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ASSESSMENT OF ENVIRONMENTAL ASPECTS OF URANIUM MINING AND MILLING

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ASSESSMENT OF ENVIRONMENTAL ASPECTS OF URANIUM MINING AND MILLING

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

In this report a preliminary assessment was made of the potential environmental impacts associated with the mining and milling of domestic uranium ores. All forms of pollution except radiation were considered.

It was concluded that the impacts identified were not believed to be of immediate concern but rather are potential problems which may arise in the long term. Future environmental studies should consider tailings pond disposal, deep well injection to dispose of toxic wastes and reclamation of spoils.

Results of this work will be of interest to State and Federal agencies and mining firms who are interested in assessing and controlling the environmental impacts of uranium mining and milling.

For further information contact the Resource Extraction and Handling Division.

David G. Stephan
Director
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ABSTRACT

This research program was initiated with the basic objective of making a preliminary assessment of the potential environmental impacts associated with the mining and milling of domestic uranium ores. All forms of pollution except radiation were considered.

The program included a review of the characteristics and locations of domestic uranium ore reserves and a review of the conventional methods for mining and milling these ores. Potential environmental impacts associated with the entire cycle from exploration and mining to recovery and production of yellowcake are identified and discussed. Land reclamation aspects are also discussed.

The methods currently used for production of yellowcake were divided into four categories - open pit mining-acid leach process, underground mining-acid leach process, underground mining-alkaline leach process, and in-situ mining. These are discussed from the standpoint of typical active mills which were visited during the program. Flowsheets showing specific environmental impacts for each category are provided.

It was generally concluded that the use of tailings ponds and deep well injection to dispose of the more toxic chemical wastes represent the major impacts which should be considered in future environmental studies.

This report was submitted in fulfillment of Contract No. 68-02-1323 by Battelle, Columbus Laboratories, under sponsorship of the U. S. Environmental Protection Agency. This report covers the period February 12, 1976, to July 7, 1976, and work was completed as of September 30, 1976.

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INTRODUCTION

Uranium is an important energy source for which projected demands will greatly increase in the near future. Identified exploitable uranium deposits in the United States are mostly in sandstones and related rocks and the principal known deposits are in Wyoming, the Colorado River Plateau, and the Texas Gulf Coast.

Uranium occurs as coatings on sand grains or as filling or cement in interstitial spaces where it has accumulated by water deposition. Because of this, the uranium content of the ore is on the order of 0.2 to 0.3 percent U_3O_8. Thus, large amounts of material must be handled in mining and initial processing operations. Some deposits are at depths which require underground mining but surface mining is a more economical method where it can be used.

Primary processing facilities are located near the mines to reduce hauling costs. Uranium from the ore is typically recovered by alkaline or acid leaching depending upon the nature of the ore. Solvent extraction and the use of ion exchange resins are important variations in concentrating the uranium values which are then precipitated to form yellowcake (85-95 percent U_3O_8).

The scope of this investigation thus was to identify the steps involved from mining of ore to output of yellowcake, evaluate alternative processing methods, and assess the potential environmental impacts associated with each operation.

SECTION 2

CONCLUSIONS

Several potentially significant, environmental impacts have been identified based on this preliminary survey of the domestic uranium industry. The impacts identified, however, are not believed to be of immediate concern but rather are potential problems which may arise in the long term. Following is a summary of the impacts believed to be of major significance.

(1) Tailings Pond Disposal. It is currently estimated that over 9 million metric tons of tailings per year are disposed of to tailings ponds by the domestic uranium industry. In addition, an equal or greater amount of waste milling solutions are also disposed of to the ponds. The liquid portions contain various heavy metals as well as being highly acid or alkaline depending on the type of mill generating the waste.

The use of a tailings pond represents only a temporary solution to the potential environmental problems which could be caused by these wastes. Methods are needed to stabilize this material and reclaim the tailings areas. Greater information is also needed on the movement and amount of contaminants that enter ground and surface waters through percolation and seepage from the tailings ponds. Studies in New Mexico, for example, show that tailings pond seepage can result in ground water contamination by selenium; contamination by other substances may also have occurred.

(2) Deep Well Injection. Several uranium mills dispose of toxic liquid and chemical wastes by deep well injection. The wastes result either from excess liquid not evaporated in the tailings pond or from waste regenerant solutions used by in-situ mining operations. Very little is known about the overall long-term impacts on ground waters due to deep well injection.

A similar though different impact can occur in those plants using in-situ mining in that a loss of leaching solution pumped into the ore body via wells could contaminate local groundwaters. This aspect of the overall industry needs to be closely monitored so that if a problem does arise the overall impact can be minimized.

(3) Reclamation. Some research has been initiated in recent years on reclamation of spoils, especially in coal mining operations, but also at uranium mines. This research is directed almost entirely to soil and water management. Additional areas of research which are needed are the development of plant species that are adapted to reclamation needs and to development of alternative uses of disturbed lands which cannot be restored to their premine condition.

SECTION 3

URANIUM RESOURCES IN THE UNITED STATES

A preliminary survey of the geologic deposition and mineralization of uranium resources has been conducted and is presented in this section. This survey is based on a review of the literature and information obtained from government agencies and industry. Some engineering judgments were applied to quantify resource estimates where data did not exist or were poorly defined.

The terms "reserves" and "resources" need to be clarified before a discussion of mineral supply can be meaningful. They are not interchangeable and require careful definition.

Reserves are that quantity of ore minerals in identified deposits that can be developed at current levels of technology and costs.

Resources (whether concentrated or dilute) are fixed in limit by the composition of the earth's crust, seas, and atmosphere. Some resources can become reserves at higher costs and as such are most often "implied reserves" extrapolated from generalized data.

To evaluate the supply of uranium, resources must be continuously reassessed in terms of new geologic knowledge and changes in technology.

TYPES OF URANIUM DEPOSITS

Uranium minerals are known to occur almost everywhere in the earth's crust which contains a mean abundance of about 2 ppm uranium. However, the larger concentrations of uranium which make up the ore reserves are located only in a few well-defined areas in the world. For example, about 30 percent of the world's reported uranium reserves are found in the Rocky Mountain area of the United States.[1] The uranium is found in rather small areas in which a few large or many small ore deposits of differing mineralization occur.

Uranium is found in a wide variety of locations. This gross variety is considered the result of uranium's (1) physical properties, particularly its polyvalency, (2) large atomic radius, (3) high chemical reactivity, (4) relative solubility of many of its hexavalent compounds in aqueous solutions, and (5) its relative abundance. Consequently, virtually no geologic environment can be considered totally free of uranium, although certain habitats are favored.

Deposits of potential economic importance first were identified at the Wood Mine in Colorado in a vein deposit. In 1898 the deposits in sandstone were discovered. Subsequently the Rocky Mountain region became the principal domestic source of uranium. It is estimated that this region contains about 90 percent of the U. S. reserves.[1] The uranium reserve regions of the western United States with production areas and areas with reserves greater than 500 tons U_3O_8 are shown in Figure 1. In view of these data, the Rocky Mountain region then must be considered as the prime source for the future use of uranium in the U. S. for at least several decades.

Deposits in the Rocky Mountain Region

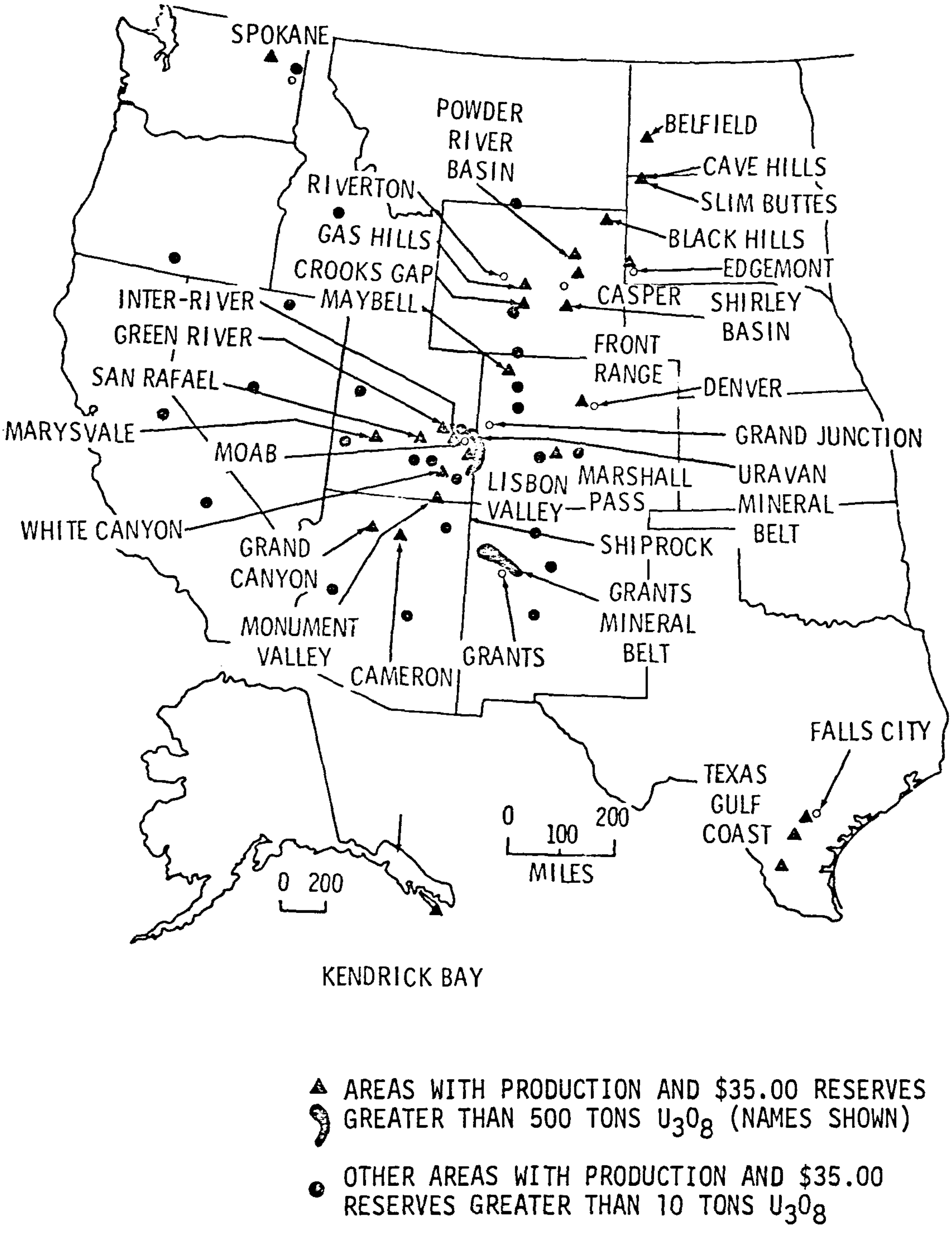
The overall Rocky Mountain area in the United States has been identified as a uranium metallogenic province. This constitutes a broad, indefinitely defined region centering on the current Rocky Mountains and in which an initial concentration of uranium may have occurred. Subsequent to this concentration in early Precambrian time, the uranium was redistributed, reworked, and reconcentrated by many igneous, sedimentary, and metamorphic processes. The currently exploitable deposits are the results of that reworking.

In the Rocky Mountain region, 98 percent of the U_3O_8 recovered has come from sandstones and related rocks. Estimates of known reserves in those rocks were more than 95 percent of the total reserves in 1958, and 97 percent in 1974.[1] There are probably comparable amounts of undiscovered, commercial-grade uranium present there also. About 70 percent of the domestic production of U_3O_8 has come from the Colorado Plateau part of the Rocky Mountains. An evaluation of the potential U_3O_8 reserves and resources of the United States should first consider the possibilities in comparable areas in the Colorado Plateau and adjoining districts, especially at depth, rather than that large high-grade deposits might be expected in other areas in the United States.

Sandstone Deposits

Most of the uranium deposits of the Colorado Plateau and adjoining districts occur in frequently predictable stream-laid lenses of sandstone, dominantly in the Chinle, Shinarump, and Morrison Formations. Uranium deposits also occur in sediments in the Wind River Formation in Gas Hills and Shirley Basin areas, Wyoming and in other formations of lesser importance elsewhere. These deposits also are known as the peneconcordant deposits, and constitute by far the bulk of the "conventional" deposits. The uranium ore bodies traditionally form tabular or lenticular layers (pods) that are nearly concordant (parallel) to the bedding. Locally they deviate from it, especially in detail. In many deposits the elongate pods have the transverse cross-section form of an erect crescent and are referred to as rolls. They thus differ in form and origin from classical sedimentary (bedded) deposits of other minerals that closely and consistently follow the bedding. The occurrences of ore in the truly bedded deposits often can be predicted.

The ore bodies vary greatly in size, from those containing only a few tons to those hundreds of meters across and containing millions of tons of ore. Some deposits are thousands of meters long. In the Shirley Basin and



Source: AEC, Grand Junction, CO

FIGURE 1. URANIUM RESERVE REGIONS, WESTERN UNITED STATES

the southern part of the Powder River Basin, Wyoming, and in the Ambrosia Lake District, New Mexico, groups of ore bodies and the intervening thinner mineralized zones extend intermittently from 8 to 10 kilometers.[2]

Within many metal deposits other than uranium, low-grade ores commonly form a mineralized halo, centered around the higher grade ores. However, for uranium deposits, the edges of the peneconcordant ore bodies terminate abruptly with no large halo of low-grade ore.

The specific sources of uranium, precise flow paths, specific and local causes of ore deposition, and the ages of the deposits are somewhat uncertain and may vary significantly from deposit to deposit. In general the ore was formed by ground-water solutions that moved downdip by gravity to a reducing environment where the uranium was precipitated. The uranium probably was deposited and reworked by various processes, including weathering in some instances as a final process. The primary source and controls to initial ore deposition often are obscure. Although guides to prospecting are available and helpful, most uranium deposits are discovered in their outcrops, and the mineralization is traced by exploration, including drilling. This is especially the case in the more irregular deposits.

The depth of favorable stratigraphic units is probably not critical to the occurrence of uranium deposits. Some deposits have been discovered at depths between 700 and 1200 meters. Certainly more can be expected to be found. Once the incentive exists for exploration to those greater depths and once targets are identified, more such discoveries can be expected. Butler[2] concluded that at least 300 million tons of ore-grade rock and probably as much as one billion tons may occur in sandstones in the United States. Much of the larger amount, if actually present, is overlain by at least 600 meters of rock and will be difficult to find and exploit. Most of the occurrences may be expected in the western part of the United States and probably in the Rocky Mountain area.

Vein Deposits

Vein deposits, including true veins, aggregates of veinlets, and mineralized breccia ("collapsed") pipes also are categorized as "conventional" deposits, together with the sandstone occurrences. They are widely distributed throughout much of the United States. With few exceptions, however, the vein deposits represent small reserves and production.

Vein deposits that have produced uranium occur throughout the Rocky Mountain region, especially in Colorado and Utah, and in northeastern Washington, western and northern Idaho, southeastern Oregon, the Great Basin of Nevada, southern California and Alaska. They are generally small. For example, five of the largest deposits in the Rocky Mountain region originally contained as much as 100,000 tons of ore. However, all vein deposits combined have yielded 1,644,000 tons or about 2.5 percent of the total ore produced in the Rocky Mountain region. The Marysvale, Utah, deposit, together with those of the Schwartzwalder Mine in Colorado, and the Midnite Mine in northeastern Washington are the largest vein deposits in the United States.

The downward extent of uranium in the vein deposits is undetermined in most districts. Butler and others[2] cite vein systems which extend to 400 meters below the surface. At the Sunshine Mine in Idaho, uranium traces (but not of a commercial grade) have been found below the 900 meter level.[2] Probably uranium in some of the better districts extends considerably below the known depth of occurrence.

Most uranium occurrences in vein deposits are likely of hydrothermal origin. Recent data, however, suggest that some vein deposits may be of secondary origin, formed by downward-moving waters.

Geologic terranes suitable for uranium deposits are extremely widespread. Undiscovered resources may equal or exceed those now known. Resources of uranium in veins were considered by Butler[2] to range from a few million to 10 million tons of ore-grade rock.

By-Product Uranium From Copper Leach Solution

The United States Bureau of Mines (USBM) has demonstrated the presence of trace amounts of uranium in certain copper deposits of the southwestern United States. Their studies have shown the practicability of recovering the uranium from some copper leach solutions as a by-product of the copper recovery. Unfortunately, uranium is not found in significant quantities in all copper leach dumps. For instance, uranium runs as high as 50 ppm in leach dumps from Twin Buttes, Nevada, but is as low as 2 ppm in similar dumps at Butte, Montana. The normal range for uranium in copper dump material is 1 to 12 ppm.

Thirteen operations were studied by USBM. However, more than twice that many more porphyry copper deposits are known, many of which should have comparable amounts of uranium present. For instance, samples of oxide copper ore from Yerington, Nevada, contain uranium. In addition, more such deposits can be expected so that the total tonnage of uranium resources may be several times larger than quoted. The total tonnage is a small, though significant, fraction of that considered available from the conventional deposits.

By-Product Uranium From Phosphoric Acid Production

Phosphate rock which is used for producing phosphoric acid is also a potential source of uranium. Many phosphate rock deposits have been examined for uranium content. Grades higher than 0.1 percent have been reported, but most phosphate rock contains between 0.003 and 0.02 percent U_3O_8. The Florida phosphate rock, which provides about 80 percent of total U. S. production, contains 0.01 to 0.02 percent U_3O_8.

With the increasing cost of uranium, there has been renewed interest in its recovery from dilute phosphoric acid produced by the "wet process". Uranium Recovery Corporation (URC), a subsidiary of United Nuclear Corporation, has just completed its first full-scale module (only the initial extraction and stripping operations take place at the phosphoric acid plant) at the W. R. Grace and Company plant near Bartow, Florida.[3]

URC has contracted to install two modules in a new phosphoric acid plant owned by a subsidiary of International Minerals and Chemical Company near Mulberry, Florida. This is nearby to URC's completed central processing plant. In addition to the URC work, programs and pilot-scale operations are being carried out by Westinghouse, Gulf Oil Chemicals, and Freeport Minerals.

Other Unconventional Deposits

Because of the wide diversity of occurrences of uranium, the potential exists for uranium resources in many environments not yet adequately understood. Among the other more promising unconventional deposits are the marine black shales, coal, lignites, and related carbonaceous shales. Conventional, as used here, includes the peneconcordant sandstone deposits and vein deposits. Other occurrences are unconventional because they are not generally produced or, at best, irregularly produced under current conditions.

A summary of the various types of uranium deposits, their principal mineral consists, and typical occurrences in the United States is given in Table 1.

LOCATION OF ACTIVE MILLS

The locations of active mills within the continental United States are shown in Figure 2. The names on the map are cities or producing zones. There are in some cases three or more active mills operating in one locale, e.g., Grants, New Mexico. Table 2 describes each of these mills with regard to sources of ore and ore mineralization.

TABLE 1. TYPES OF URANIUM DEPOSITS[4]

Type of deposit	Principal uranium minerals	Typical U.S. occurrences
Vein deposits	Uraninite, torbernite, autunite, and uranophane	Front Range, Colorado; Marysvale district, Utah; Spokane area, Washington.
Flat-lying deposits in sedimentary rocks:		
Vanadium-bearing sandstones[a]	Uraninite, coffinite	Colorado Plateau of Colorado, Utah, Arizona, and New Mexico. Black Hills area, South Dakota. Powder River Basin, Wyoming. Big Indian Wash, Utah.
Copper-bearing sandstones	Uraninite and uranium phosphates, vanadates, sulfates, carbonates, and silicates	White Canyon, Utah.
Asphaltic sandstones	Uraninite, uranium hydrocarbons, and carnotite	San Rafael Swell area, Utah.
Other sandstones	Uraninite and coffinite; and uranium phosphates, silicates, arsenates, and carbonates	Wind River Basin, Wyoming. Grants-Laguna area, New Mexico.
Limestone	Uraninite, carnotite, tyuyamunite, and uranophane	Grants-Laguna area, New Mexico.
Phosphate rock	Carbonate-fluorapatite	Central Florida; Bear Lake area, Idaho; Utah; Wyoming; and western Montana.
Lignite	Uranium hydrocarbons and minor secondary uranium minerals	Western North and South Dakota; eastern Montana.
Bituminous shales	Uranium-hydrocarbon complex	Tennessee.

(a) Early production from these areas was oxidized or "carnotite-type" ore, with the exception of the Big Indian area.

TABLE 2. ACTIVE URANIUM MILLS IN THE UNITED STATES AND ORE CHARACTERISTICS

Mill and Location	Capacity, tpd ore	Ore Source	Mineralization
Kerr-McGee Corporation Grants, New Mexico	7000	Five company-owned underground mines in Ambrosia Lake area.	Grayish-colored sandstone containing from 2 to 5 percent lime, traces of Mo and V.
United Nuclear-Homestake Partners, Grants, New Mexico	3500	Ore from Ambrosia Lake and Smith Lake areas, underground mines.	Ore minerals are coffinite, uraninite, tyuyamunite, and carnotite on sandstone or as interstitial filling. Small amounts of Mo, V, and Se.
Anaconda Blue Water Plant Grants, New Mexico	3000	Open pit Paguate Mine.	Sandstone w/uranium as interstitial lenses associated with carboniferous materials and with kerogens. Ore is low in lime w/some dolomitic and bentonitic clays. Traces of Mo and V.
Utah International, Inc. Gas Hills and Shirley Basin, Wyoming	3400	Company-owned open pits close to mill site.	Sandstone w/10-15 percent of clay. Uranium minerals are unoxidized uraninite and coffinite. Significant amounts of Se, As, Mo, and P.
Exxon Highland Mill Powder River Basin, Wy.	2850	Company-owned open pits at top of Fort Union Formation.	3000 ft of interbedded shales and sandstone. Traces of As and Se.
Western Nuclear, Inc. Jeffrey City, Wyoming	1500	Gas Hills, Wyoming, district open pits and underground. Golden Goose mine in Crooks Gap area.	Cemented sandstone with interstitial occurrence of autunite and carnotite. Traces of Mo and W.
Union Carbide Corporation Gas Hills, Wyoming	1350	Open-pit operations at Globe and Aljob company-owned mines.	Ore is in sandstone. Traces of Mo present.
Federal American Partners Gas Hills, Wyoming	950	Company-owned open pits at mill site.	Sandstone containing 1.5 to 3 percent lime. Traces of Mo and V.
Petrotomics Company, Shirley Basin, Wyoming (Start-up: 1978)	1500	Company-owned open pit mine adjacent to mill.	Ore in Wind River Formation containing uraninite-coated sandstone with 3.5 percent $CaCO_3$. Traces of Mo and V.
Atlas Corporation Moab, Utah	1500	Six Atlas mines in S.E. Utah or adjoining areas of Colorado. Also 24 underground independent mines.	Fine-grained sandstone w/uranium mostly as uraninite and some tyuyamunite ore from White Canyon, Utah, contains sulfide copper and V.
Rio Algom Corporation La Sal, Utah	750	Company-owned underground mine in San Juan County, Utah.	Ore minerals are principally uraninite ore sandstone.
Union Carbide Corporation Uravan, Colorado	2000	Sixty different underground mines in Uravan Mineral Belt, 45 are company owned.	Ores are sandstone containing carnotite and 4-5 percent limestone with 1 percent V_2O_5. Traces of Mo and Cu.
Cotter Corporation Canon City, Colorado	450	Principal source is Schwartzwalder underground mine near Golden, Colorado.	Pitchblende is main mineral along with 15-20 percent pyritic sulfides, 0.75 percent Cu and 0.15 percent Mo.
Dawn Mining Company Stevens County, Washington	500	"Porphyry" uranium deposit in Midnite open pit mine.	Secondary minerals uraninite, coffinite, and pitchblende.
Conoco and Pioneer Nuclear, Inc., Falls City, Texas	1750	Open pit mine at site.	--
ARCO-U.S. Steel, Dalco George West, Texas	125[(a)]	In situ leaching of uranium from Miocene Oakville formation.	Sandstone formation of interbedded sands, silts, and bentonitic clays. Significant amounts of Mo.
Wyoming Minerals Bruni, Texas	125[(a)]	In situ leaching of uranium.	--

(a) Capacity in tons per year of yellowcake.

FIGURE 2. LOCATION OF ACTIVE URANIUM MILLS IN THE UNITED STATES

SECTION 4

MINING AND RECOVERY PROCESSES

CONVENTIONAL MINING OPERATIONS

After a uranium deposit has been delineated and evaluated as economically feasible to mine, a mining method that is physically, economically, and environmentally adaptable to the recovery of uranium ore from the deposit must be selected. Factors affecting the selection of a mining method are

- The spatial characteristics of the ore body (size, shape, attitude, depth)
- The physical or mechanical properties of the deposit and the surrounding rock
- Ground water and hydraulic conditions
- Economic factors (ore grade, production rates, comparative mining costs)
- Environmental factors (surface preservation or restoration, air and water pollution prevention).

There are two basic types of mining techniques used by the uranium industry. These are surface and underground mining.

Surface Mining

A surface (or open pit) mine is an open-air excavation for the extraction of uranium ore. It is used to remove uranium ore from a near-surface deposit in any rock type. This method is best suited to ore bodies of substantial horizontal dimensions which permit high rates of production and low costs.[1] Surface mining accounts for more than half of the ore mined and uncovers more ore per mine than does underground mining.

Open pit mining permits a wide production flexibility; it also provides for selective mining and has the potential for 100 percent recovery of ore within the pit limits. Mechanization provides high unit production and requires fewer men. Mine safety, a major problem in underground mines, is much better in surface mines.[1]

Open pit mining is used where the ore deposits are near the surface and covered with loose, easily removable soil. Some open pit mining may be done at depths of more than 150 meters (492 ft); but usually, below 90 meters (295 ft), underground methods are preferred.(1) The ratio of overburden to ore removed in uranium mines is unusually large as compared to other types of mining with ranges from 8:1 to 35:1. The expense of removing the larger amounts of overburden is justified by the greater value of the product being recovered.(5)

The pit layout is determined by several factors as follows:(1)

- Orientation of the deposit jointings
- The stripping ratio
- Required rate of production
- The availability of equipment
- Slope stability.

The first step in surface mining is the removal and stockpiling of the topsoil for later use in reclamation. This is usually accomplished with tractor scrapers. The deeper overburden is then removed by scrapers or power shovels and hauled to the disposal area. Some blasting and ripping is also required. Optimally, the ore body is divided into areas so that one area may be stripped before starting the stripping on the next. This will enable mining to start before the whole ore body is exposed. Overburden from the first part of the mined area will be placed on the surface, but overburden from the succeeding areas will be used to backfill areas where mining has been completed. The overburden is then covered with topsoil and seeded. The final area of the pit is left open, its sides graded, and remains as a lake, if it is below the water table.

When the ore body has been exposed, it is cleaned of waste material with tractor scrapers and bulldozers. Ore is blasted or loosened with rippers and mined with backhoes working on benches and loaded onto trucks for hauling to the mill.

Some problems are encountered however, in surface mining, including adverse weather limitations in some areas, and environmental problems such as surface scarring, dust, noise, and vibrations from blasting.

Ground water intrusion also has been a problem in many of the open pit mines. Water influx occurs in any surface mine which penetrates the water table and water seepage must be removed for mining to progress. The traditional and an effective mine dewatering method is to allow the water to drain into the mine and to collect in a sump via a system of ditches. From the collection sump, the water is pumped out of the mine. In this way, the floor of the mine is kept workable. As the mine is deepened by removal of overburden or ore, the mine floor is reditched. This method requires care in scheduling the mining to assure that the sump is always the lowest point. It also requires regular, sometimes continuous, maintenance to keep the sump and ditch network clear. Water seepage from the exposed mine walls can often make necessary the provision of flatter wall slopes and/or benches and thus larger stripping requirements, due to stability considerations.

Water pumped from mines may be discharged onto the land surface; for example, to control dust, pumped through an ion exchange plant, or used as mill process water. Mine water discharged to the environment may be decanted through settling ponds to remove suspended solids before being released.

A method of reducing water influx dewatering is the use of a ring of wells located around the periphery of the mine. With proper placement, these wells cause a localized depression in the intercepted water tables. This method usually produces a highly clarified water. However, the locally induced piezometric drawn down regime may influence a slightly larger area than the sump collection method.

The amount and quality of developed mine water is also site and situation specific. Surface mine dewatering rates reported in the literature range from less than 1890 to more than 11,000 lpm (500-3000 gpm).[6]

Underground Mining

Underground mining methods are used where the depth of the deposit makes the removal of the overburden too costly. A mining system is selected or developed on a safety and cost basis; suitable ground support and sometimes preservation must be provided. The choice of a mining method usually is dictated more by the spatial or mechanical characteristics of the deposit than by any other factor.

Underground mining produces environmental problems principally by the discharge of mine waters into streams and by surface disturbances such as subsidence, both concurrent and subsequent to mining.[1]

Room-and-pillar mining is a common variation used for underground mining of uranium. Suitable deposits for exploitation by room pillar are relatively flat-lying or slightly dipping deposits in which the ore is of uniform grade and thickness. Room and pillar and modified room and pillar are methods of cutting up a deposit by excavating a grid of rooms separated by pillars of uniform cross-section. Many grid layouts have been employed, including systems with rib pillars and square pillars with checkerboard spacing.

Veins and steeply bedded deposits are often mined by shrinkage stoping. This method is basically an overhand stoping system in which part of the broken ore is accumulated as the stope is completed. The ore gains 30 to 50 percent in bulk as it is broken and some ore must be periodically withdrawn through chutes or drawpoints in order to maintain a working floor for additional mining. In general the vein material must be strong enough to stand unsupported across the width of the stope. When broken, it should not pack to the degree that it cannot be withdrawn. In deposits which approach vertical, hanging wall and footwall rock must be relatively competent to prevent failure, both for safety consideration and prevention of excessive dilution of ore.

In-Situ and Heap Leaching

Recently interest has increased in some areas in the use of in-situ leaching of underground deposits of uranium. This is especially true in South Texas where Mobil, Wyoming Minerals, and ARCO are actively engaged in pilot scale or production programs.[7,8] Investigations are also under way in Wyoming.[9]

In-situ mining simply means the leaching of the ore in the geological formation in which it occurs. The subsurface deposit is flooded with a leach solution which is subsequently pumped to the surface ready for concentration, precipitation, dewatering, and drying. Thus porosity and permeability are all important in solution mining for uranium. The rock surrounding the ore body also should be relatively impermeable. This is necessary to help contain the leach solutions within the producing formation so that surface and ground waters do not become contaminated.

Currently in-situ mining projects for uranium are using a sodium or ammonium carbonate solution for leaching of the ore. Sulfuric acid leaching has been tried but is not now favored since excessive precipitation of calcium sulfate may cause plugging of the leaching channels. Recovery of uranium values from the pregnant solution is normally done by resin ion exchange systems followed by conventional concentration, precipitation, and drying.

Solution mining is also being applied commercially to remove uranium from waste heaps or piles and is, rather broadly, termed heap leaching. Heap leaching is particularly useful for the treatment of low-grade ores which may be located at a considerable distance from the processing facilities. Uranium recovery can be done at the site or the solutions pumped or hauled to the recovery plant. Again, conventional processing such as resin ion exchange is used to recover the uranium.

CONVENTIONAL RECOVERY PROCESSES

The following discussion is only meant to provide a general view of the processes used for extraction of uranium. For a detailed description, please refer to Merritt who provides a comprehensive and relatively recent treatise on the subject.[4]

Ore Preparation

Ore preparation steps in the mill consist primarily of crushing, grinding, and blending; and these operations are similar to the corresponding processes used for other ores. Conventional equipment is used for crushing the ore to less than 2.5-cm sizes. Grinding is usually done wet to a size typically between 20 and 200 mesh.

The uranium minerals usually form a coating on sand grains which is partially removed in the grinding operation. The slimes thus generated have a high uranium content and are sometimes separated from the sands for separate treatment. Usually, however, a slime separation step is incorporated later in the operation. Uranium milling differs in this respect significantly from conventional milling operations where slime separation often takes place early in the process to enable efficient application of other physical separation techniques.

Acid Leaching

Acid leaching is the most commonly used method for extraction of the uranium values and is always done at atmospheric pressure. Sulfuric acid is used in the acid leaching process. To oxidize reduced uranium minerals, reagents such as MnO_2 and $NaClO_3$ are added although aeration is often sufficient. Leaching takes place in a number of agitated vessels arranged in series. The larger operations normally use rubber-lined steel tanks; smaller operations frequently use wooden vats. The total retention time in the leaching vessels typically is between 10 and 20 hr, depending on the leaching characteristics of the ore. Slightly elevated temperatures (35 C) may be used to reduce the total leaching time.

The acid consumption for leaching depends very much on the carbonate content of the ore and may range from 14 to 160 kg/metric ton of ore treated. The consumption is commonly between 25 and 50 kg/ton. The pH of the leach solution ranges between 0.5 in the tank where fresh acid is added to about 1.2 in the last tank.

Carbonate Leaching

Carbonate leaching is used when the carbonate content of the ore to be treated is so high that the acid consumption would be prohibitive if acid leaching were used. Carbonate leaching is much slower than acid leaching and to improve the extraction rate, elevated temperature and pressure are sometimes used. Leaching vessels are either Pachuca tanks, or autoclaves, or a combination of the two.

In one plant, using autoclaves only, the total retention time is 6-1/2 hr at a temperature of 120 C, and under a total pressure of 5 atm. In addition to the air used to achieve the operating pressure, a small amount of ammoniacal cupric sulfate solution is added to help oxidize the ore. The sodium carbonate consumption is about 25 kg/ton of ore.

Another mill leaches the ore at atmospheric pressure in Pachuca tanks at approximately 80 C for a total period of 96 hr. No oxidizing agent is used besides the air used in the Pachucas. The soda ash consumption is about 35 kg/ton of ore.

In another plant the ore is first leached for 4-1/2 hr in autoclaves at 93 C and 5 atm pressure, followed by 36 hr of leaching at 80 C in Pachucas. Again, no oxidant besides air is found to be necessary.

Liquid-Solids Separation

The uranium-bearing solution obtained by either acid or carbonate leaching must be separated from the barren solids prior to solution purification and uranium recovery. Conventional techniques that also find widespread application in the uranium milling industry are filtration and countercurrent decantation. A method that is only widely used in the uranium industry is the resin-in-pulp process.

Filtration as the primary separation technique is usually preferred in carbonate circuits. This is because carbonate solutions are often recycled; the filtration process requires very little dilution as compared with countercurrent decantation, the most likely alternative. Also, carbonate solutions are very viscous and are difficult to wash away.

Countercurrent decantation is the most widely used method in mills with acid circuits. The underflow from the countercurrently operated thickeners is pumped to a tailing disposal area. The overflow is treated with flocculating agents and then passed through a precoat filter to clarify the solution for further treatment.

In resin-in-pulp circuits, cyclones and classifiers are used to first separate the coarse sand fraction from the slimes. The coarse fraction is readily cleaned by countercurrent washing. The slime fraction is contacted with an ionic resin which adsorbs the uranium from the solution. In most operations the resin is contained in open baskets covered with either stainless steel or plastic screen with 28 mesh openings. Some mills use a continuous countercurrent process in which the resin is directly suspended in the slime slurry. The slurry is contained in cells arranged in series to form a bank. After leaving a cell the slurry is passed over a vibrating 60-mesh screen which separates the resin from the pulp. The resin is dumped into the adjacent cell on one side while the pulp moves to the next cell on the other side. After six to eight adsorption stages, the pulp is barren and can be discarded. Fresh acid eluant solution is used to desorb the uranium from the resin. Uranium can either be precipitated directly from the resin-in-pulp eluate or extracted from the eluate in a solvent-extraction circuit.

Solution Purification and Concentration

Sulfuric acid is not a solvent selective for uranium only. To produce yellowcake of acceptable quality, it is necessary to remove impurities such as molybdenum, vanadium, selenium, iron, and many others. Furthermore, pregnant solutions from acid leaching contain only between 0.6 and 2.0 g/liter U_3O_8. This is too low for efficient precipitation of yellowcake. Solvent extraction techniques and, in some cases, resin ion exchange processes are used to achieve both solution purification and concentration.

The most commonly used method for purification and concentration of acid leach solutions is solvent extraction. The process depends on the selective extraction of uranium from the pregnant solution to an organic phase which is brought into intimate contact with it. Another aqueous phase, with different acid and salt contents than the original pregnant solution, is used to strip the uranium from the organic phase back into an aqueous phase from which it can subsequently be precipitated. By proper selection of the relative volumes of the two aqueous phases, the U_3O_8 content of the final solution can be made to be between 30 and 50 g/liter, a suitable concentration for subsequent precipitation.

Ion exchange resins are used in about half of the mills using an acid circuit. In most cases, however, they use the resin-in-pulp system discussed in the preceding section. The eluant from these systems usually contains from 10 to 12 g/liter U_3O_8. Sometimes, these solutions are further concentrated by solvent extraction. This provides not only additional purification, but it also saves on reagents because a much smaller volume of solution needs to be neutralized for precipitation than would be required otherwise.

Two mills use ion exchange resins to extract uranium from clarified solutions rather than from pulps. One of these mills uses a conventional vertical ion exchange column. The other uses a unique moving bed system, pioneered in this mill, and since then applied in at least two cases for purification of mine water.

The mills with carbonate circuits use either the resin-in-pulp system or precipitate uranium directly from the clarified leach solutions. Direct precipitation from carbonate circuits is possible for several reasons. Firstly, carbonate leaching is sufficiently selective to eliminate the need for solution purification. Secondly, carbonate leach solutions have a U_3O_8 content of about 7 g/liter which makes precipitation more efficient than from the more dilute acid solutions. Lastly, neutralization of the solution is not required and, therefore, no reagent saving would be realized by further concentration.

Product Precipitation

Precipitation of yellowcake from acid circuits is achieved by neutralization to a pH of between 6.5 and 8.0. This is usually done in two stages to allow precipitation of iron hydroxide and other impurities at a pH of approximately 4.0. Any base may be used as neutralizing agent but ammonia is preferred by the majority of operators because it results in a cleaner product.

Domestic mills using a carbonate circuit precipitate yellowcake by addition of caustic soda to achieve a pH of 12. Uranium precipitates as the sodium salt. In one case the precipitate is redissolved and reprecipitated to eliminate some impurities. Other precipitation methods are practiced in other countries but have found no acceptance here.

Yellowcake Drying

Following the precipitation stage, a yellowcake is typically obtained by filtering or centrifuging the yellowcake slurry. The moist cake is then dried and/or calcined by either of two types of equipment. Most U. S. mills actually calcine the yellowcake at temperatures from 350 C to 900 C in a Skinner multiple-hearth furnace. This apparently decomposes much of the sulfate which would otherwise be present as an impurity. Three mills, however, employ steam drying at more modest temperatures (100-150 C) as a final treatment of the yellowcake before shipment.

SECTION 5

POTENTIAL ENVIRONMENTAL IMPACTS

EXPLORATION

Uranium exploration in the 1950's often consisted of flying, driving, or walking over an area with a portable Geiger counter and about the only environmental effect was the off-road jeep trails that were left. The shallow deposits that could be found by this method have been exploited and such deposits will rarely, if ever, be found now. Exploration now requires extensive drilling to locate, delineate, and appraise deeper lying deposits.

Air

Various air pollutants are generated as a result of the exploration operations. Essentially all air pollutants generated are the result of the operation of machinery, including trucks, drill rigs, backhoes, and other vehicles. The pollutants generated are those associated with the operation of internal combustion engines and dust resulting from vehicles traveling over unpaved roads and trails. These pollutants include particulates, oxides of nitrogen, carbon monoxide, unburned hydrocarbons, and sulfur dioxide. The total quantities of these combustion products emitted to the atmosphere is dependent on the number and types of equipment in use, as well as their frequency and duration of operation.

The most visible form of air pollutants is dust generated by moving vehicles. This effect can be lessened by minimizing the speed of travel over unpaved roads and trails, and the number of trips within the exploration area.

It is expected that any impact of exploration operations on air quality would be slight and restricted to the immediate vicinity of drilling rigs and that the duration of any such effects would be short term.

Liquids

Some local and minor alterations to the surface water system of the exploration area may result from temporary road building and from drilling operations. The maximum possible use of existing roads and the program of reclaiming (grading and reseeding) disturbed areas would serve to assure the minimum possible disruption to the watersheds. The planned location of mud pits distant from zones subject to erosion would minimize possible surface runoff alterations.

Care in road building and mud pit placement is important to protect not only surface water supplies (i.e., impacts on developed shallow alluvial waters) but also confined subsurface water resources. Procedures designed to minimize surface runoff alterations can also lessen the potential for alteration of aquifer recharge waters. The transfixing of various developable aquifers presents some potential for the alteration of confined-water characteristics (physical, chemical, and biological).

Land Surface

Roads--

The movement and servicing of drill rigs away from established roadways will make trails and perhaps even require that a rough road be bladed out. In the semiarid areas where much of this activity is likely to take place, these off-road trails may persist for many years. Such roads often become waterways during rainstorms and erode down to unweathered rock and soil parent material. Establishment of vegetation along these strips is extremely slow and may never occur without a reclamation program.

Drill Pads--

A drill rig, with its attendant equipment, requires an area about 30 by 45 meters. The drill rig itself needs to be level, which condition can be achieved either by bulldozing the area or by blocking up the rig. Rig-leveling causes the least surface disturbance, but a certain amount of vegetation will be destroyed just by activity associated with the drilling.

Conventional drilling methods usually require a pit for drilling mud which may be scooped out by a bulldozer to be 1.5 meters wide and 3 meters long. At the completion of drilling, the mud can be allowed to dry and the scooped out soil replaced. This small area, along with the rest of the disturbed drilling pad will be subject to wind erosion and may be slow to revegetate. Lubricating oils and fuel which may be spilled or discarded may also have a short-term adverse impact.

GENERAL IMPACTS FROM MINING

Fugitive Dust

Particulates of ore and soil may enter the atmosphere from several sources. Underground mine operations contribute less dust than does surface mining. Underground mine sources are the ventilation shafts which exhaust the air drawn through the mine. This air contains dust particles created by the mining activities.

Surface mining activities generate much greater quantities of dust. Causes of dust include scraping and digging for removal of topsoil and overburden, blasting, and hauling of overburden and ore; wind erosion of overburden may also occur, contributing to atmospheric dust. If the ore and overburden are moist, little dust is created in blasting and stripping; haul roads are frequently watered to reduce dust stirred up by ore trucks.[6] Dust from spoil piles may be created by wind action; this dust may be reduced by reclamation and stabilization of the spoil surface.

The dust emitted to the atmosphere is primarily silica with small amounts of uranium, thorium, sulfates, and other elements and compounds associated with the soil overburden and ores of the particular area. These materials are distributed over the landscape. However, due to the low quantities of dust normally involved, no significant impacts of dust upon vegetation, livestock, wildlife, or water quality should be anticipated. In areas where the ore or overburden is dry or haul roads are not watered, greater quantities of dust are emitted to the atmosphere and settle out on the surrounding area. Vegetation is not normally significantly impacted by the increased dust, unless it is completely covered, but utilization of the plants by animals may be reduced. Large amounts of dust increase the likelihood of surface water contamination through runoff.

Vehicle Emissions

Most of the emissions result from the combustion of hydrocarbon fuels in the heavy-duty diesel-powered equipment used in the mining operations. These emissions are primarily particulates, NO_x, SO_x, and hydrocarbons. Surface mine operations result in considerably more emissions than underground mines, since the overburden must be removed before the ore can be mined. The estimated air pollutants emitted from a hypothetical 1350 MT (1500 ton)/day underground and surface mine are presented in Tables 3 and 4. The quantities of pollutants from vehicles involved in mining will not likely be sufficient to cause a measurable increase in a region's inventory.

Mine Water

One of the major environmental impacts associated with mining is the withdrawal of groundwater to prevent flooding. Declining water levels in the tapped aquifers, and possibly adjacent formations, is immediately noticed.[11] This may affect the availability of local and possibly regional water supplies for municipalities and industries. Lowering of the water table may also affect the vegetation community, especially in arid regions of the west where many of the plants are dependent on subsurface water. Water levels in the aquifers will likely return to pre-mining conditions, after mining operations cease.

Another of the major environmental impacts of mining is the discharge of water into the environment. Water from relief wells drilled around the mines to reduce mine water influx and water that collects in the mines is often discharged without any treatment. Surface mine dewatering rates range 0.77 to more than 11.0 m^3/min (205-2904 gpm). Mine water may contain uranium, selenium, zinc, sodium, sulfates, nitrates, and other substances. The composition of the water varies with the composition of the aquifers and other rock formations through and over which the water flows and leaches out the various substances. Water discharged from mines also contains suspended solids picked up as it flows across mined surfaces and through collection ditches. The composition of representative discharged mine waters is shown in Tables 5 and 6.

The discharge of mine water in the arid west may transform dry washes and ephemeral streams into perennial streams. This increased water leads to changes in biota and land use by wildlife and livestock, particularly in

TABLE 3. ESTIMATED AIR POLLUTANT EMISSIONS FROM EARTH HAULING EQUIPMENT AT A 1350 MT/DAY UNDERGROUND MINE

Pollutant	Emissions, kg/day
Particulates	2.4
Sulfur oxides	5.0
Carbon monoxide	41.9
Hydrocarbons	6.9
Nitrogen oxides	68.1

Source: Reference 6.

TABLE 4. ESTIMATED AIR POLLUTANT EMISSIONS FROM EARTH HAULING EQUIPMENT AT A 1350 MT/DAY SURFACE MINE

	Emissions per Operating Day, kg/day	
Pollutant	Mining Operations	Overburden Removal
Particulates	17.0	18.9
Sulfur oxides	35.4	39.3
Carbon monoxide	294.2	327.4
Hydrocarbons	48.4	53.8
Nitrogen oxides	484.6	538.4

Source: Reference 6.

TABLE 5. COMPOSITION OF DISCHARGE WATER FROM MINES[a]

	Surface Mines			Underground Mines			
Applicant	Kerr-McGee	Getty Oil	Utah Intl.	Cotter Corp.	Union Carbide	Union Carbide	Union Carbide
Mine Designation		KGS-JY-Mine	Shirley Basin	Schwartz-walder	Eula Belle	Martha Belle	Burro
Mine Location	Shirley Basin, Wyoming	Shirley Basin, Wyoming	Shirley Basin, Wyoming	Golden, Colorado	Uravan, Colorado	Uravan, Colorado	Slick Rock, Colorado
Flow rate, $m^3/day \times 10^3$	1.7	5.4	10.9	0.3	0.3	0.2	0.1
pH	7.9	7.5	6.7-8.2	7.3	8.6	8.4	8.8
Alkalinity	180	164	144-150	244	358	384	704
Total Solids	612	840	850-1,275	1,220	730	3,103	1,790
Total Dissolved Solids	411	627	750-825	1,042	590	650	1,780
Total Suspended Solids	163	49	40-420	178	140	2,453	6
Total Volatile Solids	38	164	40-92	244	70.7	192	125
Ammonia (as N)	0.22	1.33	1.42-1.60	0.15	<0.10	<0.10	3.3
Kjeldahl Nitrogen	0.22	1.33	1.42	0.55	145	0.3	21.8
Nitrate (as N)	<0.01	0.002	0-1.06	12.0	0.35	0.39	1.9
Phosphorus Total as P	0.05	0.07	2.30	0.4	0.2	0.4	0.15

Source: Reference 12.

(a) Composition data given in mg/l unless otherwise specified.

TABLE 6. COMPOSITION OF DISCHARGE WATER FROM UNDERGROUND MINES

Operator Designation Location	Kerr-McGee[(a)] Sec. 30W Grants New Mexico	Kerr-McGee[(a)] Sec. 35 Grants New Mexico	Kerr-McGee[(a)] Sec. 36 Grants New Mexico	United Nuclear[(a)] Churchrock Mine D Grants New Mexico	Kerr-McGee[(a)] Churchrock Grants New Mexico	Rio Algom[(b)] Humeca La Sal Utah
Flow rate (m^3/day x 10^3)	5.1	14.3	8.4	7.8	8.3	
pH						7.6
Total dissolved solids						2962
Total suspended solids	22	100	38	118	47	
Total solids						3712
SO_4			13			300
Cl	51	8.5		4.9	1.2	1597
Fe						0.16
Mo	2.6	5.0	0.3	0.2	0.2	
Na	160	200	187	95	97	1335
NH_3	19	11	0.05	0.05	0.05	N.D.
$NO_2 + NO_3$	1.14	0.35	0.25	0.22	0.33	
NO_3						9.5
Se	0.03	0.07	0.01	0.04	0.01	<0.005
V	0.7	0.8	0.9	0.5	0.8	
Mn	0.7	0.06	0.11	0.09	0.8	N.D.
Total U	4.7	19	3.0	10.4	0.88	0.035

(a) Average concentrations in mg/l; Source: Reference 11

(b) Average concentrations in ppm; Source: Reference 13 arid regions. The water may enter other streams, where its components contaminate the water and are transported to other areas. The water may also evaporate leaving behind its dissolved and suspended materials. Seepage into shallow aquifers may occur thus contaminating ground water. Water from mines is sometimes decanted through settling ponds before being discharged into the environment where percolation into ground water often occurs.

Heavy metals such as selenium, vanadium, radium, and molybdenum are potentially toxic elements frequently found in uranium mine water, such as in the Grants Mineral Belt of New Mexico[11] (see Table 6). These elements may enter the human food chain if the receiving water system is used for irrigation or livestock watering.

The use of mine water for dust suppression on haul roads would cause a gradual accumulation of any dissolved or entrained solids on the roadways. Depending upon the concentration and composition of these dissolved or entrained materials, leaching of the accumulated material by rainfall could adversely affect water quality in local surface drainage areas. This possibility should be considered in each area where dust suppression is needed and the water used for dust control should be treated as necessary to prevent these potentially adverse effects.

Solids

The effects of solid wastes revolve primarily around the quantity of material excavated. The volume of waste from an underground mine is relatively small, consisting primarily of the rock and overlying material excavated from the shafts and haulage drifts. The mine waste is disposed of on the surface. The area where this material is placed will no longer be biologically productive unless it is reclaimed.

Surface mining operations require the removal of overburden to depths as great as 150 meters (492 feet) but more commonly to depths of 30-120 meters (98-394 ft)[5]; areas of 160 ha (395 ac) may be excavated. The range of overburden to ore volumes ranges 8:1 to 35:1.[5] Currently, overburden from initial pit construction is stored on the surface; as mining continues the overburden is used to backfill the pit. Current practices call for the reclamation of overburden spoils by covering with topsoil and establishing vegetation to regain lost productivity and reduce erosion. Approximately 100 ha (247 ac) are required for waste storage at a mine that is expected to disturb about 400 ha (988 ac) through excavation.[12] When spoils are not used to backfill the mine, the area so covered is at least temporily unproductive. Spoil material is not conducive to the growth of vegetation without supplemental treatment. If the spoils are not seeded or chemically treated, wind and water erosion may occur and if streams are-nearby, they may become polluted from spoils runoff.

A potential problem with backfilling is the possible contamination of ground water. This may occur when ground water saturates the backfill material and substances may leach from the mixed overburden substrates and enter the aquifers flowing through the area.

GENERAL IMPACTS FROM MILLING

Dust

Fugitive dust originates from ore stockpiles and mill tailings. It is usually siliceous in nature but some ores are high in calcium and magnesium. Some iron is usually present and small amounts of various elements may be associated with the uranium, such as vanadium, copper, and phosphorus. Dust from ore piles may be reduced during dry and windy periods by wetting. The quantity of tailings dust varies with the treatment of disposed tailings. Dried impounded tailings and untreated, abandoned tailings piles contribute significantly more dust to the atmosphere than moist or stabilized tailings.

Process dust can be emitted locally from ore crushing and grinding and yellowcake drying; however, the quantity of dust escaping is normally kept small, either by wet crushing or through the use of scrubbers. Scrubbers are also used to capture dust during the drying of yellowcake.

Although uranium and associated metals frequently found in the dust are toxic, their concentrations and the volumes of dust are sufficiently low that their impacts are localized and very minor.[6,12]

Chemicals

Gaseous emissions from milling are from fuel combustion and the chemicals used in the various processes.

The use of fuels, such as natural gas, results in the emission of hydrocarbons, SO_x, NO_x, CO, and CO_2. These effluents are small in quantity and do not result in a significant impact to the local environment.

Chemicals used in the processing of uranium ore give off small quantities of various gaseous effluents in the mill. The primary effluents from the acid leach processes are SO_2, kerosene, ammonia, and amines.[10,13] Approximately 166 kg/yr (366 lb/yr) of kerosene and 129 kg/yr (285 lb/yr) of SO_2 may be vented from a 1814 MT/day (2000 ton/day) nominal plant.[10] Effluents from the alkaline leach process may include ammonia and caustic soda vapors.[13] The small quantity of vapor emitted is quickly dissipated and is not expected to accumulate in the environment or have any significant environmental impacts.

Vapors of organic chemicals enter the atmosphere via evaporation from tailings ponds.[13]

Liquids

Liquid discharges for acid and alkaline leach systems are approximately 4.2 and 1.05 cubic meters (1000 and 250 gallons) per metric ton of ore processed, respectively.[5] The recycling of liquids considerably reduces the requirements for water and chemicals, but the wastes must eventually be disposed of. Water requirements are met by the utilization of mine water or well water. A well is normally drilled to meet the requirements for potable water.

The use of wells to supply process water results in a decrease in the amount of water available in aquifers for other uses, but the quantities withdrawn are not expected to have any major long-term effects upon regional water supplies. The use of mine water for process water eliminates the need for process water wells and reduces the volume of mine water discharged into the environment.

Liquid wastes from mills are aqueous solutions containing various chemicals (Table 7), leached elements (Table 8), and suspended ore fines and other solids. An analysis of an alkaline leach mill effluent is shown in Table 9.

Liquid wastes from milling operations are discharged into settling lakes but until recently the wastes were often discharged directly into stream channels. The current practice is to discharge the liquids along with solids into settling basins where the liquids either evaporate or percolate into the soil; excess water in the pond may be treated and discharged into streams or injected into deep wells. Some of the clarified water may be recycled for use as process water.

Wastes from an acid leaching process have a pH of about 1.5 to 2.0.[10] These liquors contain the unreacted portion of the sulfuric acid leaching agent and other soluble inorganics such as calcium, sodium, magnesium, and iron cations with sulfate and chloride anions. Small amounts of other metals leached from the ore are also present. One to three percent of the ore is dissolved in the process waste. The major organics present are those of the raffinate solution (primarily kerosine, amines, and isodecanol) introduced in the solvent extraction process. A mill processing 1,814 MT (2000 ton) of ore per day produces about 2,722 MT (3000 tons) per day of waste milling solution.[10] The waste milling solutions are used to transport the tailings sands and slimes to the disposal site.

Waste solutions from alkaline leach processes have a pH of about 9.5 to 11.0 from the unreacted carbonate-bicarbonate leach solutions.[14] The use of an alkaline leach system is more specific for uranium than the acid leach system and fewer elements are leached from the ore.[15] Water requirements for the alkaline leach system are about one-fourth those of the acid leach system. A portion of the alkaline process water is discharged to the tailings pond to prevent a buildup of dissolved solids while the remainder is recycled through the plant. Some pond water is often recycled through mills to reslurry sand and slimes for disposal. The volumes of liquids in ponds are reduced through seepage into the soil, evaporation, or, after settling and filtration, by stream discharge or deep well injection.

The quantity of seepage from the ponds varies, depending upon the pond design. In evaporation-percolation ponds, seepage may account for as much as 85 percent of the losses; in clay-lined ponds with a buildup of tailings seepage may account for only 7 percent of the loss. Excess liquids from ponds may be discharged to streams or disposed of underground in areas where sufficient land is not available; the water is neutralized and treated to remove heavy metals and other contaminants and may flow through a series of settling ponds before discharging or injecting.

TABLE 7. CHEMICALS USED IN MILLING OPERATIONS

Acid Leach Process	Alkaline Leach Process
Acid Leach Circuit:	Alkaline Leach Circuit:
sulfuric acid	sodium carbonate
sodium chlorate	sodium bicarbonate
	ammonium carbonate
Liquid-Solid Separation Circuit:	ammonium bicarbonate
polyacrylamides	
guar gums	Ion-Exchange Circuit:
animal glues	strong base anionic resins
	sodium chloride
Ion-Exchange Circuit:	sulfuric acid
strong base anionic resins	sodium bicarbonate
sodium chloride	ammonium nitrate
sulfuric acid	
sodium bicarbonate	Precipitation Circuit:
ammonium nitrate	ammonia gas
	magnesium oxide
Solvent Extraction Circuit:	hydrogen peroxide
tertiary amines (usually alamine-336)	
alkyl phosphoric acid (usually EHPA)	
isodecanol	
tributyl phosphate	
kerosine	
sodium carbonate	
ammonium sulfate	
sodium chloride	
ammonia gas	
hydrochloric acid	
Precipitation Circuit:	
ammonia gas	
magnesium oxide	
hydrogen peroxide	

Source: Reference 5.

TABLE 8. TRACE ELEMENTS LEACHED FROM ORE BY MILLING PROCESS

Magnesium	Vanadium
Copper	Iron
Manganese	Cobalt
Barium	Nickel
Chromium	Zinc
Molybdenum	Thorium
Selenium	Uranium
Lead	Radium
Arsenic	

Source: Reference 5.

TABLE 9. ANALYSIS OF AN ALKALINE LEACH MILL TAILINGS EFFLUENT

Solution Analysis	ppm
U_3O_8	6.8
Mn	0.01
Cu	0.01
Fe	1.0
Zn	0.6
SO_4	7,500
CO_3	4,000
HCO_3	1,100
Th	2.0
Na	7,100
pH	9.5
Solids Analysis	**Percent**
U_3O_8	0.017
Mn	0.01
Cu	0.0028
Fe	1.36
Th	0.0005

Source: Reference 13.

Water seeping from tailings ponds may contain many contaminants such as nitrates, sulfates, trace elements (e.g., selenium in the Grants, New Mexico area) and organic chemicals.[5,12] Ground and surface water may become polluted as a result of seepage. Numerous radiological studies have illustrated that pollutions of ground and surface water occurs from seepage and mill discharge. Contamination of wells by nonradiological pollutants resulted in water unfit for livestock in Colorado. Nitrates, which travel more rapidly in soil than some other constituents, have polluted ground water in New Mexico. Trees have died down-gradient from a tailings pile in Colorado, reportedly indicating a high mineralization of ground water.[5] Ground water contaminated with selenium and nitrates has been shown to occur near tailings ponds in the Grants Mineral Belt of New Mexico.[11] In some areas where seepage is a problem, catchment basins or wells have been placed downslope from the pond to intercept the contaminated water and pump it back to the tailings pond.

Surface water may become contaminated through ground water discharge into ponds or streams or by discharges from mill operations. Some seepage may occur along the tailings pond dam and surface ponds may develop in low areas near the tailings ponds. Prior to the use of waste treatment facilities, wastes were discharged directly into streams. This resulted in the elimination of most aquatic life immediately below the discharges. The most toxic effects were from the raffinate components.[16,17] No wastes are now discharged to streams which have not been treated to reduce the toxic components of the liquids. Treatment may include decanting through a series of settling ponds, neutralizing the acid, removing thorium and other metals, and precipitating solids.[5] Contaminants occurring in treated effluents are not expected to create any environmental problems because of the low levels and characteristics of the chemicals involved.

Liquid wastes may be injected into deep wells for disposal. The disposal zone is usually hundreds of feet below the surface and must be separated from aquifers by impermeable formations or contamination of present or potential water supplies may occur. Also, the injection well must be properly cased to prevent aquifer contamination. Contamination of aquifers from injected wastes appears to have occurred in New Mexico.[11] The effluents are treated to remove suspended solids to prevent plugging in the zone and to retard growth of microorganisms. If the disposal zone material will not neutralize the wastes, the effluents are neutralized before injection.

Tailings are presently discharged into impoundments primarily to retain the solid wastes, but they are also designed to serve as retention and settling basins for the liquid wastes. The pond sizes vary with the amount of land available, disposition of liquid effluents, and type and size of mill. Ponds range from a few to more than a hundred hectares in size with one or more ponds per mill. A 1,814 MT/day mill in Wyoming requires a tailings disposal area of about 60 ha.[10]

Tailings are discharged into impoundments, usually against the upstream edge of the dam, thus forcing the free solution away from the dam. Another method is to separate the sands from the slimes and use the sands to increase the dam height while depositing the slimes in the inner portion of the pond. As the slimes precipitate they act as a sealant to reduce seepage from the pond.

An ideal tailings pond to reduce the impacts of seepage of contaminants and to confine the waste solids should be near the mill located in a natural ravine with four basic qualifications: (1) limited runoff, (2) downstream openings capable of being dammed, (3) adequate storage volume, and (4) an underlying impermeable geologic formation. Natural runoff should be diverted from the tailings pond to prevent flooding during high rainfalls. The dam would be constructed with a clay core to prevent seepage and an outer shell of erosion resistant material. If the pond is not located on an impermeable formation, a clay blanket should be placed over the entire basin behind the dam to reduce seepage.

Tailings ponds support little, if any, aquatic life because of their pH and toxic substances. However, their effects on birds, particularly waterfowl, and other wildlife which may inadvertently use the ponds are not known.[6,10,18] It is expected that waterfowl in the central and pacific flyways do land in the ponds during migration, particularly in the arid western regions of the U.S. The birds probably do not remain in the ponds for any extended period of time, but they can be expected to ingest some of the solution. The effect of the chemicals upon feathers and skin, toxic effects, bio-accumulation, or suitability of the affected birds for human consumption has not been evaluated.

Sewage treatment facilities are necessary to handle the needs of the employees. The facilities consist of aerated lagoons, septic tanks with leach fields and oxidation ponds. Effluents from the facilities are discharged to the mill process water system or tailings pond.

Solids

Large quantities of solid wastes must be disposed of at milling sites. Approximately 98 percent of all processed ore is discharged as tailings. Over six million metric tons of tailings were produced by mills in 1974.[5] This waste is disposed of in tailings ponds and consists of approximately 80 percent sands and 20 percent slimes.[5] Some solids are also suspended in the liquid effluents.

Old methods of tailings disposal were to discharge the wastes directly into streams or to create piles, frequently near the streams. Direct discharges resulted in high sediment loads and dissolved solids in the streams. Tailings were frequently washed into streams by high waters and water percolating through the piles leached out contaminants that moved into ground water and streams. Tailings piles were not reclaimed when milling operations ceased.

Several types of environmental problems may result from tailings solids. Substances (e.g., selenium and nitrates) may leach from the tailings and enter ground and surface waters when the tailings basin is permeable. This has been shown to be a problem in the Grants Mineral Belt area of New Mexico.[11] Tailings must be kept moist to prevent wind erosion. Otherwise the tailings particles will be transported to adjacent lands and waters where contaminants may be taken up by crops or ingested by livestock. Abandoned tailings are biologically unproductive due to their high acidity or alkalinity, lack of soil and moisture and blowing sand. If tailings ponds are to be covered with soil when operations cease, additional areas must be disturbed to obtain this soil, thus increasing the area to be reclaimed.

SPECIFIC IMPACTS FROM TYPICAL MINING-MILLING OPERATIONS

This section presents a summary of the environmental impacts from example uranium processing categories. It is based on field visits to typical plants and information obtained from the literature. The following categories and number of plants in each category were selected for evaluation:

Category	Number of Plants
(1) Open pit mining-acid leach process	8
(2) Underground mining-acid leach process	4*
(3) Underground mining-alkaline leach process	4*
(4) In-situ mining	2

Open Pit-Acid Leach Process

This industry category is the most prevalent in total number of plants (8) and accounts for about 50 percent of the total U.S. production of yellowcake. The plants in this category, for the most part, are in various geographical sections but the majority of the plants are in Wyoming. Table 10 lists these plants and certain aspects concerning the processing method to produce yellowcake.

The open pit acid-leach category is typified by the Exxon, Highland Mine located in the Powder River Basin of Wyoming. The flowsheet for this mill is shown in Figure 3. Following is a discussion of the various environmental impacts indicated in this figure.

Mine Water--

The influx of water to open pit mines is discussed in detail in the preceding section. This general impact occurs in the Highland Mine since the pit is below the local water table. The water is controlled by a system of ditches and a sump from which the water is pumped to a settling basin. Final disposal of the water is to the mill process or the tailings pond.

Another aspect pertaining to mine water is the use of diversion dams to direct rainfall away from the open pit operations. Three such dams are used at the Highland Mine and the water is currently discharged to a nearby stream.

*Includes one plant which has both an acid and an alkaline leaching circuit.

TABLE 10. PROCESS VARIATIONS USED BY ACTIVE URANIUM PLANTS

Plant	Location	Liquid/Solid Separation Method	Concentration Method	Precipitation Reagent	Dryer
		Open Pit Mine Acid Leach Process			
Exxon	Wyoming	CCD	SX	NH_3	MH
Utah International, Inc.	Wyoming	CCD	IX + SX	NH_3	SD
Union Carbide, Uravan	Colorado	CCD	IX	NH_3	MH
Union Carbide, Gas Hills	Wyoming	SS	RIP	NH_3	MH
Petrotomics Company	Wyoming	CCD	SX	NH_3	MH
Anaconda Company	New Mexico	SS	RIP	MgO	SD
Conoco and Pioneer Nuclear, Inc.	Texas	CCD	SX	NaOH	--
Dawn Mining Company	Washington	CCD	IX	NH_3	--
		Underground Mine-Acid Leach Process			
Kerr-McGee Nuclear Corporation	New Mexico	CCD	SX	NH_3	SD
Federal-American Partners[a]	Wyoming	SS	RIP + SX	NH_3	MH
Atlas Corporation (acid circuit)	Utah	CCD	SX	NH_3	MH
Western Nuclear, Inc.	Wyoming	SS	RIP + SX	NH_3	MH
		Underground Mine-Alkaline Leach Process			
Rio Algom Corporation	Utah	Filtration	None	NH_3	--
United Nuclear-Homestake Partners	New Mexico	Filtration	None	NaOH	MH
Atlas Corporation (alkaline circ)	Utah	SS	RIP	NH_3	MH
Cotter Corporation	Colorado	CCD + Filtration	None	NaOH	MH
		In-Situ Mining			
Atlantic Richfield Company	Texas	--	IX	NH_3	SD
Wyoming Minerals	Texas	--	IX	--	--

(a) This plant uses some ore from open pit mines.

Legend:
- CCD - Continuous countercurrent decantation
- SS - Sand-slime separation
- SX - Solvent extraction
- IX - Column ion exchange
- RIP - Resin-in-pulp system
- MH - Multiple hearth-skinner dryer (600-1500 F)
- SD - Steam dryer-Proctor and Schwartz (200-350 F)

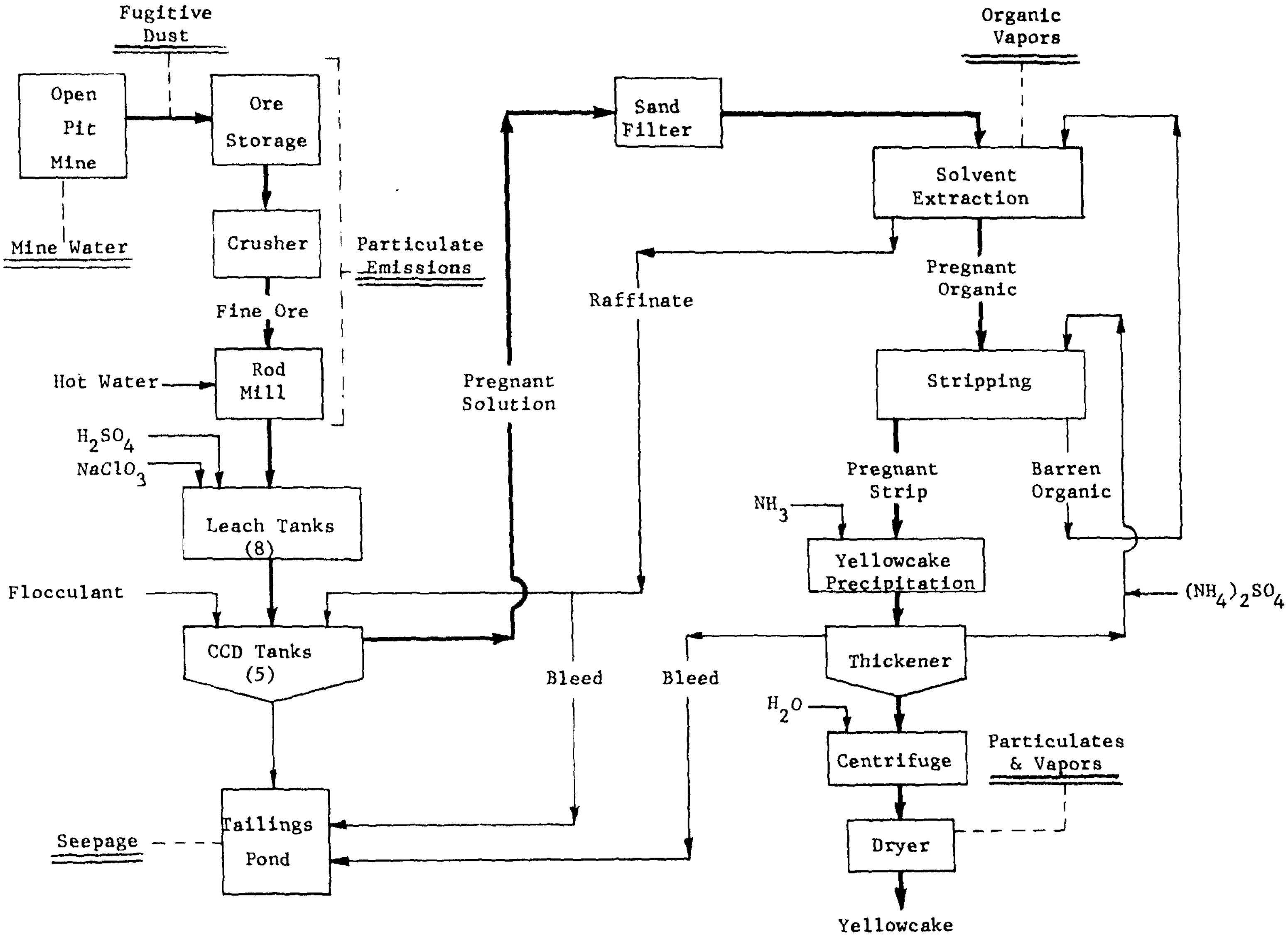


Figure 3. Uranium extraction flowsheet, open pit-acid leach process.

Fugitive Dust--

This impact is discussed in detail in the preceding section.

Particulate Emissions--

At the Highland Mine, ore is crushed by a jaw-crusher and stored in silos prior to feeding into a rod mill. Particulate emissions are generated at both the crusher station and the ore transfer and storage facilities. The emissions are controlled by two Ducon scrubbers at the crusher and ore silos. These scrubbers are rated at 95 percent efficiency and would result in a total particulate emission of about 130 tons per year.[10]

Tailings Pond Seepage--

This potential environmental impact is perhaps the major consideration within the uranium industry. Impoundment of all mill wastes to a tailings pond is almost universally applied. For the Highland Mine, it is estimated that about 2000 tons per day of solid wastes and 3000 tons per day of liquid wastes will be disposed of to the tailings pond.[10] The liquid will have a pH of 1.5 to 2.0. Included in these wastes are various heavy metal compounds, organic materials such as kerosine (165 kilograms per year) and ammonia.

Ideally, the tailings pond will be a final disposal with evaporation taking care of much of the liquid effluents. However, seepage can occur from the pond and has been noted at the Highland Mine. The current seepage is low, has a neutral pH, but is high in sulfates. It is currently being pumped back to the pond from a collection sump and is monitored closely.

Organic Vapors--

Vapors of kerosine and ammonia are, of course, prevalent in any solvent extraction and precipitation process. This impact, however, is not of significance except as it pertains to plant personnel.

Dryer Emissions--

Emissions from the drying or calcining of yellowcake prior to shipment are an environmental impact in all uranium plants. At the Highland Mine, the yellowcake is dried at about 300 C in a gas-fired furnace. The exhaust gases are controlled by a Tubulaire wet scrubber estimated at 99.3 percent efficiency. Dust emissions of U_3O_8 are estimated at about 380 kilograms per year.[10] In addition the dryer exhaust would contain organic vapors from decomposition of a polyacrylamide flocculant, and small quantities of ammonia and SO_2.

Underground Mine-Acid Leach Process

This category accounts for almost one-third of the total production of uranium in the United States. However, only four plants are contained in this category. The major production is obtained in the Grants Mineral Belt of New Mexico.

In this category, the basic process of uranium extraction remains essentially the same as described in the previous category. However, due to underground mining operations, there is an added impact of underground mine water. A generalized flowsheet for this type of mill is shown in Figure 4. This

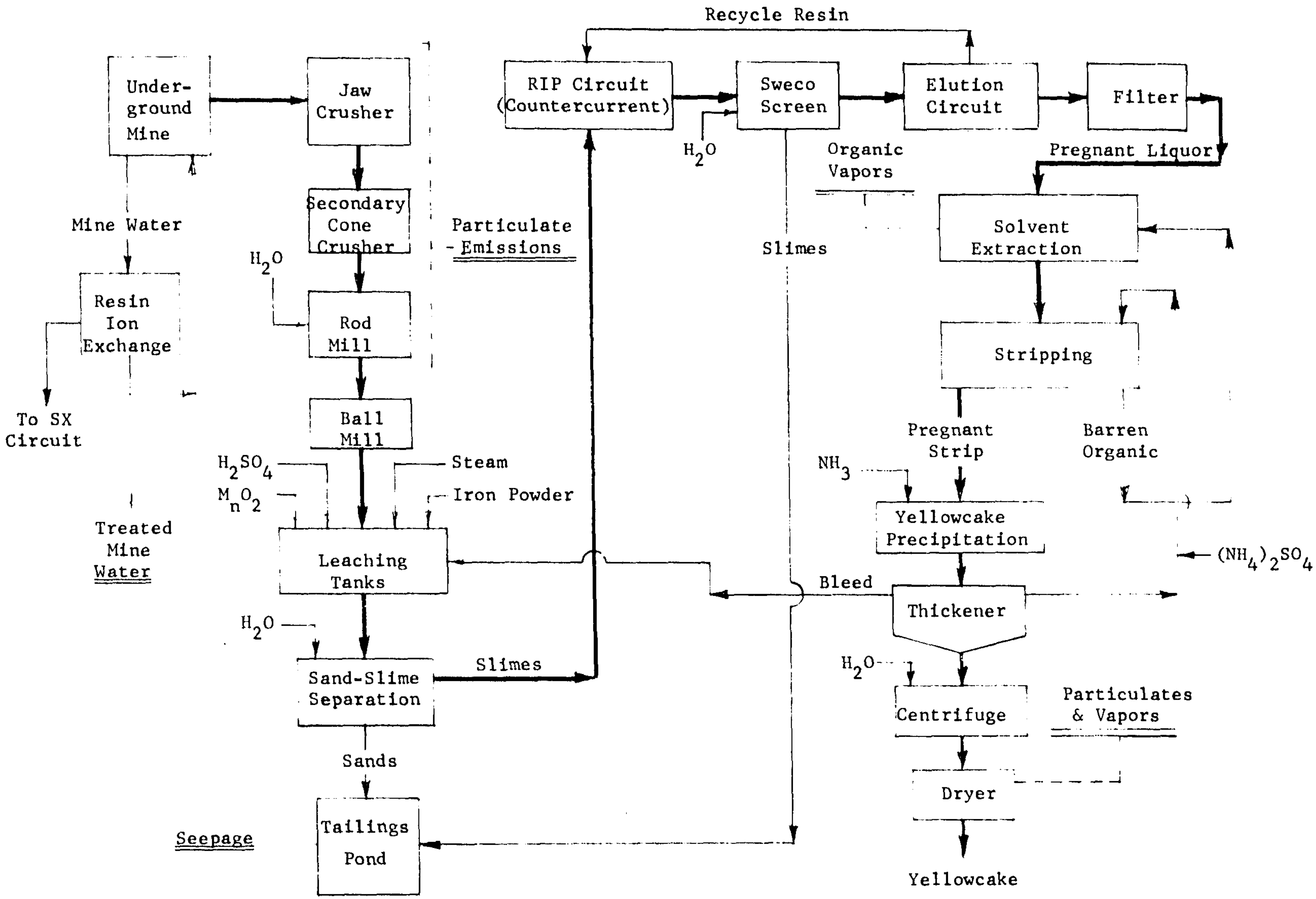


Figure 4. Uranium extraction flowsheet, underground mine-acid leach process.

flowsheet is highlighted with the sand slime separation and resin-in-pulp (RIP) circuits. The various environmental impacts due to this type of operation are discussed below.

Mine Water--

The impact of mine water from underground mining is higher than that of the open pit mining operation. In this case a substantial amount of uranium is dissolved in the mine water. For example, at the Kerr-McGee plant in New Mexico, the mine water typically contains 2-12 ppm U_3O_8, and this water is processed at the mine site to recover the dissolved uranium by resin ion exchange in fixed bed columns. Portions of this effluent water (uranium stripped) are pumped back for the underground leaching operation and the remainder is disposed of. After treatment, the mine water will typically contain about 1.0 ppm U_3O_8.

Particulate Emissions--

Most of the particulate emissions occur during primary and secondary crushing of the ore. The emission sources are controlled by wet scrubbers. No information is presently available on emission rates for example plants in this category.

Tailings Pond Seepage--

For sand-slime separation circuits, the slime portion of the tailings is impounded whereas the sand fraction is used for dam-building purposes. The tailings will have a low pH of 1.5. Most of the metal and organics content of of the tailings remain in the pond.

Seepage from the tailings pond does occur. In some mills where the tailings water is not returnable for use in the mill because of its high dissolved solids content, the deep well disposal technique is practiced to dispose of the solution. For example, at the Anaconda plant in New Mexico, up to 1500 lpm are disposed of by deep well injection. In one case, however, the excess water, after neutralization, is discharged to the Colorado River.

Organic Vapors--

The impact due to organic vapors is not significant except as it pertains to plant personnel.

Dryer Emissions--

The impact due to dryer emission may be significant, however, the exhaust gases (e.g., U_3O_8 dust, SO_2, and other organics) are typically controlled by wet scrubbers. Estimates of these emissions are described for the previous category.

<u>Underground Mining-Alkaline Leach Process</u>

Although underground mining is the most common method of uranium mining, the combination of underground mining and alkaline leaching process is utilized by only a small proportion of the uranium mills. This category accounts for only about 15 percent of the total U.S. production of yellowcake.

An example of the underground mining-alkaline leach category is the Humeca Mill operated by the Rio Algom Corporation in La Sal, Utah. The flowsheet for this mill is shown in Figure 5. A discussion of the various environmental impacts indicated in this figure follows.

Mine Water--

Water from the production shaft is utilized in the mill process. Most of the water from the ventilation shaft is diverted to a nearby ranch with the remainder being used in mining operations or disposed of in the tailings pond.

Mine Air Particulates--

The high air flow rate and low quantity of particulates (2.2 mg/m^3) will result in a very negligible impact.

Fugitive Dust--

Fugitive dust is minimal; its impact has been discussed in the previous section.

Mill Particulate Emissions--

Air cleaning equipment has been installed at the ore transfer areas, crushing plant, and ore sampling room to remove particulate matter from the air before it is discharged to the atmosphere. In these areas the air is passed through cloth bag filters. Vapors and dust from the yellowcake packaging and drying operations are passed through a venturi scrubber and centrifugal eliminator. All mill air effluent contain less than 0.03 $grains/ft^3$ (68.3 mg/m^3).

Tailings Pond--

Impact may result from both the impounded tailings solution and seepage from the pond.

The tailings solution has a pH of about 9.5 and contains high concentrations of dissolved solids. Typically, a major part of the solution will be recycled to the mill process to be used in leaching. This results in a solution disposal rate of only one-fourth that of acid-leach mills.

The impacts of seepage from the pond have been discussed earlier. Approximately 500 tons of solids and 280,000 liters of waste milling solution will be discharged daily into the pond. Approximately 10 percent of the solution is expected to be lost through seepage until the pond is sealed by tailings.

Combustion Vapor--

Approximately 32 percent of the flue gas from the natural gas fuel is directed to the carbonation tower where the CO_2 is absorbed. The remainder of the gas is discharged out a stack. The quantities of combustion products are not expected to have any impacts.

In-Situ Mining Process

Recovery of uranium by in-situ mining has been used for a number of years

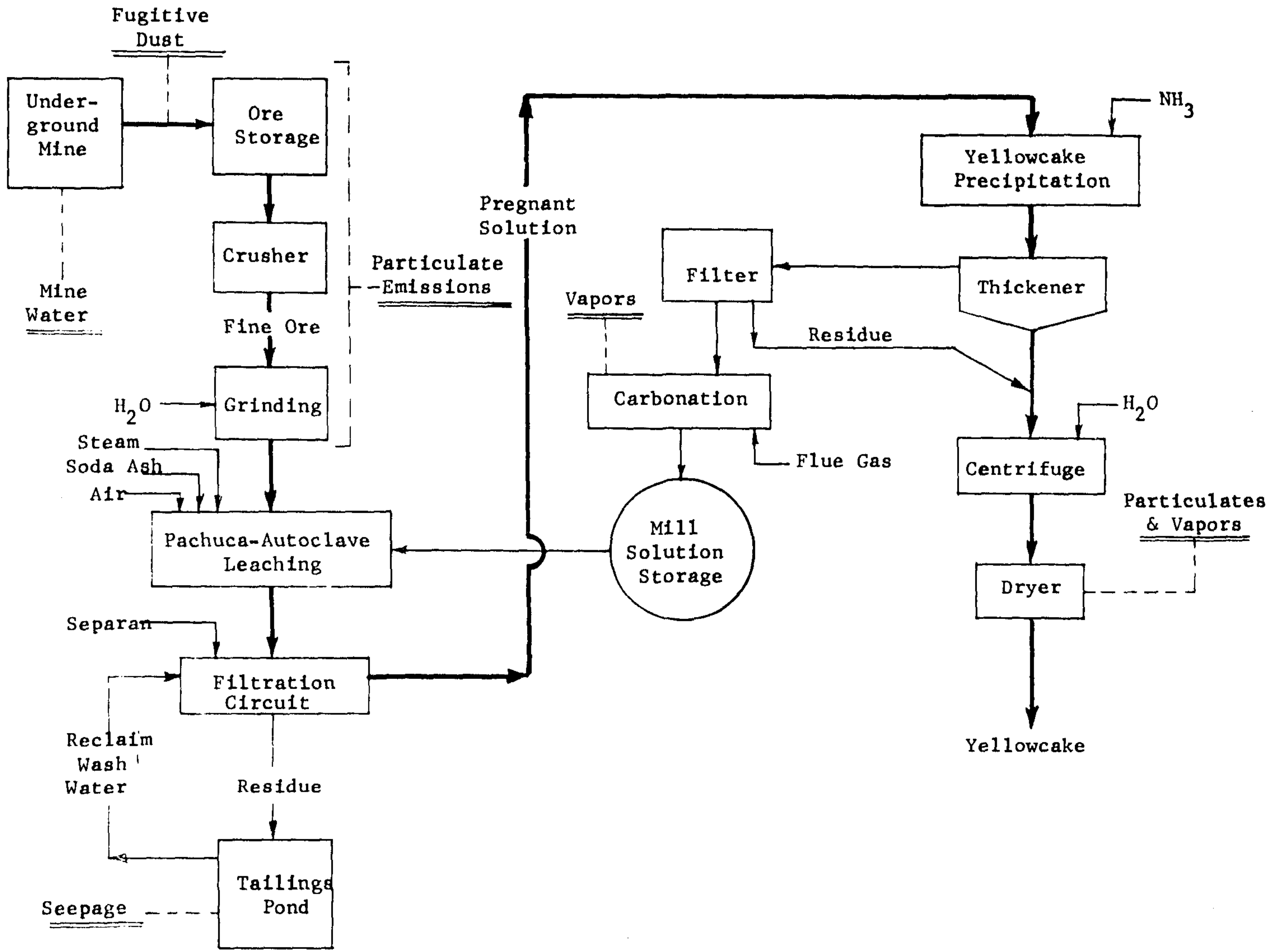


Figure 5. Uranium extraction flowsheet, underground mine-alkaline leach process.

but has just recently experienced a rapid growth rate, especially in South Texas. Presently, however, only two plants (see Table 3) are considered to be in a production stage although several other companies are involved in pilot testing. The production of yellowcake by these two plants is currently estimated at about 250 tons per year which accounts for 1-2 percent of the total U.S. production of yellowcake.

The in-situ mining category is typified by the ARCO plant located approximately 16 kilometers southwest of George West, Texas. The flowsheet for this plant is shown in Figure 6. Following is a discussion of the various environmental impacts indicated in the figure.

Potential Leachate Losses--

The potential loss of leachate (ammonium carbonate solution) produces perhaps the primary environmental impact which could arise from this type of operation. At the ARCO facility, the solution is pumped into the ore body at the rate of about 7000 lpm and ideally is totally withdrawn at the same rate. It is realized, however, that some losses must occur due to dilution and mixing with ground waters and migration of the solution both in a horizontal and vertical plane. The magnitude and effect of such losses are unknown at the present time. Consequently, ARCO has numerous monitor wells to warn of potential leachate losses.

The pumping of solution 1 mile to and from the recovery facilities also could cause an impact to the environment through pipeline failures or maintenance activities.

Sludge--

Backwash sludge from the recovery operations amount to about 15 tons per year at the ARCO plant. The sludge consists primarily of sandstone solids but probably contains small amounts of heavy metals. It is currently disposed of by burial. This environmental impact is not believed to be significant.

Sparge Air--

This atmospheric emission is considered a minor impact primarily because of the small volumes involved. The gases would contain some CO_2 and acid vapors.

Dryer Emissions--

This impact is similar to other industry categories and is described in previous sections.

Chemical Wastes--

All chemical wastes at the ARCO plant are sent to a holding reservoir where evaporation takes care of much of the liquid volume. The excess solution (less than 400 lpm), however, is disposed of by deep well injection, some 1400 meters below the surface. Typically the injected solution would have a high concentration of dissolved solids and contain significant quantities of heavy metals such as molybdenum, uranium, arsenic, and selenium, which makes the solution highly toxic. The overall impact both in the near and long term of deep well injection is unknown.

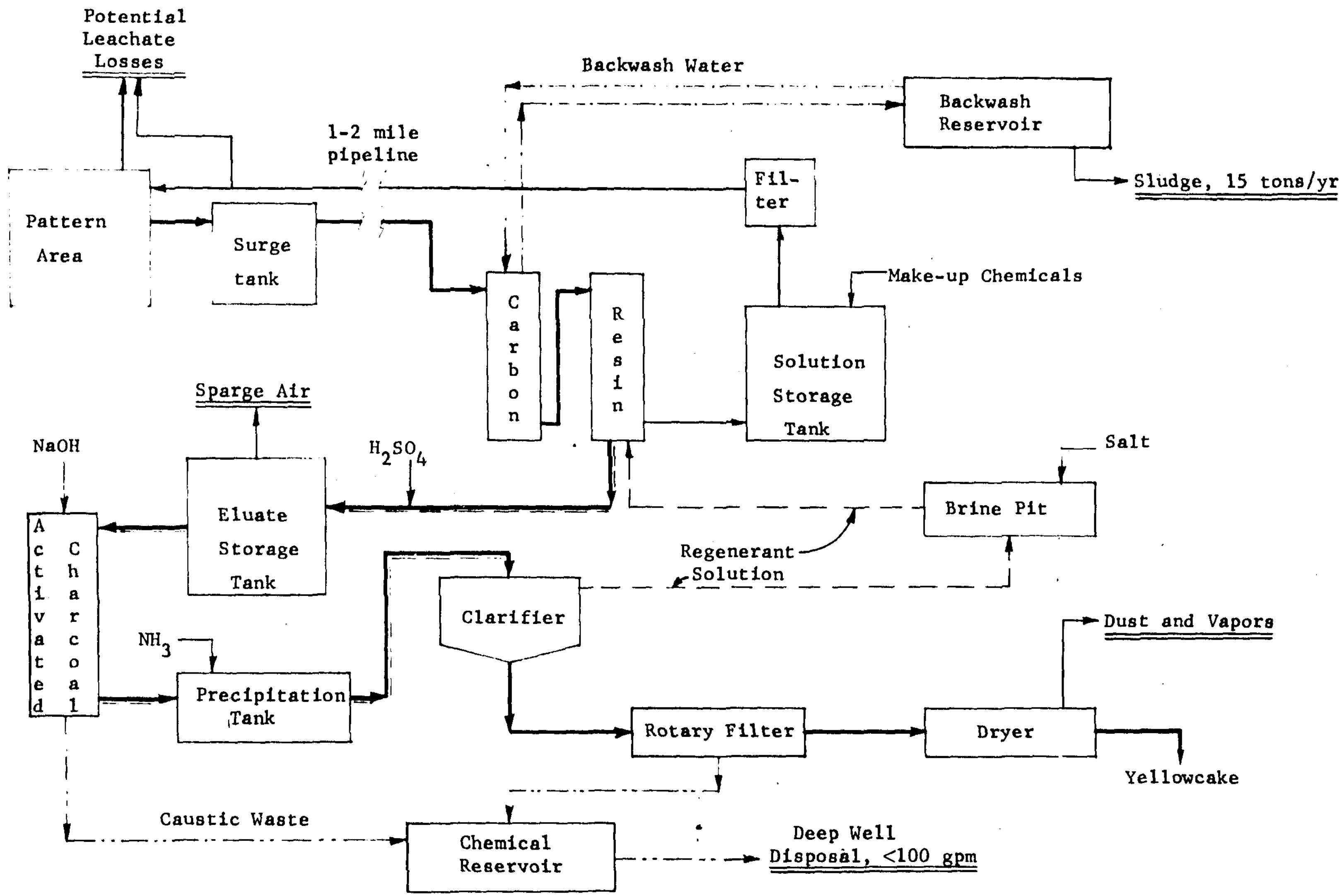


Figure 6. Uranium extraction flowsheet, in-situ mining process.

SECTION 6

RECLAMATION

DISTURBED AREAS

The objective of reclamation is to reconstitute the disturbed area in such a manner that when operations end all of the disturbed land will be suitable for alternative uses.

Spoils

Many of the known uranium deposits in the United States occur in areas where efforts to reclaim disturbed areas may be expected to meet with rather severe problems. The Wyoming Basins and Colorado Plateau areas have low rainfall, generally 25 cm (10 in.) or less, and thus the soils are poorly weathered and leached and vegetation has not been prolific enough to develop reservoirs of soil organic matter. This makes reclamation doubly difficult because the disturbed soils and spoils are often not of good quality for plants and because sufficient water for plant establishment and growth may be lacking or expensive. Because they disturb much greater areas, surface mines are of much greater concern than are underground mines.

Chemical and Physical Properties--

Soil has been defined as the upper, weathered, and biologically moled part of the regolith. Another, more detailed definition is: a natural body, engendered from a variable mixture of broken and weathered minerals and decaying organic matter, which covers the earth in a thin layer and which may supply, when containing the proper amounts of air and water, mechanical support and in part sustenance for plants. These definitions are very broad. Overburden materials, except for the so-called topsoil, which make up mine spoils do not fit within either definition. This may be the case in many of the areas where uranium ore is found. These are areas where low rainfall inhibits weathering, allows salt accumulation, and limits plant and microbiological populations.

Spoils consist of the unweathered and unconsolidated rock, gravels, and allied materials which lie from the surface down to as much as 90 m (295 feet). These materials have not been exposed to weathering processes to reduce the materials to the finer sized sands, silts, and clays or to leach out salts. Neither have they had the biological activities of plants and animals to modify the soil physical and chemical properties and to add organic matter. Thus, the spoils have poor textural properties, are barren of nutrients needed for plant growth, and have no soil fauna (worms, microorganisms, and related organisms) to aerate the surface and make nutrients available.

The usual practice to overcome these problems is to cover the spoils with previously stockpiled topsoil. Where the amount or quality of topsoil make this uneconomical, it may be possible to add fertilizers and soil conditioners to the spoils and thus reestablish the productive capacity of the area. Stabilizing the spoils against erosion with chemicals is another alternative but is generally unacceptable because (1) chemical costs are high, (2) the improvement is only temporary, and (3) the chemicals seal the surface and prevent moisture penetration.

Water Relationships--

When an area of land surface is disturbed, it follows that surface water patterns are also disturbed. Where the disturbance goes deeply beneath the land surface, ground water patterns may also be disturbed. Of particular concern in reclamation is the availability of water to support plant growth. This water must come from precipitation, ground water, or be supplied by irrigation.

The fact that spoils are in piles limits their ability to retain rainfall unless the piles are graded to provide catchment basins and terraces. In addition, spoils may weather rapidly to clay or clayey materials which resist water infiltration. The result is likely to be that most precipitation will become runoff and not only fail to provide water for vegetation but also erode the piles of spoil. This is unsightly and keeps the surface from achieving the stability necessary for successful reclamation. In addition, the runoff water is likely to carry with it suspended particles and soluble salts that pollute receiving streams.

Normal open-pit mining practices seek to minimize the large spoil piles and abandoned pits by backfilling mined-out pits. Topsoil replaced on the backfill will likely not be over about 0.3 meter in thickness and beneath it will be the unconsolidated spoil as described above. Thus the layer of topsoil may have nearly all of the water holding capacity and this will not be sufficient to sustain vegetation for very long. These areas and the spoil piles, also with a layer of topsoil, may require irrigation for several years before plants can sustain themselves.

There are practices in the grading of spoils which can help with water management and conservation. The forming of catchment basins and terraces to hold water on the spoils will increase the amount of runoff available to the plants as well as decrease water erosion. Another practice which has apparently been ignored is to establish a planned slope direction or aspect. It has been determined that vegetation on a north-facing slope requires only about half the amount of applied water as that on a south-facing slope. Water requirements of horizontal surfaces and east and west slopes are about intermediate between those of the north and south slopes. This relates to the angle of incidence of the sun and thus the soil temperature. Grading spoils so as to leave long north slopes should make water use as efficient as possible and reduce the length of time that irrigation is required to establish the vegetation.

Final Mining Pit

Open-pit mining leaves a hole in the ground when operations cease even though the mine is backfilled throughout its operation. The alternative would be to place the spoils generated by the opening of the mine back into this final pit. Likely this could be done only if the shape and position of the orebody made it possible to plan the mine so that the final pit was next to the original spoil pile. Even then, if the mine has operated for a number of years, the value received by digging up spoils which have become stabilized and probably vegetated is questionable.

The final pit must be considered in abandoning a mine and, unless handled properly, it will constitute a hazard to both people and wildlife. The remaining highwalls should be graded so that the sides can be walked up and down without danger to wildlife, livestock, or humans. Even in semiarid areas, an open-pit mine will probably intercept aquifers and the abandoned pit will fill with water to some depth which will depend upon the hydrostatic head in the aquifer.

In a semiarid area, as is the case where many uranium ore deposits are located, the resulting small lake could be an asset as a source of drinking water for domestic animals and wildlife if the water is not contaminated. It would be extremely attractive to these animals and, as stated above, would be hazardous to them unless properly graded to minimize the danger of drowning. Even when a pit has been properly graded, it will likely take some time for the banks to stabilize. Erosion of the banks by rainfall and sloughing off of materials softened by wetting from the standing water may result. To minimize this, the banks should be planted to soil-holding vegetation, preferably grass, and then monitored until establishment is successful.

Tailing Ponds

The tailings themselves should be of little or no concern in a discussion of reclamation because they should be completely stabilized and covered with up to 0.6 m (2 feet) of soil when milling operations cease. Great care is taken in the design, preparation, and management of tailings ponds to prevent radioactive liquids and radon air emissions from being released to the environment.

The actual area to be reclaimed will be larger than the pond itself because an adjoining area will have to be scraped to provide the soil cover for the pond. Such a scraped area, in a semiarid environment, is extremely difficult to reclaim because the newly exposed surface lacks the characteristics of a developed soil. Reclamation of these areas will encounter the same problems as spoil piles.

STABILIZATION

Spoils

The digging and piling of mine overburden usually leaves fine-textured and easily eroded materials on the surface and, at the same time, allows these materials to dry out. These piles are thus subject to wind erosion. They are also subject to water erosion because the materials are unconsolidated and because natural drainage channels no longer exist.

Tailings

The objective in stabilizing tailings is different from that of spoils and thus the methods to be used are likely to be different. With tailings, the concern is the escape of radioactivity while, with mine spoils, stability must be achieved to permit vegetation to become established.

Tests have been made of various chemical treatments for sealing the surface of tailings primarily to prevent wind erosion. A study was conducted by the Bureau of Mines, Salt Lake City Metallurgy Research Center on tailings at Tuba City, Arizona.[19] Materials used were an elastomeric polymer and a calcium lignosulfonate. These were sprayed on the dried ponds as aqueous solutions where they formed crusts which were strong enough to prevent wind erosion and which, upon drying, were insoluble in water. The persistence of these crusts needs to be evaluated. The direct cost of materials and their application was about $827 per hectare ($335 per acre) in 1969, while the cost to cover tailings with soil and rock at other locations was from $2,717 to $12,350 per hectare ($1100 to $5000 per acre). Reclamation of the tailings area of Exxon's Highland Mine, upon cessation of operations, was projected in 1973 at $2,470 per hectare ($1000 per acre). This will include allowing the free water to evaporate and covering the surface with 0.6 meter (2 feet) of soil into which sufficient limestone has been mixed to neutralize acid which may move up into the plant root zone. The area will be planted to grasses with medium rooting depths which will utilize most of the depth of the soil covering but not extend into the tailings.

REVEGETATION

The usual concept, a valid one, is that revegetation of a disturbed area will be most successful by using plant species that are indigenous to the immediate area. These species are at least adapted to the climate, elevation, and insolation level.

Problems emerge in two specific areas having to do with revegetation. The first is the frequent (in the past, total) lack of advance planning for future uses of the reclaimed land. The usual assumption is that the premine productivity can be restored by planting the same species that were there before mining and this becomes the reclamation program. Such a program ignores the fact that the soil and water conditions and relationships will be so disrupted by the mining activity that these same species may not now be adapted and they may not even survive the new conditions. In the semiarid areas of the country, particularly the southwest deserts, restoration of premine conditions is a restoration of range to a low level of productivity. A specific problem area is that of management of plant species suitable for reclamation. Indigenous plant species should be the most successfully established. However, many of the desirable plant species are poor or unreliable seed producers, they are slow to become established, they produce low yields, and they do not respond well to management.

Normal soil, even in dry climates, has a high population of soil fauna and microorganisms which are necessary for plant growth. These organisms break down organic matter so that it can be recycled as plant nutrients and they also mix and aerate the soil surface. In the stripping operation, the overburden materials are so mixed and inverted that there is little chance of a viable population of the soil-born organisms remaining. Even when the original topsoil is stockpiled, these organisms are likely to die out in all but the surface of the stockpile. The result is that when the topsoil is spread over the graded spoils, the soil organism populations may be lacking or so greatly reduced that normal soil functions are greatly delayed.

The spoils may quickly become inoculated with the microorganisms (fungi, bacteria) from their being carried by the wind from surrounding areas; however, the re-introduction of soil invertebrates may be quite slow.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT This research program was initiated with the basic objective of making a preliminary assessment of the potential environmental impacts associated with the mining and milling of domestic uranium ores. All forms of pollution except radiation were considered.

The program included a review of the characteristics and locations of domestic uranium ore reserves and a review of the conventional methods for mining and milling these ores. Potential environmental impacts associated with the entire cycle from exploration and mining to recovery and production of yellowcake are identified and discussed. Land reclamation aspects are also discussed.

The methods currently used for production of yellowcake were divided into four categories - open pit mining-acid leach process, underground mining-acid leach process, underground mining-alkaline leach process, and in-situ mining. These are discussed from the standpoint of typical active mills which were visited during the program. Flowsheets showing specific environmental impacts for each category are provided.

It was generally concluded that the use of tailings ponds and deep well injection to dispose of the more toxic chemical wastes represent the major impacts which should be considered in future environmental studies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Surface Mining, *Underground Mining *Waste Treatment, *Waste Disposal, *Mine Water, *Seepage, *Stabilization, Research and Development, Surface Water, Underground Water, Industrial Plants	*Mining Wastes, *Leachability of Solids, Physical Upgrading, Suspended Solids, Revegetation.	05A 13B 05B 05C 05D 05E 08G

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