UMR-MEC Conference on Energy / UMR-DNR Conference on Energy

13 Oct 1977

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Recommended Citation

Tibbs, Nicholas H.; Rath, David L.; and Donovan, Thomas K., "The Environmental Effects of Uranium Exploration and Mining" (1977). *UMR-MEC Conference on Energy / UMR-DNR Conference on Energy*. 263.
https://scholarsmine.mst.edu/umr-mec/263

THE ENVIRONMENTAL EFFECTS OF URANIUM EXPLORATION AND MINING

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Abstract

Uranium exploration and mining is increasing as the Nation's demand for energy grows. The environmental impacts associated with this exploration and mining are not severe and compare favorably with impacts from the production of other energy resources.

1. INTRODUCTION

According to the Energy Research and Development Administration (ERDA), in 1976, 8,900,000 tons of uranium ore containing 13,700 tons of U_3O_8 was processed in the United States. Production of uranium concentrate totaled 12,700 tons U_3O_8.[1] Future demand is expected to rise to between 47,100 and 66,100 tons depending upon decisions on fuel reprocessing. Cumulative demand by 1990 will amount to between 452,900 and 574,100 tons.[2] Clearly, a concerted effort will be required to discover and mine this energy resource at an accelerating rate. Two questions involved are: What is the probable cost to the environment of this exploration and mining, and how do these environmental costs compare with those from other energy sources? This paper represents a combination of current practices and suggestions for future operations. The opinions expressed herein are those of the authors.

2. DISTRIBUTION OF URANIUM DEPOSITS

Uranium exploration and mining are concentrated in the western United States. New Mexico (37 percent) and Wyoming (36 percent) are the principal producers with Texas, Colorado, Utah, and Washington also producing important quantities of ore. The typical uranium mining area is arid to semi-arid and sparsely populated, and includes some of the most desolate and some of the most scenic parts of the country. The major thrust of exploration remains in these established uranium producing areas. But, with the increasing demand and with contributions from such programs as ERDA's National Uranium Resource Evaluation (NURE) program, it must be expected that other new and major uranium-producing areas will be identified in environmental settings different than those discussed herein.

3. EXPLORATION

Drilling in 1976 was reported at a total of 34,200,000 feet. About 60 percent of this drilling was for exploration while the balance was for development (detailed outlining of ore deposits).[3] With increasing exploration coupled with decreasing discovery rates, there is a potential for exploration activities to involve increasingly larger tracts of land.

Exploration commences with nondestructive techniques. Literature searches are made followed by field visits to promising areas with spot checks for anomalous radioactivity. Geophysical techniques such as aerial gamma surveys are used to survey large areas. Finally, when promising target areas are identified, broad spaced drilling commences. Eventually, as the target is bracketed, drill hole spacing is decreased. When ore is being outlined in detail, spacings of less than 30 m often are employed. Drilling varies in depth from less than 30 m for shallow targets to in excess of 1,000 m for some deep deposits in New Mexico.

Most exploration occurs on Federally managed lands, and special requirements must be met before the surface is disturbed. The areas to be affected must be surveyed for cultural resources. Appropriate agencies must be consulted to determine critical habitat for endangered or threatened species. The most effective mitigation of impacts to these resources during the exploration phase is avoidance of any identified critical areas.

Surface disturbances associated with uranium exploration are relatively minor. The standard practice is to level a site as necessary for a portable rotary drill rig. If drilling penetrates below the water table, as is usually the case, drilling mud is necessary. Usually, a small pit is excavated at the site to allow drill cuttings to settle out of the drilling mud. For shallow holes, a portable steel tank frequently is used for this purpose. The entire drill site should not exceed 0.1 ha. To gain access to drill sites, minimal roads are constructed or a cross-country route is used.

The principal impact of surface disturbance is visual. Unreclaimed sites have an aesthetic impact, particularly from the air, because of their regular spacing. Drill sites on mountainsides can be visible from a great distance, and, if improperly reclaimed, serious erosion problems can develop in areas of high erosion potential. However, reclamation effectively mitigates these impacts. Contouring, scarification, and revegetation with appropriate species followed by seasonal inspections effectively mitigates surface impacts.

Drilling frequently intersects one or more critical aquifers. Care must be taken to avoid cross-contamination of aquifers of different quality and depressuring of deep artesian aquifers. Current practice generally consists of leaving a column of specially prepared drilling mud in the borehole and plugging the hole at the surface. Some states require plugging between aquifers. These practices effectively mitigate ground water impacts from drilling.

4. MINING METHODS

Open pit and underground mining accounted for roughly equal portions of production in 1976. About three percent of total production was supplied by other methods.[2] Notable among these is in situ leaching or solution mining.

Because of higher ore recoveries and favorable economics, open pit mining is the preferred method of mining shallow ore deposits. Open pit design and development is similar to that used for other resources but smaller in scale (see Figure 1). Topsoil is stripped and stockpiled separately for later reclamation. During the initial open pit development, overburden is stripped and stockpiled on the surface. As the pit advances, material handling is minimized by backfilling overburden to the mined out areas of the pit.

Underground mining methods are employed when ore depths are too great for surface mining. The modified room and pillar technique is generally the preferred method of extracting the ore (see Figure 2). The proportion of uranium produced by underground mining has been increasing in recent years as shallow deposits become depleted. Because of the higher capital costs of underground mining, ore bodies must be larger than for surface mining. Minimum grade minable by underground methods must also be higher than for surface mining. Consequently, resource recovery is less in underground mining.

As previously mentioned, in situ leaching accounted for a small fraction of 1976 uranium production. This production was principally in southern Texas, but the method is also being employed in Wyoming. This technique will account for an increasing portion of production in future years as more experience is gained and the technology advances.

In situ leaching permits a greater recovery of resources than conventional mining because lower grades and smaller deposits can be mined. Also, deposits otherwise inaccessible because of unstable ground or excess water can be mined by in situ leaching. However, a deposit must be of the permeable sandstone type and within the zone of saturation. A significant advantage of in situ leaching is the elimination of large volumes of waste rock, about 600 kg/kg U_3O_8, which is left in place.

In the in situ leaching method, illustrated in Figure 3, a dilute solution is introduced into a sandstone-type ore deposit through cased injection wells, constrained to flow through the ore deposit by carefully controlled hydrologic conditions, and produced through other cased wells. During its passage through the ore, the lixiviant dissolves uranium which is then recovered by a small surface plant. Following uranium recovery, the barren lixiviant is reconstituted and recycled to the injection wells. A generalized flow sheet for the entire process is shown in Figure 4.

In practice only a small part of an ore body is being leached at one time. New injection and production wells at spacings of as much as 30 m are installed as older portions of the well grid become depleted in uranium. Depleted parts of the ore host aquifer are restored principally by flushing with several volumes of ground water. Following restoration of the aquifer, the wells are filled with cement, the casing is cut off below the surface, and the surface is reclaimed.

5. ENVIRONMENTAL IMPACTS

Of the mining methods discussed above, open pit mining disturbs the most land. However, the affected areas are generally range land suitable only for low density stock grazing. Thus, economic losses to agriculture are small as a result of this land commitment.

The surface disturbance caused by underground mining is very small compared to open pit mining. A shaft site requires only 15 to 25 ha and produces millions of kilograms of uranium.

Surface disturbance required for in situ leaching is minimal. In reality it is little more than that which is associated with development drilling of an ore body. The surface plant is relatively small and has little visual impact. Disposal of the surface plant waste streams by evaporation usually requires a pond of about 40 ha which must be designed to prevent seepage. Total facility size, including leach field, should not exceed 80 ha. It should be noted that this facility produces yellow cake (U_3O_8) which in conventional mining must be produced in uranium mills.

In most cases the land commitment for mining is temporary and the affected area can be reclaimed to its previous condition as discussed below. Under effective state regulations, the amount of permanently committed land is insignificant in comparison to the energy resource produced.

Practically all new ore discoveries are in aquifers. Many of these are potential sources for domestic and public water supplies. In the arid West, impacts to ground water quality and quantity are major concerns.

In open pit mining, water encountered during pit development is removed by pumping from a sump in the base of the pit. Surface runoff from affected areas is diverted to settling lagoons. Drainage in the immediate area is routed around the pit and spoil piles by ditches.

For underground mining, it is wise to conduct a hydrologic investigation including a pumping test in the early stages of mine planning. Both engineering and environmental data can be obtained from such a test. Isolation of shallow aquifers is accomplished by grouting during shaft sinking, thus reducing the impact to local water supplies. For artesian aquifers, depressurization prior to shaft penetration may be necessary. During mining, water control is continued by draining water in the drifts to a sump at the shaft where it is pumped to the surface.

In some areas, tests of deep aquifers indicate that inflows in excess of 125 ℓ/s will be experienced. During the life of an underground mine, depending on geohydrologic conditions, the radius of influence of mine dewatering can theoretically extend out for as much as 80 km, although at this distance the drawdown would be very small. Mitigation of water supply impacts is expected by public and private concerns and plans must be developed before the impacts occur.

Water quality of both ground water and surface water should be determined before mining commences. During mining, chemicals and settling lagoons can effectively treat water for discharge. Flocculants are used to improve clarification. If present in the waste stream, dissolved uranium is removed economically by ion exchange. Barium chloride treatment precipitates dissolved radium to safe levels. The settling lagoons should be constructed to minimize leakage because of the precipitated radionuclides (principally radium-226) in the sediments.

After dewatering has ceased, the natural ground water conditions should gradually return. Some water quality deterioration may occur in the immediate vicinity of the mine because of oxidation and other chemical reactions. However, after dewatering ceases, the hydrologic gradient will continue toward the mine for a long period of time thereby confining any contamination and allowing the aquifer to return to its natural reduced state.

Protection of water resources is a principal concern in in situ leaching. The hydrologic regime of the ore deposit is investigated before leaching. In general, target deposits are in more permeable zones which are bounded above and below by less permeable strata, thus confining fluid flow to the horizontal (see Figure 3). Injection and production wells are installed by cementing the annulus between the casing and the bore from the ore deposit to the surface. This effectively prevents cross-connection of aquifers. Lixiviant is confined to the leach area by a slight excess production creating a constant influx of ground water. The entire leaching area is surrounded by monitor wells for early detection of any excursion of lixiviant. Although experience has shown excursions to be rare, in those cases which have occurred, they have been controlled and retrieved by increasing production/injection ratios near the affected monitor wells.[4]

The lixiviants used for in situ leaching are very dilute, oxidizing, alkaline or acidic solutions which would be considered non-toxic. This fact, combined with restoration procedures following depletion of the ore, assures that the host aquifer will not be adversely affected by leaching. Restoration is accomplished by flushing with ground water. When ammonia is a constituent of the lixiviant, it becomes attached to clays and a chemical flushing is required to complete restoration. The objective of restoration is to return the aquifer to baseline conditions established by preoperational sampling. Following restoration, all wells are filled with cement to assure isolation of the restored aquifer.

Since uranium exploration and mining is concentrated in the western United States, the primary impact on air quality is that of fugitive dust from wind erosion. Obviously, surface mining will have a greater impact because of fugitive dust than either underground mining or in situ leaching because of the larger disturbed areas. However, fugitive dust emissions can result from unpaved roads associated with underground and in situ operations. The most expedient control for fugitive dust is the application of water on roads, stockpiles of ore, and spoil piles. Topsoil stockpiles may be seeded to achieve temporary stabilization. Adequate site specific background information on fugitive dust should be gathered before mining operations begin to provide a comparison for operational emissions.

Another impact associated with all methods of mining is the generation of nitrogen and sulfur oxides and particulates from fossil fueled vehicles and heaters. The scale of the operations and the natural dispersion characteristic of the western uranium mining areas should preclude this impact from being significant.

The principal radiological effluents are radon and radon daughters which are blown or vented to the atmosphere in either a gaseous state or attached to particulate matter. The major sources are the ore stockpiles and ventilation exhausts from underground mines. Mine ventilation rates must be adequate to provide for miner exposure of less than 0.3 WL (working level).[5] Ore stockpiles account for approximately 75% of radiological emissions.[6] Calculations indicate that for a Wyoming mining operation offsite radiological impacts should not be significant.[7] This, of course, is dependent upon factors such as meteorological characteristics, ventilation configuration, and average ore grade. From a qualitative standpoint, surface and underground mining radiological impacts are roughly the same order of magnitude. In situ leaching, however, has less impacts since practically all of the potentially hazardous radionuclides associated with the ore are left in place.

Because uranium mining is usually conducted in areas of low population density, the influx of miners and other skilled workers not available in the local labor market can put a severe strain on community services. In addition, many areas are effected by a combination of energy related development projects. Therefore, cumulative socioeconomic impacts can be a prime consideration. Proper planning on both the state and local level, along with the increased tax revenues and payroll generated as a result of the projects, should offset these impacts. A community development program may be necessary to assure favorable living conditions for attracting new employees. In situ leaching requires fewer workers than most other mining methods. Workers with the required skills are generally available from the local labor force.

6. RECLAMATION

Reclamation is one of the most important considerations for reducing the environmental impact of mining. Without proper reclamation there can be significant aesthetic impacts. Permanent disruption of the surface can result in a long-term impact to productivity of the affected surface.

Reclamation laws vary from state to state from the extreme of no regulation to very detailed requirements. Where reclamation is required, the preferred procedure is to reclaim affected areas to previous conditions as nearly as possible. Revegetation programs are designed to reestablish native species that are desirable for cover and forage for domestic and native fauna and effective for soil and water conservation.

Because of the arid conditions typical of western uranium mining areas, revegetation is difficult to achieve.[8] Test plots of different species and combinations of species should be established and monitored during the mining program to aid in the development of reclamation plans. Because of low precipitation, time of seeding is an important element in assuring successful reclamation. Seeding should be done immediately before the time of year of expected maximum soil moisture to enhance reclamation success.[9]

Another important factor is overburden and topsoil management. Because of scarce topsoil resources, overburden frequently must be utilized to augment topsoil in reclamation. Overburden should be analyzed for constituents potentially harmful to vegetation and segregated according to its suitability.

Reclamation of in situ leaching sites is straightforward. Upon depletion of the ore body or bodies, the surface plant can be readily dismantled and all disturbed areas reclaimed. In most instances, it should be possible to obliterate surface evidence of the facility's existence.

7. COMPARISON OF IMPACTS

No energy resource can be mined without environmental effects. It is also apparent that near-term energy requirements do not permit the luxury of abandoning any of our sources of energy, particularly coal or uranium. However, the authors believe that uranium mining compares quite favorably with other energy resource production and provide comparisons below to support this opinion. Emphasis is given to coal in the following comparisons because it will be the other important energy source in the near future.

According to Rose, et al.,[10] uranium mining is safer than coal mining. Accidental deaths in uranium mining are 0.174 per 1,000 MWe; for coal mining, deaths are 0.5 per 1,000 MWe. In recent years total coal mining accidental deaths have been approximately 200 per year. Rose, et al., state that occupational health hazards are also much more serious for coal. However, the occupational risks of radiation-induced cancer to uranium miners are yet to be fully evaluated.

Land commitments in supplying a 1,000 MWe power plant for a projected lifetime of 30 years requires the mining of about 1,200,000 m^3 of uranium ore; a comparable coal fired plant requires about 62,000,000 m^3 of coal.[11] Because of the greater volumes of coal required per unit of energy, impacts associated with mining of this coal should be proportionately greater than the impacts associated with uranium mining. Because the trend in coal mining is to larger and more surface mines as opposed to uranium mining in which underground production is increasing, this disparity in environmental impacts will continue to increase. This disparity can be reduced by properly designed reclamation programs.

Open pit mining of uranium annually disturbs 7 ha/1,000 MWe. Practically all of this disturbance is temporary; about 0.8 ha is permanently committed. By comparison, coal strip mining disturbs between 40 and 800 ha/1,000 MWe, depending upon region and mining method. Much of this land is temporarily committed but certain types of surface mining such as contour mining have resulted in a relatively large permanent commitment of land in the past.[12] Recent Federal legislation should lessen future permanent disturbance.

The collectors required for a centralized solar power plant could be considered a solar mine; they would require 3,700 ha per 1,000 MWe. Another interesting comparison is that wind power would require over 20,000 ha per 1,000 MWe.[13]

As previously mentioned uranium mining is in areas of low intensity agricultural use. By comparison coal mining is being conducted on large areas of prime agricultural land in the Midwest.

Although uranium mining may require extensive dewatering, the ore zone aquifer is basically left undamaged and natural recharge should return the water level to its original elevation. In addition, in the case of underground mining, the aquifers above the ore zone are unaffected. In contrast, area strip mining of coal, principally in the west, has destroyed aquifers above the coal beds. Recharge-discharge relationships for all affected aquifers are permanently altered as a result of surface coal mining. The water quality implications of this cannot easily be assessed. However, local chemical changes in ground water are expected, and there probably will be a degradation in ground water quality.[14,15]

8. CONCLUSION

The exploration and mining of uranium do not result in preclusive environmental costs. Uranium mining results in less adverse environmental effects than the production of other near-term energy resources. With proper planning reinforced by sound regulatory guidance, uranium mining can be conducted with a minimal impact to the quality of the human environment while continuing to contribute significantly to the Nation's energy resources.

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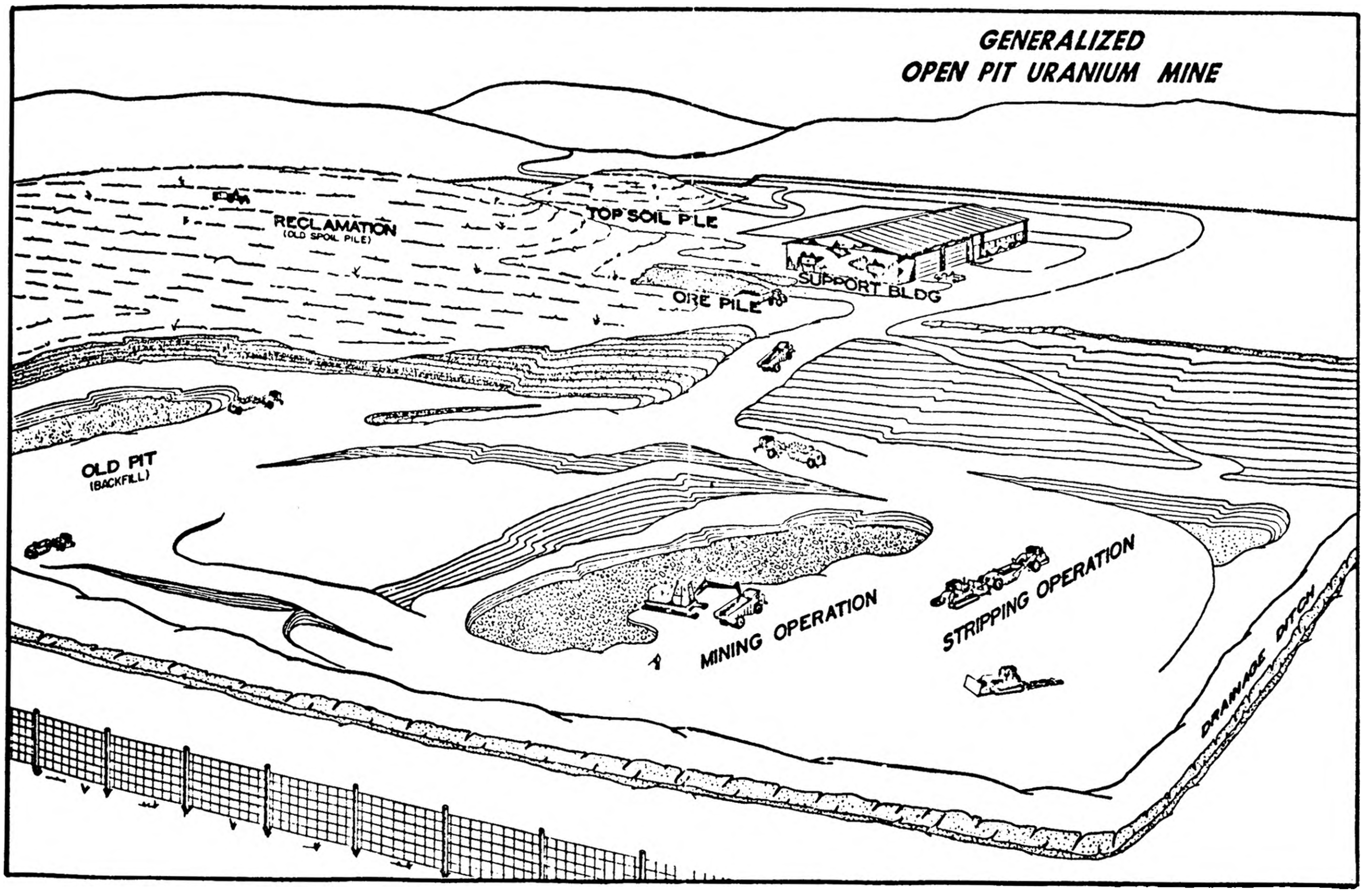

Figure 1

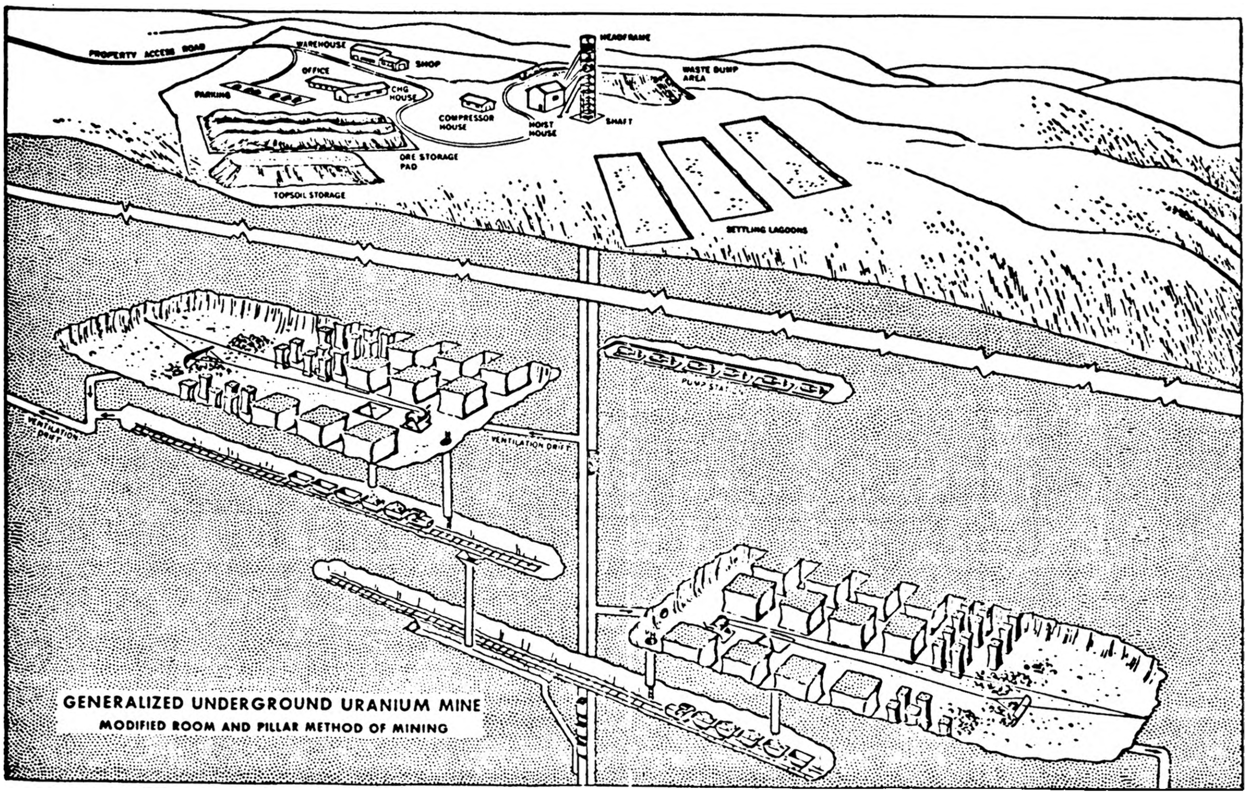

Figure 2

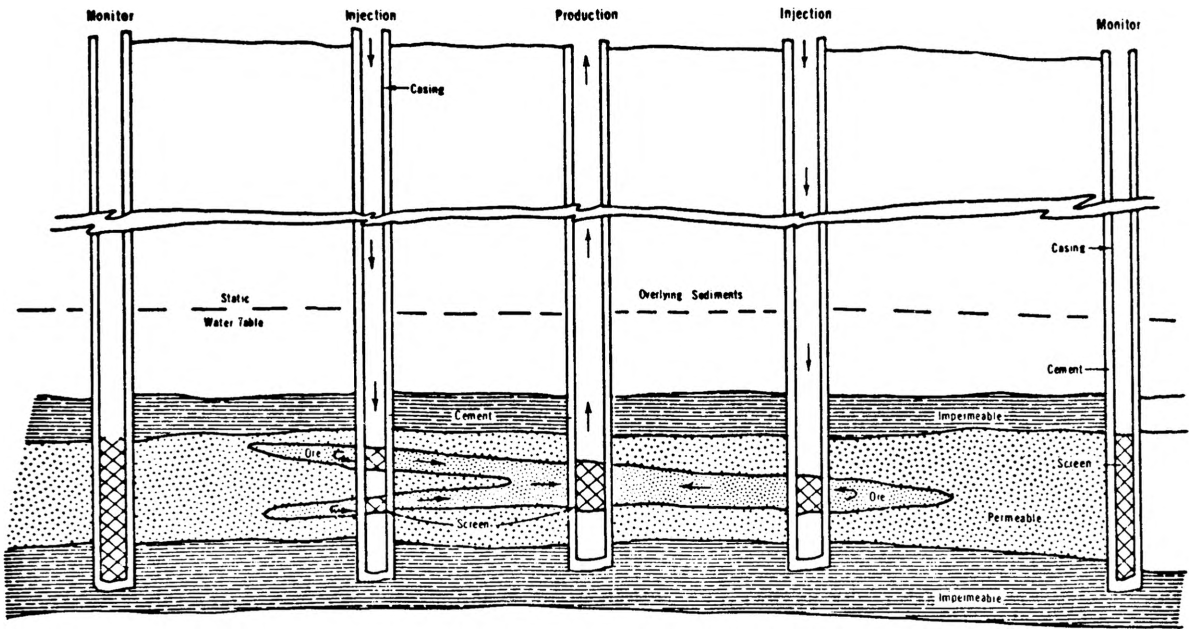

Figure 3 Cross section of a typical in situ leaching pattern

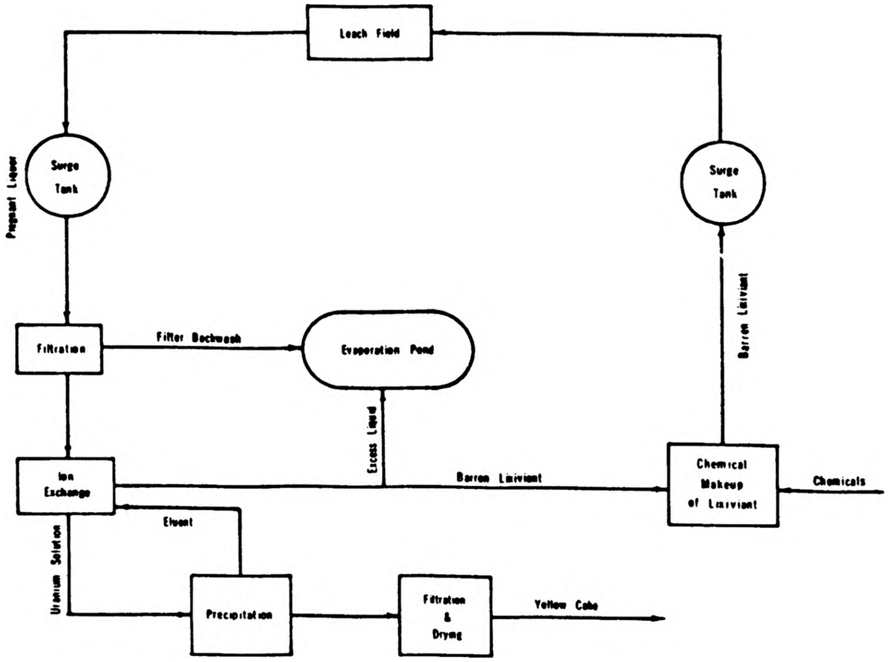

Figure 4 Generalized flow sheet for an in situ leaching project