2,7:3,6-Dimethanonaphth[2,3-b]oxirene,3,4,5,6,9,9-hexachloro1a,2,2a,3,6,6a,7,7a
-octa-hydro,(1a alpha ,2 beta ,2a beta ,3 alpha ,6 alpha ,6a beta ,7 beta ,7a
alpha)-)

Epichlorohydrin (Oxirane, (chloromethyl)-)

Epinephrine (1,2-Benzenediol,4-[1-hydroxy-2-(methylamino)ethyl]-,(R)-,)

Ethyl carbamate (urethane) (Carbamic acid, ethyl ester)

Ethyl cyanide (propanenitrile)

Ethylenebisdithiocarbamic acid, salts and esters (Carbamodithioic acid,
1,2-Ethanediylbis-)

Ethylene dibromide (1,2-Dibromoethane)

Ethylene dichloride (1,2-Dichloroethane)

Ethylene glycol monoethyl ether (Ethanol, 2-ethoxy-)

Ethyleneimine (Aziridine)

Ethylene oxide (Oxirane)

Ethylenethiourea (2-Imidazolidinethione)

Ethylidene dichloride (Ethane, 1,1-

Dichloro-)

Ethyl methacrylate (2-Propenoic acid, 2-methyl-, ethyl ester)

Ethylmethane sulfonate (Methanesulfonic acid, ethyl ester)

Famphur (Phosphorothioic acid, O-[4-[(dimethylamino)sulphonyl]phenyl]
O,O-dimethyl ester)

Fluoranthene

Fluorine

Fluoroacetamide (Acetamide, 2-fluoro-)

Fluoroacetic acid, sodium salt (Acetic acid, fluoro-, sodium salt)

Formaldehyde (Methylene oxide)

Formic acid (Methanoic acid)

Glycidylaldehyde (Oxiranecarboxyaldehyde)

Halomethane, N.O.S.

Heptachlor (4,7-Methano-1H-indene,
1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-)

Heptachlor epoxide (alpha , beta , and gamma isomers)
(2,5-Methano-2H-indeno[1,2-b]-oxirene,
2,3,4,5,6,7,7-heptachloro-1a,1b,5,5a,6,6a-hexa-hydro-,(1a alpha ,1b beta ,2
alpha ,5 alpha ,5a beta ,6 beta ,6a alpha)-)

Hexachlorobenzene (Benzene, hexachloro-)

Hexachlorobutadiene (1,3-Butadiene, 1,1,2,3,4,4-hexachloro-)

Hexachlorocyclopentadiene (1,3-Cyclopentadiene, 1,2,3,4,5,5-hexachloro-)

Hexachlorodibenzofurans

Heptachlorodibenzo-p-dioxins

Hexachloroethane (Ethane, hexachloro-)

Hexachlorophene (phenol, 2,2'-Methylenebis[3,4,6-trichloro-)

Hexachloropropene (1-Propene, 1,1,2,3,3,3-hexachloro-)

Hexaethyl tetraphosphate (Tetraphosphoric acid, hexaethyl ester)

Hydrazine

Hydrocyanic acid

Hydrofluoric acid

Hydrogen sulfide (H sub 2S)

Indeno(1,2,3-cd)pyrene

Isobutyl alcohol (1-Propanol, 2-methyl-)

Isodrin (1,4,5,8-Dimethanonaphthalene,
1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro, (1 alpha ,4 alpha ,4a beta ,5
beta ,8 beta ,8a beta)-)

Isosafrole (1,3-Benzodioxole, 5-(1-propenyl)-)

Kepone (1,3,4-Metheno-2H-cyclobuta[cd]pentalen-2-one,
1,1a,3,3a,4,5,5,5a,5b,6-decachlorooctahydro-)

Lasiocarpine (2-Butenoic acid,
2-methyl-,7-[[2,3-dihydroxy-2-(1-methoxyethyl)-3-methyl-1-oxobutoxy]methyl]-
2,3,5,7a-tetrahydro-1H-pyrrolizin-l-yl ester)

Lead and compounds, N.O.S.

Lead acetate (Acetic acid, lead(2+) salt)

Lead phosphate (Phosphoric acid, lead(2+) salt(2:3))

Lead subacetate (Lead, bis(acetato-O)tetrahydroxytri-)

Lindane (Clohexane, 1,2,3,4,5,6-hexachloro-, (1 alpha ,2 alpha ,3 beta ,4 alpha ,5 alpha ,6 beta)-)

Maleic anhydride (2,5-Furandione)

Maleic hydrazide (3,6-Pyridazinedione, 1,2-dihydro-)

Malononitrile (Propanedinitrile)

Melphalan (L-Phenylalanine, 4-[bis(2-chloroethyl)aminol]-)

Mercury and compounds, N.O.S.

Mercury fulminate (Fulminic acid, mercury(2+) salt)

Methacrylonitrile (2-Propenenitrile, 2-methyl-)

Methapyrilene (1,2-Ethanediamine, N,N-dimethyl-N'-2-pyridinyl-N'-(2-thienylmethyl)-)

Metholmyl (Ethamidothioic acid, N-[[(methylamino)carbonyl]oxy]thio-, methyl ester)

Methoxychlor (Benzene, 1,1'-(2,2,2-trichloroethylidene)bis[4-methoxy-)

Methyl bromide (Methane, bromo-)

Methyl chloride (Methane, chloro-)

Methyl chlorocarbonate (Carbonchloridic acid, methyl ester)

Methyl chloroform (Ethane, 1,1,1-trichloro-)

3-Methylcholanthrene (Benz[j]aceanthrylene, 1,2-dihydro-3-methyl-)

4,4'-Methylenebis(2-chloroaniline) (Benzenamine, 4,4'-methylenebis(2-

chloro-)

Methylene bromide (Methane, dibromo-)

Methylene chloride (Methane, dichloro-)

Methyl ethyl ketone (MEK) (2-Butanone)

Methyl ethyl ketone peroxide (2-Butanone, peroxide)

Methyl hydrazine (Hydrazine, methyl-)

Methyl iodide (Methane, iodo-)

Methyl isocyanate (Methane, isocyanato-)

2-Methyllactonitrile (Propanenitrile, 2-hydroxy-2-methyl-)

Methyl methacrylate (2-Propenoic acid, 2-methyl-, methyl ester)

Methyl methanesulfonate (Methanesulfonic acid, methyl ester)

Methyl parathion (Phosphorothioic acid, O,O-dimethyl O-(4-nitrophenyl) ester)

Methylthiouracil (4(1H)Pyrimidinone, 2,3-dihydro-6-methyl-2-thioxo-)

Mitomycin C
(Azirino[2',3':3,4]pyrrolo[1,2-a]indole-4,7-dione,6-amino-8-[[(aminocarbonyl) oxy]methyl]-1,1a,2,8,8a,8b-hexahydro-8a-methoxy-5-methy-, [1aS-(1a alpha ,8 beta ,8a alpha ,8b alpha)]-)

MNNG (Guanidine, N-methyl-N'-nitro-N-nitroso-)

Mustard gas (Ethane, 1,1'-thiobis[2-chloro-)

Naphthalene

1,4-Naphthoquinone (1,4-Naphthalenedione)

alpha -Naphthalenamine (1-Naphthylamine)

beta -Naphthalenamine (2-Naphthylamine)

alpha -Naphthylthiourea (Thiourea, 1-naphthalenyl-)

Nickel and compounds, N.O.S.

Nickel carbonyl (Ni(CO) sub 4 (T-4)-)

Nickel cyanide (Ni(CN) sub 2)

Nicotine and salts (Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)-)

Nitric oxide (Nitrogen oxide NO)

p-Nitroaniline (Benzenamine, 4-nitro-)

Nitrobenzene (Benzene, nitro-)

Nitrogen dioxide (Nitrogen oxide NO sub 2)

Nitrogen mustard, and hydrochloride salt (Ethanamine,
2-chloro-N-(2-chloroethyl)-N-methyl-)

Nitrogen mustard N-oxide and hydrochloride salt (Ethanamine,
2chloro-N-(2-chloroethyl)N-methyl-, N-oxide)

Nitroglycerin (1,2,3-Propanetriol, trinitrate)

p-Nitrophenol (Phenol, 4-nitro-)

2-Nitropropane (Propane, 2-nitro-)

Nitrosamines, N.O.S.

N-Nitrosodi-n-butylamine (l-Butanamine, N-butyl-N-nitroso-)

N-Nitrosodiethanolamine (Ethanol, 2,2'-(nitrosoimino)bis-)

N-Nitrosodiethylamine (Ethanamine, N-ethyl-N-nitroso-1)

N-Nitrosodimethylamine (Methanamine, N-methyl-N-nitroso-)

N-Nitroso-N-ethylurea (Urea, N-ethyl-N-nitroso-)

N-Nitrosomethylethylamine (Ethanamine, N-methyl-N-nitroso-)

N-Nitroso-N-methylurea (Urea, N-methyl-N-nitroso-)

N-Nitroso-N-methylurethane (Carbamic acid, methylnitroso-, ethyl ester)

N-Nitrosomethylvinylamine (Vinylamine, N-methyl-N-nitroso-)

N-Nitrosomorpholine (Morpholine,

4-nitroso-)

N-Nitrosonornicotine (Pyridine, 3-(1-nitroso-2-pyrrolidinyl)-, (S)-)

N-Nitrosopiperidine (Piperidine, 1-nitroso-)

Nitrosopyrrolidine (Pyrrolidine, 1-nitroso-)

N-Nitrososarcosine (Glycine, N-methyl-N-nitroso-)

5-Nitro-o-toluidine (Benzenamine, 2-methyl-5-nitro-)

Octamethylpyrophosphoramide (Diphosphoramide, octamethyl-)

Osmium tetroxide (Osmium oxide OsO sub 4, (T-4)-)

Paraldehyde (1,3,5-Trioxane, 2,4,6-tri

methyl-)

Parathion (Phosphorothioic acid, O,O-diethyl O-(4-nitrophenyl) ester)

Pentachlorobenzene (Benzene, pentachloro-)

Pentachlorodibenzo-p-dioxins

Pentachlorodibenzofurans

Pentachloroethane (Ethane, pentachloro-)

Pentachloronitrobenzene (PCNB) (Benzene, pentachloronitro-)

Pentachlorophenol (Phenol, pentachloro-)

Phenacetin (Acetamide, N-(4-ethoxyphenyl)-)

Phenol

Phenylenediamine (Benzenediamine)

Phenylmercury acetate (Mercury, (acetato-O)phenyl-) [*2871]

Phenylthiourea (Thiourea, phenyl-)

Phosgene (Carbonic dichloride)

Phosphine

Phorate (Phosphorodithioic acid, O,O-diethyl S-[(ethylthiomethyl] ester)

Phthalic acid esters, N.O.S.

Phthalic anhydride (1,3-isobenzofurandione)

2-Picoline (Pyridine, 2-methyl-)

Polychlorinated biphenyls, N.O.S.

Potassium cyanide (K(CN))

Potassium silver cyanide (Argentate(l-), bis(cyano-C)-, potassium)

Pronamide (Benzamide, 3,5-dichloro-N-(1,1-dimethyl-2-propynyl)-)

1,3-Propane sultone (1,2-Oxathiolane, 2,2-dioxide)

n-Propylamine (1-Propanamine)

Propargyl alcohol (2-Propyn-1-ol)

Propylene dichloride (Propane, 1,2-

dichloro-)

1,2-Propylenimine (Aziridine, 2-methyl-)

Propylthiouracil (4(1H)-Pyrimidinone, 2,3-dihydro-6-propyl-2-thioxo-)

Pyridine

Reserpinen (Yohimban-16-carboxylic acid,
11,17-dimethoxy-18-[(3,4,5-trimethoxybenzoyl)oxy]-smethyl ester, (3 beta ,16

beta ,17 alpha ,18 beta ,20 alpha)-)

Resorcinol (1,3-Benzenediol)

Saccharin and salts (1,2-Benzisothiazol-3(2H)-one, 1,1-dioxide)

Safrole (1,3-Benzodioxole, 5-(2-propenyl)-)

Selenium and compounds, N.O.S.

Selenium dioxide (Selenious acid)

Selenium sulfide (SeS sub 2)

Selenourea

Silver and compounds, N.O.S.

Silver cyanide (Silver cyanide Ag(CN))

Silvex (Propanoic acid, 2-(2,4,5-trichlorophen

oxy)-)

Sodium cyanide (Sodium cyanide Na(CN))

Streptozotocin (D-Glucose, 2-deoxy-2-[[methylnitrosoamino)carbonyl]amino]-)

Strychnine and salts (Strychnidin-10-one)

TCDD (Dibenzo[b,e][1,4]dioxin, 2,3,7,8-tetrachloro-)

1,2,4,5-Tetrachlorobenzene (Benzene, 1,2,4,5-tetrachloro-)

Tetrachlorodibenzo-p-dioxins

Tetrachlorodibenxofurans

Tetrachloroethane, N.O.S. (Ethane, tetrachloro-, N.O.S.)

1,1,1,2-Tetrachloroethane (Ethane, 1,1,1,2-tetrachloro-)

1,1,2,2-Tetrachloroethane (Ethane, 1,1,2,2-tetrachloro-)

Tetrachloroethylene (Ethene, tetrachloro-)

2,3,4,6-Tetrachlorophenol (Phenol, 2,3,4,6-tetrachloro-)

Tetraethyldithiopyrophosphate (Thiodiphosphoric acid, tetraethyl ester)

Tetraethyl lead (Plumbane, tetraethyl-)

Tetraethyl pyrophosphate (Diphosphoric acid, tetraethyl ester)

Tetranitromethane (Methane, tetranitro-)

Thallium and compounds, N.O.S.

Thallic oxide (Thallium oxide Tl sub 2O sub 3)

Thallium (I) acetate (Acetic acid, thallium (1+) salt)

Thallium (I) carbonate (Carbonic acid, dithallium (1+) salt)

Thallium (I) chloride (Thallium chloride TlCl)

Thallium (I) nitrate (Nitric acid, thallium (1+) salt)

Thallium selenite (Selenius acid, dithallium (1+) salt)

Thallium (I) sulfate (Sulfuric acid, thallium (1+) salt)

Thioacetamide (Ethanethioamide)

3,Thiofanox (2-Butanone, 3,3-dimethyl-1-(methylthio)-, O-[(methylamino)carbonyl] oxime)

Thiomethanol (Methanethiol)

Thiophenol (Benzenethiol)

Thiosemicarbazide (Hydrazinecarbothioamide)

Thiourea

Thiram (Thioperoxydicarbonic diamide [(H sub 2N)C(S)]2S sub 2, tetramethyl-)

Toluene (Benzene, methyl-)

Toluenediamine (Benzenediamine, ar-methyl-)

Toluene-2,4-diamine (1,3-Benzenediamine, 4-methyl-)

Toluene-2,6-diamine (1,3-Benzenediamine, 2-methyl-)

Toluene-3,4-diamine (1,2-Benzenediamine, 4-methyl-)

Toluene diisocyanate (Benzene, 1,3-diisocyanatomethyl-)

o-Toluidine (Benzenamine, 2-methyl-)

o-Toluidine hydrochloride (Benzenamine, 2-methyl-, hydrochloride)

p-Toluidine (Benzenamine, 4-methyl-)

Toxaphene

1,2,4-Trichlorobenzene (Benzene, 1,2,4-trichloro-)

1,1,2-Trichloroethane (Ethane, 1,1,2-trichloro-)

Trichloroethylene (Ethene,trichloro-)

Trichloromethanethiol (Methanethiol, trichloro-)

Trichloromonofluoromethane (Methane, trichlorofluoro-)

2,4,5-Trichlorophenol (Phenol, 2,4,5-trichloro-)

2,4,6-Trichlorophenol (Phenol, 2,4,6-trichloro-)

2,4,5-T (Acetic acid, 2,4,5- trichloro-

phenoxy-)

Trichloropropane, N.O.S.

1,2,3-Trichloropropane (Propane, 1,2,3-trichloro-)

O,O,O-Triethyl phosphorothioate (Phosphorothioic acid, O,O,O-triethyl ester)

Trinitrobenzene (Benzene, 1,3,5-trinitro-)

Tris(1-aziridinyl)phosphine sulfide (Aziridine,
1,1',1"phosphinothioylidynetris-))

Tris(2,3-dibromopropyl) phosphate (1-Propanol, 2,3-dibromo-, phosphate (3:1))

Trypan blue (2,7-Naphthalendisulfonic acid,
3,3'-[(3,3'-dimethyl[1,1'-biphenyl]-4,4'-diyl)bis(azo)]bis(5-amino-4-hydroxy-,
tetrasodium salt)

Uracil mustard (2,4-(1H,3H)-Pyrimidinedione, 5-[bis(2-chloroethyl)amino]-)

Vanadium pentoxide (Vanadium oxide V sub 2O sub 5)

Vinyl chloride (Ethene, chloro-)

Wayfarin (2H-1-Benzopyran-2-one, 4-hydroxy-3-(3-oxo-1-phenlybutyl)-)

Zinc cyanide (Zn(CN) sub 2)

Zinc phosphide (Zn sub 3P sub 2)

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