Some Implications of In Situ Uranium Mining Technology Development

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EXECUTIVE SUMMARY

In recent years, in situ mining of uranium has emerged as a viable method for recovery of uranium from sandstone ore bodies. Since the licensing of the first commercial facility in 1975 in Texas, the industry has grown to 17 commercial operations and numerous pilot facilities in four states. Because of the technology's low capital and operational costs, persons familiar with the technology expect to see even more growth in numbers of commercial facilities and in geographic locations in the next few years. There are predictions that in situ mining will account for over 10% of the United States production of yellowcake in the near future. In those areas where in situ mining technology is applicable, it is receiving considerable attention by industry, regulators and public interest groups. According to Buma,* in situ uranium mining technology has increased the minable uranium ore reserves by three times, although this increase has not been confirmed by the USDOE estimates.

Based on the need to develop environmentally acceptable methods for energy production, including ore extraction, and the need to be cognizant of potential environmental impacts of new or expanding technologies, the Technology Assessments Division of the Office of Environmental Assessments under the Assistant Secretary for Environment in the United States Department of Energy (USDOE) initiated a technology assessment of the in situ uranium mining technology in March 1979. Various aspects of this technology assessment are being conducted by Battelle at the Pacific Northwest Laboratory and at Battelle's Human Affairs Research Center and by the Futures Group, Inc., under the direction of the USDOE. The Technology Assessment is scheduled for completion in 1981. While the technology assessment is primarily orientated toward the Office of Environment in the USDOE and concerns of primary interest to that agency, many parts of the technology assessment will be of interest to other Federal agencies, state governments, industrial firms and public interest groups.

The primary focus of the study by the Battelle research staff, which is reported here, was to explore the impediments to development and deployment of the in situ uranium mining technology and to evaluate the environmental impacts of a generic in situ facility. This report is intended to be a source document for the technology assessment.

Background information is derived from current operations in Texas and Wyoming. The data and information came from the open literature and from

* Buma, G. 1977. Uranium solution mining state-of-the-art. Contributed by the Petroleum Division of the American Society of Mechanical Engineers for presentation at the Energy Technology Conference and Exhibit, Houston, Texas, September 18-22, 1977. The American Society of Mechanical Engineers. New York.

discussions with Federal, state and local officials, public interest groups and industry representatives, from license dockets, and from a workshop conducted by Battelle staff.

In order to identify and evaluate the impacts and impediments, the first step is to describe the technology and the environment in which the technology exists. Thus, the first three chapters of the report describe the current technology, physical and ecological environment and the institutional and socioeconomic environment. Based on this description of the technology and its environmental setting, the potential impacts are identified and evaluated. Additionally, potential issues or problems that could impede development and deployment of the technology are identified and discussed. Both impacts and impediments are presented because even if the technology has acceptable or positive impacts on the physical, ecological, institutional and social environments, the impediments could still prevent or hinder the development and application of the technology.

The study reported here indicates that, based on available information, there do not appear to be any significant demonstrated negative environmental impacts. Moreover, the impacts of in situ mining compare favorably with those impacts expected from conventional mining techniques. Exposure to radioactive elements is less, atmospheric emissions of radioactive and nonradioactive materials are generally less and socioeconomic impacts are decreased. In fact, because of the generally small and unskilled labor forces associated with in situ mining, development has provided much needed economic stimulus to economically depressed areas of Texas. There are still, however, several areas of unknowns and several areas of inadequate information that will need to be addressed before a complete quantification evaluation of impacts can be made. These areas include, but are not limited to, levels of radon emissions and groundwater restoration methods and impacts. Several issues mostly relating to the interaction of industry with state and Federal regulators need to be addressed. Currently, research and monitoring programs are underway to evaluate the unknowns and increased emphasis is being placed on clearer and more frequent communications between regulators and industry representatives in efforts to address the impediments and impacts in a responsible manner.

The remainder of this summary contains brief overviews of each of the report chapters. More details on any of the aspects covered in the summary are found in the report.

TECHNOLOGY DESCRIPTION

The first step in developing an in situ uranium mining facility is to locate an ore body with sufficient uranium for economic mining. Techniques for locating and assaying uranium ore bodies are the same for in situ mining as for conventional mining methods. However, in addition to being an economically minable body, the ore body must meet several geologic criteria. These criteria are:

- complete saturation with groundwater
- permeability, porosity and hydrology that are favorable for application of the technology
- uranium form that is amenable to leaching.

Generally, a relatively horizontal bed underlain and overlain by impermeable strata is required; however, these impermeable strata above or below the ore body may not be necessary if vertical permeability is low and the other geologic criteria are met.

Once the ore body has been defined and shown to be amenable to in situ leaching, the in situ facility is constructed. The two parts of the in situ facility are the well field and the main processing facility where the uranium is recovered. In situ facilities range in size from research and development or pilot facilities which produce less than 100,000 lbs (45,360 kg) of yellowcake during the duration of facility operation to large commercial facilities which produce up to 2,000,000 lbs (907,200 kg) of yellowcake per year. The well fields are constructed in patterns that are chosen to maximize hydraulic and economic factors determined by the characteristics of the ore body. Usually the well field design is based on one of several common patterns with the distances between the wells determined by the geohydrology and geochemistry of the site. Each well is constructed to meet regulatory requirements and to prevent movement of fluid into potable aquifers. A well field can occupy from a few acres to a few hundred acres of land.

The central processing plant, which usually occupies only a few acres of land, contains processing tanks, chemical storage tanks and, when the final product is dried yellowcake instead of yellowcake slurry, may contain a dryer facility. In the southern, warmer and drier areas, the process tanks are commonly placed on a cement slab with little or no cover, whereas in the north, all processing equipment is kept inside to prevent freezing.

The uranium recovery process consists of two main circuits within which fluids are recycled. The first circuit is called the lixiviant sorption circuit and consists of injection of lixiviant into the ore body, extraction of the uranium by the lixiviant solution and sorption of the uranium in the solution onto an ion exchange column. The two types of lixiviant solutions which have been used to extract the uranium are alkaline and acid lixiviants. Ammonium carbonate-bicarbonate lixiviant, a type of alkaline lixiviant, is used most frequently because of its compatibility with the geochemistry of the ore bodies currently being mined. The second circuit is called the elution/precipitation circuit, which consists of the elution of uranium from the ion exchange column by a salt solution and precipitation from solution by addition of appropriate chemicals. This precipitated uranium solution, called yellowcake slurry, may be shipped directly to the uranium hexafluoride plant or dried to a powder, yellowcake, and packed in drums before shipping.

Since most of the fluids used in the uranium recovery process are recycled, there is very little liquid waste. The primary source of liquid wastes are 1-2% bleeds of the lixiviant and eluant streams to prevent buildup of contaminants. Other liquid waste streams include filter backwashes and scrubber system effluents. Solid wastes which are small in overall volume, consist primarily of contaminated sand in Texas and calcite sludges in Wyoming. There are also some small amounts of atmospheric emissions from release of process chemicals, evaporation from ponds, and dryer emissions. Liquid wastes are placed in lined evaporation ponds, either for evaporative volume reduction or as a holding pond before deep well injection. The small amounts of solid waste are drummed and sent to a licensed low-level burial site.

Before, during, and after operation of an in situ facility, information is gathered about the environment, potential discharges and potential environmental impacts on a regular and specified basis. These monitoring programs include surveys of the air, water, soils, plants and animals for the effects of both radiological and nonradiological effluents. There are inplant programs that monitor workers for radiological and chemical exposures, including exposure to uranium compounds. The purpose of the monitoring programs is to detect any significant change in the various parameters and allow for early mitigation before a significant impact can take place.

The monitoring of the groundwater outside the mine zone is important for detection of excursions of the lixiviant solution. An elevation of the concentration of specified groundwater constituents indicates an excursion and corrective operations can be initiated. The excursion can be corrected by overproduction, modifying the injection/production balance of the well field, or by reducing or stopping injection.

After mining of the ore body has been completed, the groundwater must be restored to a specified level of constituent concentrations. The most direct and widely considered technique is pumping the residual fluids from the well field. As pumping continues, the fluid in the ore body is replaced by groundwater from outside the well field. Pumping continues until the groundwater quality is restored to premining levels. This method, called groundwater sweeping, is very simple and effective but is highly water consumptive and results in large volumes of waste water that must be placed in the lined evaporation ponds and disposed of as other liquid wastes. Other methods that have been suggested include recirculation or clean water recycle, injection of specifically tailored fluids to aid in recovery of hard-to-remove elements or to stabilize elements. Bacterial and chemical precipitation techniques are being researched.

After all mining and restoration are completed, the buildings are decontaminated and removed. The ponds are emptied of wastes and leveled. Finally, at the discretion of the landowner, the site is revegetated with native vegetation.

ENVIRONMENTAL OVERVIEW

Uranium sandstone deposits are believed to have formed when the uranium was leached from a source material, probably granite ore bodies, and transported in a dissolved state by the groundwater. Oxygenated groundwater percolating through the source material oxidized and mobilized the uranium. As the uranium bearing groundwater moved through the aquifer, it came in contact with reducing conditions. The uranium precipitated out along the oxidation-reduction front in what is commonly referred to as the roll-type mineralized deposit.

The uranium sandstone deposits are found throughout the western United States from Washington to Texas. Because of the wide range of geological locations of deposits there is a great variation in the physical and ecological environment from areas of low rainfall (less than 8.8 cm) to areas with a large rainfall (51.6 cm). Likewise there is a wide range in vegetation community types and land uses. Generally, however, most in situ facilities are located in areas remote from large population centers and in areas of sparse vegetation (fields, pastures or rangeland). Surface hydrology consists primarily of ephemeral streams or tributaries with low flow rates. Some surface waters contain high amounts of vanadium and moderate amounts of other trace metals. Groundwater occurs in thick sedentary sequences throughout the region. The groundwater commonly contains trace and heavy metals although concentrations are usually within acceptable public health limits. Radioactive element concentrations may, however, be above standards in wells near ore bodies.

The institutional and socioeconomic environments surrounding in situ mining in Texas and Wyoming are considered for the five stages: exploration and testing, mine construction, mine operation, waste disposal, and reclamation. At each stage, the economic participants and activities, governmental participants and activities, and public interest group participants and activities may vary. One set of the participants remains involved throughout all the stages, and others are added at later stages, but once added, remain through the final stage.

The principal economic participants are either subsidiaries of large corporations or small independent operators. The subsidiaries generally belong to energy companies, although one of them is owned by U.S. Steel Corporation. The product is in demand; most of the supplies needed for production are readily available. The labor needed is generally unskilled and nonunionized; equipment -- principally water well drilling rigs -- is also available. Oil drilling rigs may not be available for mining deeper ore bodies which could constrain development of some deposits. The shortage of engineers and geologists skilled in in situ mining techniques could constrain development.

In both Texas and Wyoming, Federal, state, and local agencies are actively involved in licensing in situ facilities. Texas is an agreement

state,* therefore the USNRC is less directly involved in licensing in situ facilities than in Wyoming, a nonagreement state. The USEPA is also involved, primarily through promulgating regulations that state agencies must enforce. State agencies also impose their own regulations on the industry and local agencies have jurisdiction over roads and utilities.

Most of the governmental activity has been direct regulation of the industry. No level of government, to our knowledge, has been involved in any major support activities. The areas regulated include pollution control, occupational safety, and nuclear safety and safeguards. Concerns over use of water and its purity may result in additional regulations being developed.

Local governments, in addition to regulating the industry, have had to deal with some of its impacts. Industrial development has led to marked growth in population in certain areas, with consequent need for government services. However, in every case so far, in situ mining has been but a small addition to an already large impact from other forms of uranium production and other energy source development. One positive aspect of in situ technology development is that it allows mining of uranium to occur with a reduction in overall impacts compared to the use of conventional mining and milling techniques.

A potential new participant that has both governmental and economic interests is Indian tribes. In some areas of the country, they own large reserves of uranium that could be exploited by in situ mining techniques. Therefore, they would be owners and regulators of the resource. The development of tribal reserves would involve the Bureau of Indian Affairs as another Federal governmental participant.

Public interest group participants and activities are the same for all five stages. In general, the interest groups are either environmental groups or local residents. Environmental groups have shown mixed feelings about the in situ technology. Some environmental groups see the technology as offering a great promise for a less environmentally damaging way to exploit uranium resources. However, there is some concern that improper application of such techniques could lower groundwater quality.

Local residents generally have somewhat similar mixed feelings. The minimal visual and environmental impacts of in situ facilities make them much more attractive neighbors than open pit or underground mining. In addition,

* An Agreement State is any state which has entered into an agreement with the United States Nuclear Regulatory Commission under provisions of the Atomic Energy Act of 1954. The state then has the authority to regulate any one or more of the following materials: byproduct, source material or special nuclear material in quantities not sufficient to form a critical mass, for protection of public health and safety from radiological hazards.

they provide a new source of employment for area residents. At the same time, they make resource exploitation feasible in areas that would not have been touched without the techniques and so may upset those who want an absolutely pristine environment.

IMPACT ASSESSMENT

In situ uranium mining has been hailed as an environmentally safe method for extraction of uranium by some advocates and recommended as an environmentally desirable alternative to conventional uranium mining methods. Based on available information, our evaluation shows that in situ uranium mining operations do not adversely affect the physical, chemical, ecological, social or institutional environments as much as conventional uranium mining methods do. The rural communities experience economic stimulation that does not stress local institutions in the way in which other technologies often do with the boom/bust cycle. However, there are several areas where more data is needed before a complete evaluation can be made.

Generally, construction activities account for the greatest nonradiological impact on air quality through fugitive dust and diesel emissions. Routine operations result in only minor releases to the atmosphere of nonradiological constituents from process emissions, chemical storage tank vents and waste storage ponds. Radiological releases from the same sources are also small. The greatest source of measured radiological emissions is the dryer stack which is equipped with a Venturi scrubber. In five years of in situ facility operations in Texas, no radioactive releases have been measured at the fence line above standards of 10 CFR 20, Table II (Pers. Com. to C. E. Cowan from E. D. Bailey, Texas Department of Health, May 29, 1979). The level of radon emissions especially in the workplace is unknown at this time, although they are believed to be less than for a comparable conventional uranium mining and milling operation.

During routine operations, in situ facilities do not discharge waste waters into surface waters; therefore, contamination of surface waters should not occur. Although there is a possibility that surface waters could be contaminated by migration of contaminated groundwater, the probability is believed to be remote due to the existence of systems for monitoring for excursions, techniques and requirements for restoration, and geochemical processes which are believed to limit migration of contaminants.

Groundwater contamination from mining is unlikely because of excursion monitoring, restoration and natural geochemical processes. Seepage of waste water from ponds is also unlikely because of the use of lined ponds and leak detection systems. However, there are potential adverse impacts on the groundwater due to withdrawal of water during mining and especially during restoration. Continuous withdrawal of water during mining could affect other local users through lowering of water levels and depletion of water resources. Restoration withdrawals are large enough to seriously impact neighboring water supplies and could influence groundwater flow patterns and quantity of flow for considerable distances.

Due to the very small amount of surface area disturbed during construction and operation, loss of flora and fauna will be minor. There will also be some minor impacts on fauna due to noise and traffic. Effects of effluents on flora and fauna are judged to be minor based on past experience.

In situ uranium mining is a safe industry for occupational workers. Although no documented information was available, many plant operators stated that occupational exposure to chemicals is kept well below regulations. Radiological exposure is very low. In fact, in eight years of operation, no incident involving occupational exposure has occurred which has resulted in restricting workers activities or working hours.* Likewise, public exposure to either radiological or nonradiological chemicals is even lower and has never been above standards (10 CFR 20) or resulted in restrictions on the in situ uranium mining facility.

As the technology spreads into new regions or experiences rapid growth in areas where it already exists, impacts on the institutional and socioeconomic environment are likely to occur. Institutional impacts include legal impacts, organizational impacts and political impacts. Socioeconomic impacts include business impacts, fiscal impacts, psychological impacts, and sociological impacts. All of these impacts, expected to occur from any single in situ mining facility, are likely to be far smaller than those arising from more conventional uranium mining techniques. However, since in situ mining techniques allow operations on a smaller scale, more areas may be affected and multiple facilities may occur in a given uranium-bearing area.

Legal impacts can include legislation or litigation aimed at settling legal issues arising from the mining technology or its effects. Experience in Texas and Wyoming suggests the following impacts are possible:

- New interpretations of existing laws may be needed.
- New laws that exempt or specifically address in situ mining techniques may be required.
- Legislation to assign agency jurisdiction over new activities may be required.
- The question of regulation on Indian Lands may need to be resolved.

Organizational impacts include changes in the existence or operation of organizations. The principal impact of this type associated with in situ mining is to require the creation of a new agency or the modification of an existing one to regulate it. The regulations, expertise, and resources of the

* Hunkin, G. G. 1979. Uranium in-situ mining: a report to the Royal Commission of Inquiry concerning the health and environmental protection - uranium mining. Hunkin Engineers, Inc., Littleton, Colorado.

existing agencies may not be appropriate to this new mining technique. Until responsibilities are clearly assigned, organizations may overlap in jurisdiction. For instance, it took an interagency memorandum to resolve whether the Occupational Safety and Health Administration (OSHA) or the Mine Safety and Health Administration (MSHA) should protect the workers at in situ facilities who are now governed by MSHA.

Political impacts include the use of the political process to express opinions about the technology or its effects. Some of the following impacts are possible:

- Opposition to in situ mining based on threats to groundwater could arise.
- In situ techniques could provide a new focus for those who oppose nuclear power generally.
- The spread of nuclear activities to new areas made economically feasible by in situ techniques may create controversies in states that have not had such controversies before.
- The influx of newcomers into usually remote areas is apt to have effects on the political activities of local communities.

Business impacts are effects on business operations. The following are likely:

- Competition for labor and equipment, especially skilled engineers and more powerful drilling rigs.
- Increased competition for unskilled workers between in situ mining facilities and local businesses.

Fiscal impacts include effects on governments resulting from efforts to provide basic services and raise revenues by which to do so. The following are possible:

- Local governments may experience strains if they are asked to provide basic services to an increasing population.
- Local governments may have to provide new services as well as expanded levels of old ones.
- In situ facilities, because of their capital intensity (cost for capital exceeds cost for labor), may provide more revenue per impact (e.g., school, police) than would other facilities.

Psychological impacts include changes in perceptions, attitudes, beliefs, and behavior. The following are possible:

- Landowners may be more willing to allow in situ mining on their land than mining that disrupts the landscape.
- In situ techniques may make uranium mining activities more acceptable because in situ activities are less visible.
- Increased in situ activities could create worry and may create opposition among those who were previously untouched by any form of nuclear activity.

Sociological impacts include effects on the structure or nature of communities, social institutions, and lifestyles. Experience in Texas and Wyoming suggest the following:

- Radical changes in lifestyles or sociological patterns are not anticipated from any one in situ facility.
- Economic changes resulting from in situ operations may slow down or reverse other sociological changes that may have otherwise occurred, such as large-scale migration to urban areas in search of higher paying jobs.

IMPEDIMENTS

It is important to be aware of not only the potential environmental impacts of the in situ uranium mining technology but also of any problems or issues that may act to varying degrees as constraints or impediments to the development and deployment of the technology. The list of issues and explanatory information given below was developed from the literature, informal interviews with regulatory and interest group representatives and data collected at a workshop held in Corpus Christi, Texas in November 1979.* These issues have been categorized into major, minor and latent issues in the report based on the extent to which they constrain or impede the technology. In this summary the major issues are emphasized.

The major environmental health and safety issues are concerned primarily with various aspects of groundwater restoration. These issues include consumptive use of groundwater, nitrate-nitrite formation in groundwater due to use of ammonia lixiviants, ammonia/nitrate persistence during restoration, acceptable/reasonable standards for groundwater restoration limits and for evaluation of restoration capacity. The major institutional and socioeconomic

* Cowan, C. E., and M. A. Parkhurst. 1980. Proceedings of Workshop on In-Situ Uranium Mining Technology. November 28-30, 1979, Corpus Christi, TX. CONF-791191. TIC, Oak Ridge, TN.

issues are concerned primarily with the interactions between government regulators and industry. These issues include uncertainties about standards and criteria, understanding and knowledge of in situ technology, exchange of technical and other related information, current enforcement practices, and acceptable restoration goals.

At present the exact restoration goals are not clearly defined and regulations vary significantly from agency to agency. Restoration is defined as the reduction of the quantity of dissolved minerals within the mined ore aquifer to levels that protect the environment and human health; however, there is considerable debate as to what levels are acceptable or what is necessary to protect public health and safety. Several of the possibilities discussed include:

- Restoration to baseline water quality values.
- Restoration of constituents to a given amount or percentage above baseline.
- Restoration to values consistent with defined water use category.
- Restoration to better than previous use classification if the previous use classification was due to the presence of the mined element.
- Restoration to within established water quality standards.

Restoration of the groundwater back to baseline is generally considered to be the most difficult to achieve and may be technically impossible because of physical-chemical changes in the geochemical formation resulting from uranium extraction and lixiviant ion exchange on the clays. Restoration to other levels, such as previous water use category is much less difficult technically but depends on the type of lixiviant solution used, confinement of the aquifer and other site specific parameters. Therefore, the feasibility of successful restoration depends to a great extent on the levels which are chosen as restoration standards. Very stringent restoration goals may make restoration infeasible either technically or economically and impede further development of the technology. However, adequate protection of the public needs to be assured.

The most commonly employed method of groundwater restoration is groundwater sweeping. This involves removal of groundwater from the mined zone with resulting inflow and dilution by freshwater pulled into the mine zone until the restoration goals are reached. This method is highly water consumptive and can severely impact groundwater supplies in arid areas where uranium mining occurs. Thus, a need exists to develop less water consumptive methods in order to reduce the impact of restoration on groundwater supplies. Reverse osmosis units, which remove contaminants and allow reinjection of much of the waste water, have been suggested as an alternative to groundwater sweeping; however, these units have been unreliable under field conditions. Development and demonstration of practical and economical methods for reducing the groundwater

depletion impact during restoration may be necessary before the technology can become viable in many arid areas of the country.

Currently, most in situ uranium mining operations use ammonia bicarbonate-carbonate leach solutions. However, there is a great deal of concern about the potential environmental and public health impacts of ammonia that could be converted to nitrates and nitrites. Some levels of nitrates and nitrites are acceptable in the groundwater to meet standards for the protection of public health. Nevertheless, because of these public health and environmental concerns, leach systems that do not use ammonia need to be developed and demonstrated. Non-ammonia leach systems that use sodium bicarbonate or sulfuric acid are also known to result in some environmental impacts and restoration problems; therefore, other systems may need to be developed and demonstrated to be technically effective and environmentally safe. The ideal lixiviant would be one that would oxidize the uranium, maintain it in solution by complexation and interact little with the barren host rock. No lixiviant tested to date is entirely inert to other minerals associated with the uranium.

A related concern is the restoration of groundwater quality in ore bodies already leached by ammonia bicarbonate-carbonate solutions. Removal of all the ammonia absorbed to clay particles is considered to be neither economically practical nor technically feasible using current methods. Therefore, new methods are needed to remove the added ammonia or reduce the potential for its conversion to nitrates and nitrites which could adversely affect human health.

Excursion and restoration limits usually are set by using baseline water quality values; however, groundwater has natural variability that may not be accounted for in the baseline samples. Also geochemical changes may occur as the result of removal of the uranium and trace metals which would change the groundwater equilibrium. Thus, a need exists to determine restoration limits that reflect the potential variabilities in groundwater quality and potential geochemical changes that result from leaching. Consideration must be given to potential health and environmental effects resulting from constituents remaining after restoration. In order to determine the ability to remove a given lixiviant at a given site, pilot restoration demonstration is required as part of the plant license. Several people have pointed out that since the ore body has not been mined the geochemical changes cannot be fully predicted and these pilot restorations may not adequately represent the real restoration. Thus, there is a need for definition of methods for establishing restoration goals and restoration capacity that adequately protect the environment and represent the true restoration capabilities.

Among many regulators, a certain level of uncertainty exists regarding the nature and severity of environmental impacts of chemicals and procedures associated with the technology. This may lead to uncertainty with regard to the form that new standards or regulations should take, and to uncertainty regarding the most appropriate level for criteria and standards. As learning occurs, and as studies are conducted, criteria and requirements may change in response to the findings. Also as the technology changes, criteria may change.

Among the industry, apprehension exists regarding constantly changing regulations or standards. Regulations often change too fast to allow sufficient rebuttal and are often not appropriate for certain forms of the technology. Keeping up with, or responding to, ever changing regulations, takes increasing amounts of industry staff time and resources.

Another complication of these uncertainties was noted at the November 1979 workshop. Growth of the industry may be impeded by the reluctance of companies new to the in situ uranium mining technology to initiate operations in the face of unknown future regulations. Workshop participants noted, for example, that regulators could conceivably make regulations so restrictive that compliance would be physically or economically impossible. While the uncertainty of the future regulations has not forced out companies already in production, the uncertainty has discouraged other interested companies from initiating operations.

Inflexible regulatory requirements allow regulators very little discretion in dealing with particular environmental and permitting problems associated with a particular facility. For example, in Wyoming, statutory language allows the Industrial Siting Administration only two decisions on construction either "go" or "no go." There is no conditional go ahead allowed, therefore, when a single part of a permit is incomplete, it could delay the entire project.

Many industrial representatives feel that permitting requirements are too rigid to allow the development of new variations on the technology because the regulations contain mandatory methods for doing things rather than allowing the operator the flexibility to choose the method to meet the intent of the regulations. The industrial representatives feel that the company must be able to continually adapt and refine the technology to achieve the best extraction and economics for a particular site. Regulators and public interest groups tend to be more conservative and are concerned that the new technological advances may have adverse environmental impacts that need to be regulated.

Industrial representatives have noted that regulators are not experts in the necessary fields and often do not fully understand the technology that they are regulating. Governmental and industrial representatives agreed that regulators must have adequate information and must be adequately educated about the technology before they can effectively regulate the industry. Basically, industrial representatives are concerned that regulations may be formulated from information gathered about other industries. There was a concern that, if the special needs of the industry were not considered, regulations could be promulgated that would prevent expansion into new geographical areas and impede responsible industrial growth.

The possibility of this worst case happening may be remote. Regulations in Texas have become less restrictive and more flexible in recent years. Also, the USNRC has been licensing in situ facilities for several years and bases all licenses on the most current information available and on past regulatory

experience (state and Federal) with the in situ industry. State agency requirements in Wyoming are in some cases more restrictive than the USNRC requirements.

Additional problems have arisen from outdated information: the industry has problems that the regulators may not yet understand. Because companies are focussing on getting plants on-line and have needed to keep industrial processes secret, they have not spent time educating the regulators. Education of regulators and communication with the public were considered by some workshop participants to be especially desirable with the hopes that reasonable regulations may be issued and drastic changes or "tighter is necessarily better" attitudes may be forestalled.

Based on discussion concerning the extent to which these problems (ill informed, not adequately educated regulators) occur, the participants felt that these problems are further exacerbated by high regulatory staff turnover, reducing opportunities to become knowledgeable in the field. Regulators having become educated in the technology usually leave or are transferred to a new assignment. Part of the problem is caused by agency structure that results in frequent reorganization and reassignment of personnel. Another contributing factor is the salary differential between state and Federal agencies and industry.

Regulatory problems and the reactions of environmental groups are due, at least in part, to inadequate or outdated information. First, the technology is undergoing and probably will continue to undergo, rapid and frequent changes, making constant exchange of information on state-of-the-art technology necessary. Second, in situ uranium mining is a relatively unknown technology outside the states of Texas and Wyoming where it is applied commercially. Most of the development of in situ facilities has occurred in Texas and, therefore, most of the information on environmental impacts has been accumulated in that state. Due to the agreement state status of Texas, much of the information gathered by industry, regulators, and environmentalists is not readily available to the Federal government or to groups or agencies outside Texas. In addition, the information has been gathered for Texas and may not be totally applicable to other states. Many of the participants at the November 1979 workshop recognized the need for increased exchanges of experiences and information, perhaps in workshops and conferences.

When a company or in situ operation is found to be violating a permit requirement or causing a measurable environmental impact that the regulatory agency is unaware of, the reaction of the regulatory agencies often is to increase regulations or delay permits. These changes or delays have numerous ramifications on all the companies in the industry. Recently, emphasis has been placed on punishing offenders and not punishing the entire industry.

FINDINGS AND RECOMMENDATIONS

Based on the analysis of the available information, significant negative environmental impacts do not appear to result from development and deployment of in situ uranium mining technology. Areas that are unknown or where inadequate information is available include radon emission and effectiveness of groundwater restoration techniques, including the removal of nitrates and nitrites. Research is ongoing in these areas to answer questions about environmental impact and to develop effective and environmentally safe methods for restoration. Issues impeding development and/or deployment of in situ uranium mining technology are primarily related to interactions between government regulators and industrial representatives. Some of the major issues include inadequate communication, uncertainties about criteria and requirements and definition of acceptable restoration goals. Little has been done to try to overcome these impediments.

It is, therefore, recommended that the research into methods to address the major environmental health and safety issues be encouraged and continued. It is also recommended that activities be developed for more effectively dealing with the institutional impediments and for encouraging clearer and more frequent communications between regulators and industry representatives.

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1.0 INTRODUCTION

1.1 BACKGROUND

In situ leach mining has recently emerged as a new technology for the recovery of uranium from deeply buried sandstone ore bodies or from ore bodies that are not economically recoverable by conventional mining methods (Buma 1977). In southern Texas, mining and oil companies are engaged in pilot and commercial operations, and in Wyoming commercial operations have been licensed. A pilot operation started in New Mexico at the end of 1979, and pilot operations are starting or planned for Colorado. Other states where in situ activity is anticipated are Arizona, California, Montana, Oregon, South Dakota, Utah, and Washington. In situ leaching is being pursued by many companies because it permits economically feasible recovery of otherwise unrecoverable, small, low-grade uranium reserves (Hill et al. 1978). According to Buma (1977) the advent of in situ mining and the attendant ability to mine low grade deposits economically has increased the domestic reserves of minable uranium by a factor of 3; however, this increase has not been confirmed by the USDOE estimates.

In situ mining was first proposed in 1957 for use on Colorado Plateau sandstone and a test was performed with unreported results (Toth 1978). The first modern in situ leaching operation was conducted by Utah Construction and Mining Company in 1960. Originally, an underground mine had been started at the Shirley Basin, Wyoming site. However, ground conditions were poor, rendering conventional mining methods impractical and an alternative method of mining had to be considered. From 1961 to 1963, the company experimented with well spacings, drilling and well development techniques, and several leach solutions. From 1963 until 1969, the company successfully used these techniques to recover uranium. In situ leaching was the only method of uranium production in the Shirley Basin site during the period (Larson 1978). Subsequently, the Shirley Basin site was mined by open pit methods.

The first in situ uranium mining test in Texas was apparently conducted between 1967-1971 at the Duterstat site in Gonzales County. During the 1970-74 period, numerous tests were conducted by various consortia at the Bruni site in Webb County and at the Burns and Clay West sites near the town of George West. In January, 1975, the first commercial in situ uranium mining permit in the United States was issued to ARCO for a 3-acre (1.2 hectare) site at the Clay West mine (Taylor 1978).

Since the issuance of that permit in 1975, the growth and change in the industry has been phenomenal. In Texas alone in 1978 there were 16 permits approved for approximately 1,540 production acres (623 hectares) and there were 7 additional permit applications being processed for an estimated 2,000 additional acres (809 hectares) of production (Taylor 1978). In Wyoming the Irigaray and Highland in situ sites were licensed for commercial operation by the USNRC in 1979. Pilot and Research and Development in situ facilities licensed by the USNRC numbered 12 at the end of 1978 (USNRC 1979a). In fact in 1980, in situ uranium mining methods will be producing approximately 10% of

the U.S. uranium supply (Larson 1980). Sites of in situ facilities are shown in Figure 1.1 and commercial facilities and production capacities are given in Table 1.1. In addition, Figure 1.1 indicates the major areas where uraniferous sandstone deposits are located and where in situ operations are most likely to occur.

With the growth of the in situ uranium mining industry and its potential for even more rapid growth in the future, there has been considerable debate about the benefits and costs of the technology. Proponents of the in situ process have indicated that in situ uranium mining has many economic and environmental advantages over conventional (open pit and underground) uranium mining methods. Capital investment and lead times for an in situ facility are less than those required for a conventional facility of the same production capacity (Buma 1977). The in situ operation produces less solid and liquid waste and has fewer safety concerns. However, opponents are concerned about the lack of knowledge about the long-term consequences to groundwater quality and the possibility of irreversibly harming groundwater supplies.

1.2 PURPOSE OF STUDY

Based on the Department of Energy's interest in the environmental impacts of new energy technologies and on the anticipated growth of the in situ uranium mining industry in the near future, the Technology Assessments Division of the Office of Environmental Assessments under the Assistant Secretary for Environment is conducting a technology assessment of the in situ uranium mining technology. Various aspects of the Technology Assessment are being conducted by several contractors including Battelle, at Pacific Northwest Laboratory, Battelle's Human Affairs Research Center and the Futures Group, Inc., under the direction of the USDOE. The Technology Assessment is scheduled for completion in 1981.

This report, prepared by the Battelle research staff at the USDOE, Pacific Northwest Laboratory and Battelle's Human Affairs Research Centers, is intended to be a source document for the USDOE Technology Assessment. The purpose of the study reported here is to explore the impediments to development and deployment of the in situ uranium mining technology and to evaluate the environmental impacts for a reference facility. The specific objectives are:

- to describe the current in situ uranium mining technology
- to describe the physical, ecological, institutional and socioeconomic environment
- to evaluate, based on available data, the environmental impacts and, in a limited manner, health effects
- to discuss impediments to further development of the in situ mining technology.

FIGURE 1.1. Geographic Distribution of Commercial and Pilot In Situ Uranium Mining Facilities

TABLE 1.1. Rated Capacities of Commercial Scale Uranium In Situ Leach Mining Operations--Current and near Term Projections as of May 1980

<u>Commercial Scale</u>	<u>Rated Capacity</u>	
	(lb/yr)	(kg/yr)
U.S. Steel (Clay West)	1,000,000	453,600
U.S. Steel (Burns)	1,000,000	453,600
Wyoming Mineral Corp. (Bruni)	250,000	113,400
Wyoming Mineral Corp. (Sulfur Creek)	500,000	226,800
Intercontinental Energy Corp. (Zamzow)	250,000	113,400
Uranium Resources Inc. (Longoria)	100,000	45,300
Uranium Resources Inc. (Benavides)	300,000	136,000
Mobil Oil Co. (O'Hern)	175,000	79,400
Mobil Oil Co. (Holiday-El Mesquite)	650,000	294,800
Mobil Oil Co. (Nell)	100,000	45,300
Union Carbide Corp. (Palangana)	300,000	136,000
Everest Minerals Co. (Hobson)	150,000	68,000
Wyoming Mineral Corp. (Irigaray)	500,000	226,800
Exxon Minerals-U.S.A. (Highland)	750,000	340,200
Ogle Petroleum (Bison Basin)	400,000	181,400
Rocky Mountain Energy Jt. Venture (Nine Mile Lake)	500,000	226,800
Union Oil-Power Resources Jt. Venture (Keota)	500,000	226,800

Source: Larson 1980

1.3 ORGANIZATION OF REPORT

The next chapter, Chapter 2, contains a description of the technology from exploration through groundwater restoration and reclamation. The description includes discussion of the differences between facilities and differences in process chemistry. The purpose of this chapter is to form a basis for the presentation of impacts and impediments where impacts are changes in the environment that occur as a result of the technology and where impediments are issues or problems that could potentially constrain development of the technology. Chapter 3 contains a description of the physical environment within which the technology will exist and which the technology will impact. Chapter 4 contains a description of the institutional and socioeconomic environment in which the technology exists. This discussion also points out some of the current impacts of the in situ uranium mining technology on the institutional and socioeconomic systems in the areas where in situ mining has been applied. Chapter 5 discusses the impacts of the technology on the

environment and Chapter 6 discusses the impediments to further deployment of the technology. Both impacts and impediments are presented because even if the technology has acceptable impacts on the physical and social environment and to human health and safety, the impediments will still prevent or hinder the development or application of the technology. Chapter 7, Conclusions, presents some of the research and ongoing activities addressed at mitigating impacts and overcoming impediments. Finally at the end of the report, a glossary of common in situ uranium mining terms and a list of acronyms are provided.

2.0 TECHNOLOGY DESCRIPTION

The following description of the in situ uranium mining technology provides a common point of reference for the sections describing the impacts arising from and the issues and problems impeding deployment and development of the technology. The in situ technology is an emerging and continuously developing technology. Therefore, many variations exist among facilities in chemical usage, waste disposal and waste treatment techniques, and size of processing facilities. In situ facilities range from research and development or pilot facilities which produce less than 100,000 pounds (lb) of yellowcake (45,360 kg) during the duration of facility operation to large commercial facilities producing up to 2,000,000 lb (907,200 kg) of yellowcake per year.

This chapter includes a discussion of the variation in facility design, well field construction, recovery chemistry, and waste treatment and disposal methods. This chapter also describes the environmental monitoring programs, excursion control procedures and reclamation and restoration. The generic facility that is used here as the basis for discussion of potential releases and their impacts assumes an alkaline leach method and production 500,000 lb (226,800 kg) of yellowcake per year.

2.1 GEOLOGIC AND HYDROLOGIC CONDITIONS FOR IN SITU MINING OF URANIUM

Uranium bearing ore bodies must satisfy several criteria in order to be technically suitable and economically feasible for mining using the in situ technology (Merritt 1971, Hancock 1977). These criteria are:

- a relatively horizontal orientation underlain and overlain by impermeable strata
- complete saturation with groundwater
- permeability adequate to sustain economically acceptable flow rates of the leaching chemicals
- a uranium form that is amenable to leaching
- porosity and hydrology that are favorable to application of the technology
- sufficient size of deposit and grade of ore to justify the operation.

Impermeable strata above and below the ore body may not be necessary for successful mining if vertical permeability is low and other geologic conditions are met (Nuclear Engineering International, June 1980). These criteria are designed to ensure that the flow of the leaching chemicals can be controlled and that the facility will be economically viable. Many uraniferous sandstone deposits in Texas and Wyoming satisfy these criteria. Some sandstone deposits

are not amenable to in situ leaching because of low permeability or violation of one of the other criteria. Therefore, in situ leaching cannot be applied universally to mine uranium. It is, however, a relatively straight forward technique to apply on ore bodies where it is feasible.

The most common type of uranium deposit mined using in situ methods is called the well-front or roll-type deposit and is associated with fluvial sandstone and conglomerates. Details of the geology of uranium deposits throughout the uranium mining district are discussed in Chapter 3.

2.2 EXPLORATION TECHNIQUES

Exploration techniques for deposits to be mined using in situ technology are the same as those used for conventional mining. A typical exploration program consists of selection of a favorable area, field reconnaissance, land acquisition, and ore body definition and evaluation. Ore body definition and evaluation use a combination of geologic mapping, geochemical and geophysical surveying, drilling, and logging. Each of these techniques overlaps the others to some degree.

Geologic mapping consists of determining areas where potential uranium deposits exist. Some type of remote sensing is most commonly used. Remote sensing consists of using equipment aboard airplanes or satellites to detect ore bodies through location of certain geographic features. For example, remote sensing systems have been used to examine correlations between linear features and the distribution of uranium deposits. Remote sensing techniques have also been used to examine thermal-infrared images in Texas to locate channel-filled uranium deposits in the Catahoula Tuff. Another approach that is being tested is to use Landsat images in which the computer is programmed to detect the spectral signature of a uranium deposit. The signature is then used to locate other possible uranium deposits on the Landsat images (Abshier et al. 1978, Hogg 1980).

Uranium and its decay products (e.g., radon, helium, polonium and lead) are used to locate ore deposits through geochemical surveys. Surveys examine rocks, soil, sediment, water, and gas. Rock samples may be taken from the surface or from cuttings from deep-well drilling. Rock samples can be used to determine the degree of leaching and the redox state of the ore body. Sampling of surface and groundwater can be used to determine the location of uranium deposits when the hydrologic regime of the area is known (Abshier et al. 1978, Clark 1974, Hogg 1980).

Geophysical or radiometric surveys utilize various physical properties of the ore bodies and its uranium component as a basis for locating minable uranium deposits. Among the devices used for gamma ray detection are electrometers, ionization chambers, Geiger tubes, scintillation crystals, semiconductor detectors, plastic phosphors and liquid scintillators. Other geophysical methods use indirect exploration techniques such as determination of lithologic units and structural elements, where uranium deposits may exist (Abshier et al. 1978).

Drilling is the most widely used method of exploration for uranium especially in relatively shallow deposits (Clark 1974). Most exploratory drilling is done in districts known to contain uranium deposits. Exploration drilling is initially done with 1 to 2 mile (1.6 to 3.2 kilometers) spacing. When encouraging mineralization is found, additional holes are drilled on a tighter spacing to delineate the extent, thickness, and quality of the ore (San Juan 1979, Hogg 1980).

Exploratory drill holes are usually 4 to 6 inches (10.16 to 15.24 cm) in diameter, and are drilled by conventional rotary-drilling methods using truck mounted drill rigs. Drill sites are usually about 100 by 150 feet (30 to 46 meters), or about 1/3 acre (1.4 hectares) in size. A mud pit 10 to 15 feet (3 to 5 meters) long and 5 to 6 feet (1.5 to 2 meters) wide and deep is excavated near the drill-hole location to be used as a catchment basin and recirculation pond for the drilling mud. This mud is used to carry the rock chips, or cuttings, up the test hole to the surface. Some cuttings are collected for examination of radioactive constituents and the others are disposed of in the mud pit (San Juan 1979). When the drilling is completed, the well is logged (a continuous record is made of some characteristic versus depth in the well) using scintillation devices to detect the presence of radioactive ore. Additional logs record the formation density and porosity (Abshier et al. 1978). After exploration drilling is complete and logging is accomplished, the holes are filled, sealed and capped, topsoil is replaced, and all disturbed areas are graded and planted (San Juan 1979).

Most drill holes are plugged by filling them with drill cuttings, mud, and cement. This is to seal the various aquifers from each other. By arrangement between the surface owner and the drilling company, holes that produce an adequate supply of good water are sometimes cased and equipped for stock watering or irrigation use. Drilling is performed along existing roads as much as possible. When this is not feasible, temporary roads are constructed (San Juan 1979)

2.3 IN SITU FACILITIES

All in situ facilities are designed to extract the uranium from an ore body and produce a uranium-bearing product. The facilities include a well field and a processing, or uranium recovery, facility. Many facilities contain drying equipment and produce dried yellowcake as the final product; however, some produce yellowcake slurry. Figure 2.1 shows the components of an in situ facility and indicates the major variations that may occur between facilities.

The first major variation that can exist among facilities is the location of the well field and primary extraction equipment, or ion exchange columns. The more common arrangement is to have the central processing plant located near the well field. This allows the uranium bearing solutions to be pumped directly to the processing building for uranium extraction and production of

FIGURE 2.1. In Situ Facility

the yellowcake (see Figure 2.1). At the Clay West facility (owned by U.S. Steel), several well fields are located a few miles from the main processing buildings. In this case, primary (resin) extraction takes place in satellite facilities at the well field, and the uranium loaded resins are transferred to the central processing plant where the extraction and production processes are completed (see Figure 2.1). This method allows for extraction of more ore bodies and longer useful life for the central processing plant.

The central processing plant contains the processing and chemicals tanks used to complete the uranium-recovery process as well as waste treatment and disposal sites. In many of the drier and warmer areas of the country, such as Texas, the processing equipment is placed on cement slabs and processing occurs in the open air. In the northern climates, the processing equipment is placed in closed buildings to protect the equipment from freezing.

The second major variation in in situ facilities is the form of the final product. After the uranium-bearing solution has been processed in the main processing facility, the product formed is yellowcake slurry. This product may be shipped directly to the uranium hexafluoride conversion plant or can be dried to a yellowcake powder in either a calciner or rotary vacuum dryer. The drying equipment and yellowcake packing unit are always in a closed building which is equipped with a Venturi scrubber for treating dryer and packing stack exhausts.

The largest use of land associated with an in situ facility is the well field. Well fields can occupy anywhere from a few acres to a few hundred acres. The central processing plant and dryer facility are located on less than an acre of land although much more acreage may be included in the main facility permit area. The total area occupied by the central processing plant and well field at any time is usually less than 1000 acres (4050 hectares).

2.4 WELL FIELD

The first step in the mining of a deposit consists of drilling a series of wells around the ore deposit. This well field contains injection, production, and monitoring wells. The injection and production wells are used to circulate the lixiviant through the ore and monitor wells are used to detect the contamination of groundwater outside the production area. The lixiviant is a chemical solution that oxidizes and dissolves the uranium in the ore body. Quality construction of wells and proper well spacing are extremely important in maximizing uranium recovery and containing the lixiviant within the production area. Construction techniques and well placement are specified in the in situ license (see Chapter 4).

2.4.1 Well Drilling and Casing

Injection and recovery wells usually are drilled by the hydraulic rotary technique. This technique uses a drilling fluid generally called "drilling

mud" or "mud." Drilling mud is commonly a water-based solution containing mud additives such as bentonite, guar gum, polyanionic cellulose polymers, or other special materials.

The mud lubricates and cools the drilling bit, prevents collapse of the hole walls and is used to transport drilled ore to the surface. Other agents such as air, water mist, foam, or various gasses may also serve as drilling fluid.

Injection and production wells require careful construction. The wells must be vertical and relatively straight and must be of sufficient diameter to accommodate the casings and cement. An inside diameter casing of 4 inch (10.16 cm) is commonly used and requires a borehole diameter of at least 6 3/4 in. (17.15 cm) for proper cement sealing (Tweeton and Connor 1978). A well is usually drilled to fully penetrate the ore body and may be extended somewhat deeper to accommodate plugs and casing shoes.

Various tests are often run in the uncased hole to gather data on the hole and the surrounding geology and hydrology. Electrical or geophysical logs may be run by lowering instruments into the hole to measure formation resistivity, natural gamma radiation, and natural, or self potential.

After logging has been completed, the casing material is selected. Common casing materials are polyvinyl chloride (PVC), fiberglass, and steel pipe. Of these, PVC is the most economical and, therefore, used most frequently. Fiberglass and steel are used when depth or geologic conditions warrant their use. A plastic or stainless steel screen or a slotted pipe is placed in that part of the hole where the ore body is located. A cementing basket is attached to the casing so that it will be located just above the ore zone, preferably in a shale layer. This basket forms a seal and prevents cement from flowing into the screen or slotted pipe.

Small weep holes are drilled slightly above the cementing basket, and a centralizer is placed over the casing to keep the casing in the center of the hole during cementing operations. At this point the casing is installed, section by section, in the hole. Two examples of injection-recovery well cross-sections are shown in Figure 2.2. The well on the left uses a permanent screen or slotted casing. The righthand well has been drilled using underreaming techniques and uses a retrievable screen.

After the casing is in place, a cement slurry is forced inside the casing and out through the weep holes into the annulus, the space between the casing and the borehole wall. After the cement is forced into the casing, water is pumped in under pressure forcing the cement out of the casing through the weep holes, and up through the annulus to the surface, thus, clearing the casing. A plug across the casing (Figure 2.2) prevents cement from flowing into the ore zone. Proper cementing of the casing protects against vertical migration of the lixiviant.

After well construction is completed, the screen is washed with a low-pressure water jet. Fine particles and any remaining drilling fluid are

FIGURE 2.2. Cross Sections of Two Types of Injection-Recovery Wells
Source: Larson 1978

removed from the borehole wall. Final flushing using high-pressure jetting, airlifting, mechanical surging, or chemical injection removes sand bridges and readies the well for use. (See O'Rourke et al. 1977 for a further description of well-drilling methods.)

2.4.2 Well Patterns

The well pattern spacing will determine the effective circulation, confinement, and extraction efficiency of the lixiviant solution. Well fields are laid out, after preliminary testing, to optimize hydraulic and economic factors. The hydraulic response of an ore body aquifer is estimated by determining aquifer properties using pumping or injection tests, core samples from the aquifer, and/or laboratory measurements of cores or samples. The spacing, geometric arrangement, and pumping rates of the injection and production wells can then be fit to the ore body configuration for efficient operation (Thompson et al. 1979).

Well patterns are described by the number of wells that make up a single injection and production well unit. Two common well formations are the 5-spot and 7-spot patterns. A 5-spot pattern, for example, is a square pattern with a production well in the center surrounded by four injection wells. Other well types include the staggered line drive pattern, that follows the shape of the ore body and multipliers of the five-spot and seven-spot patterns. Figure 2.3 illustrates these patterns. Modifications of these patterns depend on ore body, and groundwater characteristics. Push-pull mining is used in some cases to inject the lixiviant into the ore zone and withdraw the uranium-bearing solution from the same hole after it has had sufficient time to solubilize the uranium. Most injection wells are within 25 to 200 ft (7.6 to 61 meters) of the production wells. Computer modeling of leaching conditions for a particular ore body can be used to assist in the planning of the most appropriate well spacing for the ore body.

Monitor wells are used inside and outside the mining zone. These wells provide surveillance and define the area of containment. Some monitor wells are used to survey the water quality in the aquifers above and below the production aquifer. The location and number of monitor wells are specified in the operations permits issued by the USNRC or the state (see Chapter 4).

2.5 URANIUM RECOVERY PROCESS

The uranium recovery process follows these major steps:

- oxidation, dissolution and removal of the uranium from the ore body by the lixiviant
- extraction of the uranium from the lixiviant by ion exchange resins
- elution of the uranium from the ion exchange resins

FIGURE 2.3. Diagrams Showing the Common Injection-Recovery Well Patterns Used in Uranium In Situ Leach Mining. Source: Larson 1978

- precipitation and removal of contaminants from the uranium
- drying and packaging of the uranium yellowcake if desired.

These steps are illustrated in Figures 2.4 and 2.5. The general recovery process consists of two stages or circuits within which process fluids are recycled. These circuits are:

- lixiviant sorption circuit
- elution/precipitation circuit.

Table 2.1 contains a list of the common chemicals used for alkaline and acid lixiviant systems in each of the process stages.

2.5.1 Lixiviant Chemistry

In order to extract the uranium from the ore body, a chemical solution called the lixiviant, which is used to oxidize and dissolve the uranium, must be injected into the ore. The chemical composition and concentration of the lixiviant depends on the geochemistry of the ore body and is chosen to maximize production given the existing geochemical conditions. Considerations that are used for determining lixiviant type and strength are:

- Uranium extraction efficiency
- Effect on permeability
- Differential mobilization of impurities
- Effects of lixiviant type and concentration on ion exchange properties of the geochemical constituents
- Effects of geochemical components of the ore matrix on effectiveness of the lixiviant.

A typical lixiviant is constituted from groundwater from the ore body to which an oxidant and an acidic or basic solution is added. Table 2.2 gives examples of the concentrations of various components in the lixiviant.

There are basically two types of lixiviants, alkaline and acid, which are used to dissolve and oxidized the uranium. Each offers advantages and disadvantages to the in situ operator depending on site specific conditions such as underground performance and extractability. Each lixiviant and its advantages and disadvantages are presented below.

2.5.1.1 Alkaline Lixiviants

Alkaline lixiviants have been the most extensively used in existing in situ operations in both Texas and Wyoming. The most common lixiviants are

FIGURE 2.4. Generalized Uranium Recovery Process. Source: USNRC 1978d

FIGURE 2.5. Schematic Diagram of the In Situ Uranium Recovery Process. USNRC 1978c.

TABLE 2.1. Chemicals Used in Alkaline and Acid Leaching Processes

	Sodium Bicarbonate Leach	Ammonium Bicarbonate Leach	Acid Leach
Lixiviant	Sodium Carbonate-bicarbonate	Ammonia (NH ₃)(b) CO ₂ (b)	Sulfuric Acid(c)
Oxidant	O ₂ or H ₂ O ₂ or air Sodium Chlorate(d) NaOH (pH Control)(d)	O ₂ or H ₂ O ₂ (b) or air Chlorine	H ₂ O ₂ or NaClO ₄ (c)
Elution	NaCl(a) Sodium bicarbonate(a) Sodium carbonate(d)	Ammonium bicarbonate(b) Ammonium chloride(b) (as needed)	Nitric Acid(c) Sodium nitrate(c) Sulfuric acid (b)
Precipitation	Ammonia(a) Hydrochloric Acid(a,e) Sodium hydroxide(e) H ₂ O ₂ (e)	Ammonia(b) Hydrochloric acid(b,e) Hydrogen peroxide(H ₂ O ₂)	Lime(c) or Magnesium slurry(c) Ammonia hydroxide(f) Magnesium oxide (f)
Containment Control	Barium chloride	Sodium hydroxide(g)	

- (a) USNRC 1978d
 (b) USNRC 1978c
 (c) Clark 1974
 (d) USNRC 1979d
 (e) Thompson et al. 1978
 (f) Texas Department of Health 1978
 (g) Reed et al. 1976

TABLE 2.2. Composition of Injected Lixiviant Solutions

Component	Lixiviant		
	Ammonium Bicarbonate	Sodium Bicarbonate	Sulfuric Acid
NH ₄ (ppm)	0 - 3,500	(Baseline)(a)	(Baseline)(a)
Ca (ppm)	10 - 500	10 - 500	50 - 2,000
Mg (ppm)	20 - 200	20 - 200	20 - 1,000
Na (ppm)	100 - 2,000	200 - 3,500	100 - 1,000
K (ppm)	10 - 100	10 - 100	10 - 100
CO ₂ (ppm)	---	---	---
HCO ₃ (ppm)	850 - 10,000	850 - 10,000	---
Cl (ppm)	20 - 3,500	20 - 3,500	50 - 5,000
SO ₄ (ppm)	50 - 1,000	50 - 1,000	50 - 5,000
O ₂ (ppm)	0 - 2,000	0 - 2,000	0 - 2,000
U ₃ O ₈ (ppm)	1 - 15	1 - 15	1 - 15
Ra-226 pCi/l	10 - 500	10 - 500	10 - 500
pH	6.5 - 9.0	6.5 - 10.5	1.0 - 2.0

(a) Baseline refers to the value for that constituent found in natural groundwater.

Source: USEPA 1979

ammonium (NH_4) or sodium (Na) bicarbonates (HCO_3^{2+}) and carbonates (CO_3^{2+}). Ammonium bicarbonate-carbonate solution is the most widely used of the two solutions. Alkaline lixivants are very effective for leaching of sandstone type ores where the uranium exists as a precipitate on the surface of the sand grains. The alkaline lixivants do not dissolve as many trace minerals as the acid leach but mobilize greater quantities of naturally occurring radioisotopes and generally do not have as high recovery rate as acid leach. Alkaline solutions are most effectively applied in formations that are high in lime and carbonate content. Ammonium based alkaline leach solutions are used mostly in formations containing clays that swell upon contact with sodium. However, ammonia adsorbs (USEPA 1979) to the clay particles and becomes very difficult to remove during restoration.

In addition to the carrier substances discussed above, the solution contains an oxidant that converts the uranium to the hexavalent state from its uranium (+4) state in the ore matrix. The most commonly used oxidants include oxygen (O_2), hydrogen peroxide (H_2O_2), sodium chlorate (NaClO_4), and air. Oxidation reactions are represented in the following chemical equations:

or

After the uranium has been oxidized to the hexavalent state, the ammonium (NH_4) or sodium (Na) bicarbonates (HCO_3^{++}) and carbonates (CO_3^{++}) dissolve the uranium by forming soluble complexes. These reactions may take the form of one of the following uranyl complexes:

or

In some facilities, chlorine may be added to the lixiviant to prevent the growth of algae (Durler 1979). Additional details of lixiviant chemistry and the importance of each component of the lixiviant solution are available in the literature (Westinghouse 1977 and 1978).

2.5.1.2 Acid Lixivants

Acid Lixivants have only been used on a few pilot operations and have never been applied to a commercial plant. Sulfuric acid (H_2SO_4) has been used most extensively because of economics and availability. Sulfuric acid is most effective in leaching uranium from conglomerate ores since it can dissolve the minerals encasing the uranium. Preliminary findings also indicate that restoration of the acid leached aquifer will be less complicated than a similar alkaline leached formation (USNRC 1979c, USEPA 1979).

Acids, however, often react with clays, calcite, silica and lime to form compounds that may reduce the permeability of the formation. For example, in deposits high in lime (greater than 12%) the lime will react with the sulfuric acid to form gypsum (CaSO_4). High carbonate concentrations in the ground-water neutralize the acid and require an excessive amount of sulfuric acid to solubilize the uranium. Acids also dissolve other trace minerals from the formation (USEPA 1979). A Bureau of Mines (Tweeton et al. 1979) and other studies or publications (Phillips 1978, Loest 1979) on an in situ acid leaching project in Wyoming suggest that the concentrations of trace minerals are comparable with those concentrations found in alkaline lixiviants and that the method may be reasonable in some site-specific cases.

The acid lixiviant also contains an oxidant, hydrogen peroxide, to convert the uranium to a hexavalent state. The sulfuric acid then acts on the uranium oxide to form a uranium sulfate complex which is dissolved. Sulfuric acid appears to require the presence of iron in the deposit in order for the oxidation reaction to occur (Texas Dept. of Health 1978). The oxidation and leaching reactions associated with the acid leach process are not known with certainty. They are, however, probably represented by the following chemical equations:

Amell and Langmuir (1978) contains a discussion of the chemical reactions associated with acid leaching and the importance and role of iron in the leach process.

2.5.2 Uranium Extraction

Uranium is extracted from the ore body and readied for drying in two stages or circuits as illustrated in Figure 2.4 (page 2.11). The first stage, the lixiviant sorption circuit, consists of solubilization of the uranium by the lixiviant and extraction of the uranium from the lixiviant by ion exchange columns. The second stage, the elution and precipitation circuit, consists of stripping the uranium from the ion exchange columns, removing contaminants from the solution and precipitating the uranium from the solution. Each of these stages is described below.

2.5.2.1 Lixiviant Sorption Circuit

In the lixiviant circuit, the lixiviant solution chosen to optimize dissolution of the uranium (see Section 2.5.1) flows into injection wells, circulates through the ore body and is then withdrawn through the production

wells. While some injection processes are conducted under pressure, the most common method for injecting lixiviant solution is to create a negative hydraulic pressure in the ore zone by pumping from the production well(s) at a higher rate than the injection rate, commonly called "overproduction". This allows injection to occur without applied pressure. This also keeps a drawdown cone at the production well center. Water surrounding the area migrates into the mining zone and limits the leaching solution's ability to diffuse outside the production area, thereby minimizing lixiviant excursions.

The uranium-loaded lixiviant pumped from the ground is called pregnant lixiviant. The liquid passes through a manual control valve into a holding or surge tank prior to uranium extraction on the ion exchange resins. Hydrocyclone or sand filters may be used at this point to separate the suspended solids. The uranium is preferentially extracted from solution by the ion exchange sorption columns. These resins may be in the fixed bed, moving fixed bed, or fluidized bed configuration. Generally, there is a series of these resin beds which creates greater extraction efficiency. Saturated resins may contain 1 to 4 lb (1/2 to 2 kg) U_3O_8 per cubic foot of resin. The reaction for the resin (R) loading is likely to be one of the following:

or

The anionic resin that sorbs uranium in the extraction circuit may also pick up vanadium, molybdenum, selenium, and sulfate. The solution remaining after extraction of uranium is called the barren lixiviant. Most of it is recycled through reinjection. Before recycling, the solution may be filtered or treated by reverse osmosis or deionization to reduce contaminants to acceptable levels. The solution is reconstituted with the oxidant and lixiviant chemicals, and the pH adjusted, prior to reinjection. A bleed stream of the barren lixiviant is diverted to waste ponds prior to reconstitution so that the production pumping rate continues to exceed the injection rate. This bleed rate should be equal to the influx of groundwater into the production zone and is usually 1 to 2% of the lixiviant flow. The bleedstream becomes part of the liquid wastes produced by the operation and is discussed in Section 2.6.

The presence of calcium in the lixiviant can cause problems if it precipitates as calcite ($CaCO_3$) in a basic solution or as gypsum ($CaSO_4$) in an acidic environment. These precipitates may plug wells or interfere with the ion exchange columns. Where calcium is expected to cause difficulties, an ion exchange water softening unit may be necessary to keep the concentration level low. This unit may be installed to extract the calcium before the solution reaches the uranium extraction columns or prior to the reconstitution of the barren lixiviant. Disposal of the calcite precipitate as solid waste is discussed in Section 2.6.

2.5.2.2 Elution and Precipitation Circuit

The elution and precipitation circuit consists of a multi-stage elution column, the precipitation chemical addition tanks, contaminant control, and eluant makeup units (Figures 2.4 and 2.5). The uranium-loaded resin is fed into the elution columns where it is eluted with a chloride (Cl^-) or carbonate ($\text{CO}_3^{=}$) solution or with sulfuric acid (H_2SO_4). The chloride ion displaces the uranium ion complex in the alkaline process thereby regenerating the resin (R). The chemical reactions are:

or

or

or

The regenerated resin may be rinsed to control other contaminants affecting the extraction and elution efficiencies. The resulting ion exchange column rinse water, as well as any depleted resin, is handled as plant waste (see Section 2.6). Removal of uranium (adsorbed as uranyl tricarbonate) from the saturated ion-exchange resin is a batch process. If there are no facilities at the site to remove the uranium from the resin, the resin can be loaded into a tank on a trailer and transferred to the central processing plant for processing as described in Section 2.3 (Figure 2.1).

The uranium ion is precipitated from solution through one of several pathways. Basically, the desorbed uranium complex is reacted with acid to remove the anion complex. The uranium is then precipitated with staged additions of ammonia (NH_3), peroxide (H_2O_2), or sodium hydroxide (NaOH). Ammonia reacts with uranium to form ammonium diuranate ($(\text{NH}_4)_2\text{U}_2\text{O}_7$), ADU, as shown:

A sodium hydroxide (NaOH) precipitation process yields sodium diuranate ($\text{Na}_2\text{U}_2\text{O}_7$). Magnesia is another possible precipitant and reacts as shown below when preceded by ammonium hydroxide.

The acid leached uranium combined with ammonium hydroxide (NH_4OH) reacts in the following way:

A contamination control process prior to acidification may be necessary to keep product quality high and increase elution efficiency. Vanadium, molybdenum, selenium, and sulfate are the common contaminants stripped from the ion exchange resins with the uranium. One method of reducing these ions is by bleeding the barren eluant at an increased rate. However, this requires increased addition of chemicals and makeup water which produces more waste effluent (Section 2.6). A chemical method requiring little consumption of water uses barium chloride to precipitate the sulfates. The insoluble barium sulfate can then be handled as a solid waste. Vanadium, selenium, and molybdenum can be adsorbed by activated carbon columns. They may then be disposed of as solid waste or may be recovered as marketable by-products. The need for contaminant control depends on the composition of the ore body and the chemistry of the process.

The barren eluant may require chemical restoration to its original level before recycle to the elution column. This is done by addition of the proper amounts of salt or acid.

2.5.3 Product Drying and Packaging

The precipitated uranium is allowed to settle and then is decanted. The resulting slurry may be shipped to a uranium hexafluoride (UF_6) conversion facility, shipped to a drying facility at a conventional mill or other in situ facility, or dried in-plant (Figure 2.1). Preparation for the drying process includes a product wash and dewatering step using a centrifuge or a filter press. The rinse water is returned to the settling tank where the uranium remaining in solution may be precipitated. The dewatered, but still moist, diuranate cake contains about 50% solids. The moist diuranate cake may either enter a multihearth furnace which dries and calcines the cake converting it to yellowcake or the moist cake may be dried in a rotary vacuum dryer which does not require subsequent calcining. The yellowcake is then crushed and packaged in drums for shipment. The yellowcake product is sold by its U_3O_8 content. Most processes produce a yellowcake in the form of an ammonium or sodium diuranate. This product is about 50-85% U_3O_8 on a dry basis (Texas Dept. of Health 1978, San Juan 1979).

The entire packaging operation is enclosed in a sealed hood with a dual ventilation system. Furnace emissions are vented to a Venturi scrubber to recover the uranium. The scrubber solution is returned to the precipitation circuit. The rotary vacuum dryer has a bag-type dust filter flange system. Dust is returned to the dryer and the condensed vapor is returned to the precipitation circuit. The slurry or dried yellowcake is transported to a UF_6 conversion plant by common carriers licensed for radioactive shipment.

2.5.4. Process Chemicals

Table 2.3 shows the process chemical feed rates for the representative ammonia carbonate-bicarbonate leach systems and a 500,000 lb (226,800 kg) per year production. The values represented in this table were taken from only one facility. Chemical usage, especially of the lixiviant chemicals, is highly dependent on site-specific characteristics and these values should not be taken as absolute but rather as an indication of magnitude of chemical usage. Chemical usage values for sodium carbonate- bicarbonate leach systems and acid leach systems were not available.

TABLE 2.3. Chemical Feed Rate for Ammonium-Carbonate, Bicarbonate Leach^(a)

Compound	Feed Rate	
	Pounds per hour (kilograms per hour)	Tons per year
Lixiviant chemicals for 800 gpm (3028 l/min) injection		
Carbon dioxide (CO ₂)	75-225 (34-102)	325-985
Ammonia (NH ₃)(50%)	75-250 (34-113)	175-525
Hydrogen peroxide (H ₂ O ₂)(50%)	75-250 (34-113)	325-1100
Elution and precipitation reagents for 4.5 gpm (17 l/min) total eluant bleed		
Ammonium bicarbonate (NH ₄ HCO ₃)	35-100 (16-45)	150-440
Ammonium chloride (NH ₄ Cl)	75-200 (34-91)	325-875
Hydrochloric acid (35% HCl)	25-70 (11-32)	110-305
Ammonia (NH ₃)	5-20 (3-9)	22-90

(a) Source: USNRC 1978c

2.6. PROCESS WASTES AND WASTE MANAGEMENT

The in situ process is designed to recycle process chemicals as much as possible (Figure 2.4); however, some liquid, solid and atmospheric emissions are produced. The waste streams are identified in Figure 2.4 and 2.5. This section describes the constituents of the waste streams and the common disposal methods.

2.6.1 Liquid Effluents

The amounts and constituents in liquid effluent streams depend on the chemical processes used in the plant, constituents in the groundwater and characteristics of daily operations. In general the process wastes have a low volume but high dissolved solid content. The major liquid waste streams include filter, reverse osmosis and deionizer backwashes when these are used to treat the lixiviant solutions; decant solutions from precipitation tasks, bleed or purge waters; and scrubber system effluents. If contaminant control systems are included in the plant, carbon column backwash and brine solutions from water softener systems will also become important. Other liquid waste streams that are less important in terms of volumes are regeneration washes of ion exchange columns, plant maintenance wastes, laboratory wastes and sanitary wastes. The major waste streams are indicated in Figure 2.5. During restoration large quantities of liquid wastes are generated. These are discussed in Section 2.10.

Table 2.4 gives the approximate chemical compositions for liquid waste streams from different in situ operations. Because of the small amount of data used to generate the values and the variability from site to site, they are only meant to represent the approximate composition and concentrations of constituents and not actual average values.

Two methods are commonly used for disposal of process liquid wastes. These are use of a lined evaporation pond and deep well injection. Suitability of each method to an in situ facility depends on the climate, cost and site characteristics. Generally, deep well injection is limited to in situ operations in Texas, whereas evaporation ponds are used in the other states where in situ has been applied.

Most in situ facilities have one or more evaporation ponds although in Texas these ponds are used only for temporary storage of the wastes before deep well injection. The size of the pond is determined from the estimated liquid waste flow rates, amount of rainfall and the evaporative potential of the site. The pond is lined with relatively impermeable clay or with a chlorinated polyethylene (CPE) membrane. A 30-mil CPE liner is used most frequently. Monitoring systems are also installed at the ponds to detect leakage (Section 2.7). Depending on the local evaporation rate, much of the water in the pond evaporates. At the time of site restoration, the unevaporated portions are mixed with cement, drummed and disposed of as other solid wastes.

Deep well injection is only suitable for permanent disposal of wastes at a very few in situ sites. Under Federal and state regulations (see Section 4.4) the wastes can only be injected into a deep formation of saline water where it will not contaminate potable aquifers. As the term implies, the wells are drilled 3000 or more feet deep and require special casing (see Section 4.4). Liquid waste streams are usually collected in waste ponds or tanks and mixed prior to injection. They may also be treated by reverse

TABLE 2.4. Major Constituents in Liquid Waste Streams
for Different Lixiviant Systems

Constituent	Concentration (mg/l)		
	Ammonium carbonate- bicarbonate ^(a)	Sodium carbonate- bicarbonate ^(b)	Sulfuric ^(c) acid
Ca	78 - 2,040	2,200 - 3,900	0.3
Mg	18 - 400		0.03
Na	100 - 3,400	1,000 - 1,800	7,600
HCO ₃	300 - 3,600	440 - 1,300	230
SO ₄	400 - 4,700	9 - 19	18,200
Cl	350 - 44,000	1,000 - 1,400	61
NH ₄	50 - 23,000		
Mo	0 - 100		
V	0 - 25		0.7
As	0 - 75		
K	25 - 600		
SiO ₂			1.0
Al			0.06
Free Acid			330
U ₃ O ₈	1 - 30	1-2	0.1
pH	4.0 - 9.5		
Gross α	1,000 - 15,700	1,120	0 - 140
Gross β	4,550 - 6,060	757.3	0 - 330
Radium-226	600 - 2,500	100 - 500	3 - 15

- (a) Sources: Texas Water Commission 1976, 1977a,b, 1978a,b,c,d,e, 1979
USNRC 1978a
Steingraber 1980
(b) Source: USNRC 1979d
(c) Source: USNRC 1979c

osmosis to recover all reusable liquids before injection, although this is not common practice. The amount of waste injected in these disposal wells varies from about 5 gpm to 200 gpm (19 to 757 l/min) with total volumes ranging from 2,000,000 to 9,000,000 gallons per month (7,570,000 to 34,065,000 l/min). Injection pressures range from 950 to 1200 psi.

2.6.2 Solid Wastes

Amounts and kinds of solid wastes generated by an in situ operation vary depending on the constituents of the groundwater, the chemical processes used,

the waste treatment and contamination control systems and the daily operations. Solid wastes are generated from 1) the carbonate removal process, 2) the evaporative concentration of impounded liquid wastes, 3) supplemental contaminant control, 4) sediments trapped in filters and surge tanks, 5) well acidification, and 6) daily plant operations. There could also be solid wastes generated in conjunction with the water treatment methods used to restore the groundwater after cessation of operation. Figure 2.5 indicates the major solid waste streams.

An excess of calcium carbonate is produced under certain conditions in the leaching process (Section 2.4.2). The increase in pH that occurs during the process of replenishing leach reagents results in calcite (CaCO_3) precipitate that must be removed and discarded prior to injection of the reconstituted lixiviant. This precipitated calcite will contain some contaminants, the principle one being radium (USNRC 1979a). The radium levels have been measured at between 500 and 1000 pCi/gram of waste.

A second source of solid wastes is the crystalline material formed during evaporative concentration of impounded liquid waste streams. The liquid waste streams are described in the previous section. Solid wastes generated would consist primarily of assorted ammonia and alkaline earth salts such as ammonium chloride, ammonium sulfate, calcium carbonate, and radium sulfate (USNRC 1979c).

The third potential source of solid wastes is the contaminant control systems. Requirements for contaminant control are site-specific and depend on the concentration of molybdenum, vanadium, and sulfate in the leach zone. Molybdenum and vanadium are adsorbed on activated carbon columns which may be regenerated or disposed of as solid wastes. Sulfate is usually removed by using barium salts. The barium sulfates formed must then be discharged as solid wastes (USNRC 1979c).

The fourth potential source of solid waste is sediments trapped in filters and surge tanks. These could include sand brought up with the leaching solution and chemical sludges that gradually accumulate in chemical holding tanks, especially surge tanks. These sludges include sodium chloride (NaCl), sodium sulfate (NaSO_4) and residual water. When these solid wastes accumulate to an unacceptable level they must be removed and disposed (USNRC 1979c).

The fifth potential source of solid waste is solids that result from well acidification. In some cases, the wells may become plugged by precipitated solids. Plugs are removed by acidification and the solids reprecipitated in the waste pond (USNRC 1978a).

The final identified source of solid wastes is from disposal of resins, filter medium, scrap metal, PVC piping and laboratory waste material that may be radioactive. In addition, normal operations result in unspecified quantities of uncontaminated waste such as waste paper, scrap material and sand or gravel (USNRC 1979c).

Potentially radioactive solid waste is either drummed as it is produced or is discharged to the solid waste storage pit. This pit is lined and has a leak detection system. A berm, constructed at the top of the pit, diverts runoff from rainfall into the waste pond. The storage pit is kept moist to prevent wind erosion. This also restricts radon-222 and radium-226 from becoming airborne. Periodically, the wastes are removed, mixed with concrete, drummed and shipped to a licensed radioactive disposal site. Uncontaminated solid wastes that have never come in contact with hazardous materials are buried at a landfill; metal may be sold as scrap (Durler 1979).

The amount of solid waste generated at an in situ facility varies considerably from site to site. At some facilities, such as Irigaray and Highland, the largest contributors to the solid wastes are from control of calcite, both through calcite bleed and well acidification. In some facilities located in Texas, the largest contribution is sand trapped in filters. Based on a limited amount of available data, the total solid waste generated by an in situ facility ranges up to 13 kg per kg of yellowcake produced (Thompson et al. 1978, USNRC 1978a, USNRC 1979c, USNRC 1978b, Hunkin 1975).

2.6.3 Atmospheric Emissions

The primary sources of atmospheric emissions from an in situ facility include the open surfaces of ponds and tanks, the product drying and packing unit, the internal combustion engines in vehicles and drilling rigs, dust from vehicular traffic on unimproved roads, and releases during process chemical handling.

Emissions also occur from operation of diesel and gasoline powered engines used during construction and operation. For example, trucks are used frequently in in situ operations to transport materials and to inspect equipment. Also during construction of well fields graders and drilling equipment will be used. All of these sources result in nonradiological atmospheric emissions. Table 2.5 contains a listing of the levels of primary pollutants expected from diesel and gas powered equipment operations. These values are from only one facility and only represent an indication of the level of emissions.

Table 2.6 shows ranges of values of nonradioactive emissions to the atmosphere during operations of selected components from an in situ leach facility. The values are based on a 500,000 lb/year (226,800 kg/year) yellowcake production. For most facilities there are also negligible releases of process chemicals (USNRC 1979c, Texas Air Control Board 1978, 1979). Table 2.7 shows example values for radon and uranium atmospheric emissions during normal in situ leach operations. Both sets of values were calculated for the Irigaray Project (USNRC 1979c). For the Nine Mile Lake Project, U-238 particulate emissions were projected to be 84.4 mCi/yr or 3.7×10^{-7} Ci/kg yellowcake and radon-222 emissions were estimated as 76.0 Ci/yr or 3.3×10^{-4} Ci/kg yellowcake from the dryer (USNRC 1979c). The largest documented estimate of radon-222 releases was 286 Ci/yr from the Everest Minerals' Hobson Project (Stover 1979).

TABLE 2.5. Annual Emissions From an In Situ Facility During Construction and Operations From Gas or Diesel Powered Equipment

	<u>Tons/Year</u>	<u>MT/year</u>
Particulates	0.95	0.86
CO	4.6	4.2
Hydrocarbons	1.3	1.2
NO _x	19	17.2
SO _x	1.3	1.2

Source: USNRC 1979c

TABLE 2.6. Annual Nonradioactive Atmospheric Emissions From an In Situ Leach Facility

<u>Source</u>	<u>Annual Emission Rates, 10³ lb/yr (10³ kg/yr)</u>			
	<u>NH₃</u>	<u>CO₂</u>	<u>NH₄Cl</u>	<u>H₂O</u>
Recovery processes	6-9 (2.7-4)	1500-3000 (680-1360)	30-54 (13.6-24.5)	
Calcium control unit	2-4 (1-1.8)	6-9 (2.7-4)	0.06-0.09 (0.03-0.04)	390-470 (177-213)
Calcite storage pond	2.5-3.5 (1.1-1.6)	9-10 (4-4.5)	9.5-10.5 (4.3-4.8)	~8000 (~3600)
Liquid waste ponds	9-11 (4-5)	7-8 (3.2-3.6)	27-31 (12.2-14)	~9300 (~4200)

Source: USNRC 1978c

TABLE 2.7. Annual Radioactive Atmospheric Emissions From an In Situ Leach Facility

<u>Source</u>	<u>Annual Emission Rates Ci/yr</u>	
	<u>²³⁸U</u>	<u>²²²Rn</u>
Recovery process	0.151	
Calcium control unit		0.04
Calcite storage pond		1.36
Surge tanks		76

Source: USNRC 1978c

The amounts and kinds of nonradioactive releases will vary, depending on the process chemicals used. Therefore, these values should be used only to indicate the likely range and not as absolute values. A more complete set of atmospheric emissions was not available.

2.7 ENVIRONMENTAL AND OCCUPATIONAL MONITORING

Before construction, during operation and after reclamation and restoration, monitoring programs are conducted to gather information about the natural environment, the potential facility discharges and the potential impact of these discharges upon the environment. This information is gathered in three stages: preoperational, operational monitoring and post-operational monitoring. Monitoring programs are specified as part of the license requirements for construction and operation. These programs have evolved to the present form based on the potential impacts of the in situ process. As more information on potential environmental impacts is acquired and as the technology changes, the monitoring programs will probably change. The description presented below is based on several recent license applications granted by the USNRC (USNRC 1978a,c,d, 1979c,d) and the state of Texas (USNRC 1979e). It is assumed that these procedures are currently employed.

2.7.1 Preoperation Monitoring Program

The preoperational monitoring effort is comprised of two stages. The first stage is a preconstruction environmental survey that are conducted to gather data on the quality and condition of the undisturbed natural environment. The second stage is a construction monitoring program that is aimed at identifying and mitigating any potential environmental impacts due to facility construction, e.g., soil erosion by wind or water, stream siltation, displacement and/or destruction of fauna and flora.

An important requirement of the mining permit is the collection of premining baseline water quality data from surface streams and groundwater from production, trend and monitor zones. Water sampling from the production zone is used as the basis for determining restoration goals. Baseline water quality data from trend and monitor zones provides comparative data with which to detect lixiviant solution excursions as well as to provide restoration goals in the event of an excursion. Knowledge gained from conducting the preconstruction water quality survey is used to determine which water quality parameters should be selected for continued monitoring during the construction and operational phases.

Several stream sites and test wells are sampled in the various zones, both down-gradient and up-gradient from the proposed site area. The precise locations of these test wells are specified on a site-specific basis. Baseline samples are collected from the respective stations on three separate occasions within a 2 to 3 week period and subsequently analyzed. Typical major and minor groundwater quality parameters that are analyzed in a preconstruction survey are listed in Table 2.8.

TABLE 2.8. Current Baseline Water Quality Parameters
(All units are in mg/l except pH, in units,
and conductivity, in $\mu\text{mho/cm}$)

<u>Major Constituents</u>	<u>Minor Constituents</u>
calcium	aluminum
magnesium	ammonia (as NH_4^+)
sodium	arsenic
potassium	barium
carbonate (as $\text{CO}_3^{=}$)	boron
bicarbonate	cadmium
sulfate	chromium (as Cr^{+2})
chloride	copper
nitrate (NO_3^-)	iron
fluoride	lead
silica	manganese
TDS	mercury
conductivity	molybdenum
alkalinity (as CaCO_3)	nickel
pH	nitrite (NO_2^-)
bacteriological testing	selenium
	silver
	uranium
	vanadium
	zinc

Sources of atmospheric emissions (Section 2.6.3) include processes using ammonia, the open surfaces of ponds and tanks, the product drying and packaging unit, the internal combustion engines in equipment used at the site, and dust due to vehicular movement on unimproved roads. The preconstruction survey includes determining baseline values for those air quality parameters likely to be impacted by plant construction and operation. The air quality parameters most commonly analyzed are: ammonia, ammonium chloride, carbon monoxide, hydrocarbons, nitrogen oxides, and particulates. A baseline ecological study is conducted prior to the commencement of any site construction. The study consists of sampling both the terrestrial and aquatic environments. The terrestrial survey includes transect trapping for rodents and visual counts of other terrestrial vertebrate species. Vegetation studies consist of determining by stratified sampling the vegetative cover in three 10 hectare plots.

Aquatic habitats are sampled when there is a possibility of impacts resulting from soil erosion and siltation of surface streams due to road and site construction and preparation. Parameters measured as part of the survey include identifying the (1) concentration of suspended sediments, (2) presence of stream flow, (3) abundance of aquatic organisms, and (4) presence or absence of suitable habitat for fish spawning.

In anticipation of the radiological contributions to the environment by the construction and operation of an in situ uranium mining project, the natural background level of selected radionuclides in surface water, groundwater, air, soils and vegetation is established as part of the preconstruction monitoring program (Table 2.9).

2.7.2 Operational Monitoring Program

The operational monitoring program attempts to measure the potential environmental impacts from atmospheric or liquid effluents released by the facility. The source terms for this impact analysis are identified and quantified by the concurrent implementation of an in-plant occupational monitoring program. Operational monitoring includes both in-plant occupational monitoring and out-of-plant environmental monitoring.

The purpose of conducting the operational monitoring program is to detect any significant change in the levels of various parameters over those described in the operation surveys. Early detection in most cases allows mitigation before a significant environmental impact can take place.

2.7.2.1 Occupational Monitoring

The work area environment in which work forces are present is monitored for the concentrations of chemical and radiological contaminants. External radiation received by plant workers is monitored via thermoluminescent dosimeters (TLD) which are exchanged and analyzed on a quarterly basis by a qualified service. These dosimeters are of the personnel and/or area type. If sufficient dosimetry data are collected to suggest that routine doses are well below recommended levels, the dosimetry program may be modified or terminated pending the USNRC or state approval.

During facility startup and operation, radon samples from breathing zones and/or occupied areas are taken in the vicinity of the adsorption and elution circuit, the precipitation circuit, the ion exchange (IX) feed surge tanks, the calcium reaction circuits, and any well field buildings. In addition, routine grab samples are taken to evaluate the exhaust blower effluents.

TABLE 2.9 Radiological Monitoring Program

<u>Surface and Groundwater</u>	<u>Air</u>	<u>Soils and Vegetation</u>
Gross alpha and beta	Radon-222	Radium-226
Radium-226	Radium-226	Lead-210
Thorium-230	Thorium-230	
Uranium (U ₃ O ₈)	Uranium (U ₃ O ₈)	
Radon-222		
Lead-210		

Uranium particulate samples from breathing zones and/or occupied areas are taken in the vicinity of the precipitation circuit, the dry/pack area (when in operation) and the exhaust blower. Surveys of equipment and facilities on the site are performed using a beta-gamma probe meter to monitor any buildup of radiation and identify locations of removable contamination.

Other radiological monitoring is performed before construction to identify additional work areas where airborne radioactivity levels would exceed 25% of the maximum permissible concentration (MPC) given in 10 CFR 20, Appendix B, Table II, Column I.

The potential for airborne radioactivity and external contamination is quantified by an ongoing radiological monitoring program presented in Table 2.10. Table 2.11 indicates the instrumentation that will be available at the Irigaray site to support this program (USNRC 1978a).

All radiation survey instruments are calibrated semi-annually by qualified personnel who have received relevant training by a qualified

TABLE 2.10. In-Plant Radiological Monitoring Program

<u>Location</u>	<u>Material Monitored</u>	<u>Sampling Frequency</u>
1. Adsorption and elution circuit	Rn-222 U	Monthly ^(a) Monthly ^(b)
2. Precipitation circuit	Rn-222 U	Monthly ^(a) Monthly ^(b)
3. IX feed surge tanks	Rn-222 U	Monthly ^(a) Monthly ^(b)
4. Calcium reaction circuits	Rn-222 U	Monthly ^(a) Monthly ^(b)
5. Exhaust blower effluents	Rn-222 U	Monthly ^(a) Monthly ^(b)
6. Dry/pack operation	U	Weekly
7. Well field buildings	Rn-222	Monthly ^{(b)(c)}

-
- (a) If the air sampling program reveals work locations where concentrations exceed 25% of the applicable value in 10 CFR 20, Appendix B, Table I, Column I, the sampling frequency will be increased to weekly.
- (b) If the air sampling program reveals work locations where concentrations exceed 25% of the applicable value in 10 CFR 20, Appendix B, Table I, Column I, a program will be established to determine time-weighted exposures of employees working at these locations and establish such procedures specified by Section 20.103(b)(2) to maintain employee exposures as low as reasonably achievable.
- (c) If the conditions in (b) are exceeded, sampling frequency will be increased to weekly.

Source: USNRC 1978a,c,d, 1979c,d.

TABLE 2.11. Radiation Detection Instruments

<u>Instrument</u>	<u>Radiation Detected</u>	<u>Purpose</u>	<u>Sensitivity/Range (if applicable)</u>
Eberline Instrument Corp. E-120 Survey Meter	Beta, Gamma	General survey	1400 CPM per mR/hr for Cobalt 60
Eberline Instrument Corp. PAC-4S Survey Meter (AC-3) Probe	Alpha	General survey	50-50K CPM. Alpha efficiency $\approx$ 45% for Thorium 230 α (1" dia.) source, 2 π)
Eberline Instrument Corp. RN-14 Radiation Monitor (HP-190 thin window)	Beta, Gamma	General survey	2500 CPM per mR/hr for Cesium 137. Beta efficiency: (2 π , 1" source) approximately 10% for Carbon 14
Eberline Instrument Corp. RM-19 Radiation Monitor (Ac-3-7)	Alpha	Personnel survey	2×10^7 CPM per μ Ci/ cm ² for Plutonium 239
Eberline Instrument Corp. Ms-2 Mini Scaler (Ac-3 Probe)	Alpha	Air filter par- ticulate analysis	Alpha efficiency $\approx$ 17% for Thorium 230 α (1" diameter source, 2 π)
Eberline Instrument Corp. SAC-R5 Radon Detection System	Alpha	Radon gas Concen- tration Analysis	$<1 \times 10^9$ μ Ci/ml Radon 222
Eberline Instrument Corp. Rd-14 Alpha Detection	Alpha	Sample Analysis	75% Efficiency of 2 π on plateau

Source: USNRC 1978a.

service. National Bureau of Standards calibration standards are used and performance checks are performed before each field use.

Liquid waste effluents destined for the evaporation pond are monitored for radium-226, gross alpha, gross beta and uranium at two-week intervals. The plant stack leading from the scrubber circuits for the calcining/packaging system is monitored during each shift. Control readings are recorded at least once per shift when the calciner is operating. Samples

representative of a 24-hr release rate are collected from the exhaust stack of the calciner scrubber during normal operation of this equipment on a weekly basis and analyzed for uranium.

Each in situ facility is required to develop a bioassay program taking into consideration the elements identified in the proposed USNRC Regulatory Guide 8.22, Bioassay at Uranium Mills. This bioassay program includes quarterly urinalysis and annual in-vivo lung counting for uranium of all employees assigned to the calcining/packaging operations. The routine uranium urinalysis program is supplemented by additional samples collected from employees when exposure to airborne uranium exceeds 40 MPC hours in any seven consecutive days. If any urinalysis exceeds 30 micrograms of uranium per liter, an additional sample is collected from the employee. If the additional sample confirms the earlier results, an investigation to determine the cause of the exposure is initiated. Any deviations from the USNRC regulatory guidelines must be justified and approved by the USNRC.

There is no record of the USNRC or the State of Texas requiring that the concentrations of process chemicals be monitored within the routine work areas of an in situ mining operation.

The in situ uranium mining operator is required to maintain a safety program that contains the basic elements required for, and found to be effective at, other source material extraction operations to assure that radiation exposures are kept as low as reasonably achievable (ALARA). In general, the safety program will include the following:

- Airborne and surface contamination sampling and monitoring.
- Personnel exposure monitoring.
- Qualified management of the safety program and training of personnel.
- Written radiation protection procedures.
- Written operating procedures maintained for all process operations.
- Periodic audits by highly qualified outside parties and frequent inspections to assure the program is being conducted in a manner consistent with the ALARA philosophy.

Workers wear radiation dosimeter badges, and special clothing and are trained in procedures for handling spills and accidents. Rubber or synthetic gloves, aprons, coveralls, and rubber boots are standard equipment for workers. If unexpected gross contamination occurs, the worker is instructed to shower and change clothes immediately. No protective clothing is allowed to leave the site. Workers receive special training on radiation protection.

Standard hygienic procedures for protective clothing are as follows: for any application where protective clothing is required, gloves are washed prior

to removal. Outer clothing is washed after removal. Workers wash their hands after removal of protective clothing and shower if specifically required by company rules, or if deemed necessary by their supervisor.

Pumps, pipes, or other equipment that have been in contact with concentrated uranium solutions are considered contaminated. (Such solutions include recycle and rich eluate, precipitation circuit fluid, and yellowcake slurry.) A gamma-beta survey is conducted prior to initiating maintenance. If no contamination is measured, normal maintenance procedures are instituted. However, if contamination is measured, decontamination procedures are applied, followed by a verifying gamma-beta survey. Contaminated equipment is handled with rubber or synthetic gloves with standard hygienic procedures observed. Pumps are treated as contaminated equipment while being disassembled and decontaminated. Following verified decontamination, normal maintenance procedures are used.

Workers do not enter the yellowcake slurry storage tanks or thickener for maintenance purposes except by supervisor approval and with supervisor observation. Prior to entry, air is circulated through the tank. Also prior to entry, but following the air circulation, air is pumped from the top of the tank and sampled for radioactivity. The inside of the tank and the contained materials are kept moist (water spray) to prevent solid material from becoming airborne. Rubber or synthetic gloves, overalls, and rubber boots are worn when performing any maintenance involving removal of material from these tanks or when entering the tank. Standard hygienic procedures are observed.

Contamination surveys are conducted routinely in work, eating areas and administrative offices. If surveys reveal that contamination levels exceed the USNRC standards then decontamination procedures are used.

2.7.2.2 Environmental Monitoring

Upon plant or process startup, the offsite environment is monitored to provide a rapid check of the effectiveness of process designs for effluent controls. The atmospheric, aquatic and terrestrial environments are monitored for chemical and radiological contaminants. During operation, all liquid and solid waste streams are contained in lined evaporation ponds. The waste ponds are underlain by a leak detection system. The inspection tubes for these ponds are monitored weekly for the presence of liquid. Any water taken from the detection system is analyzed for calcium, chloride, alkalinity, sodium and sulfate to determine if the pond is leaking. If a leak is detected, appropriate corrective action is initiated.

Monitor well locations involve both surface spacing and subsurface placement in order to effectively determine the containment of the leach solution. On the surface, wells are spaced around the perimeter of the well field so that any migration of leach solution (excursion) will be detected. Subsurface emplacement involves the location of monitor wells in the aquifers above and below the production zone aquifer.

Monitoring wells are sampled every two weeks during project operation. Indicator parameters that must be analyzed to establish the presence of a potential leachate excursion are: water level, conductivity, chloride, alkalinity (as CaCO_3), sulfate, and bacteria. In the event that two of these indicator parameter analyses are significantly higher than background survey levels, the well water is reanalyzed for a more complete set of parameters within 48 hrs (Kasper and Engelmann 1978). If the second analysis shows that two parameters have again exceeded the upper control limit, an excursion status for the well is established and appropriate corrective action initiated.

The in situ industry does not appear to be required to conduct a formal offsite nonradiological operational air quality monitoring program. However, a construction permit issued by the Texas Air Control Board contains the following statement:

"Emissions from this facility must not cause or contribute to a condition of 'air pollution' as defined in Section 1.03 of the Texas Clean Air Act or violate Section 4.01 of the Texas Clean Air Act, Article 4477-S, V.A.T.S."

A Texas Air Control Board official (Pers. com Pete Wright, June 24, 1980) explained that in Texas in situ uranium mining facilities qualify for Exemption 112. This exemption means that if 1/4 mile (0.4 kilometers) from the facility there are no visible or measurable emissions from the facility during operation, no operational monitoring is required.

Liquid effluent wastes are monitored for nonradiological chemicals prior to disposal into the evaporation ponds. Samples are taken every two weeks and analyzed for: ammonia, calcium, chloride, alkalinity, sodium, sulfate, carbonate, magnesium, and pH.

The radiological monitoring program consists of monitoring the air, water, soil and vegetation on a regular basis for the constituents identified in Table 2.12. Twenty-four hour, high-volume air samples are taken on a monthly basis at five site-specific sampling stations and analyzed for natural uranium, thorium-230, and radium-226. The air sampling is correlated with meteorological data to meet the intent of the USNRC Regulatory Guide 4.14 on effluent monitoring. Waste ponds and surface waters are sampled for radioactivity on a regular basis. An operational radiological monitoring program is summarized in Table 2.12.

2.7.3 Post-Operational Monitoring Program

The success and effectiveness of the restoration program is verified by collecting and analyzing water samples quarterly for the parameters listed in Table 2.8. The restoration program continues until the restored groundwater meets the levels of water quality specified in the restoration goals. The monitoring continues for one year after restoration goals are reached to verify its success.

TABLE 2.12. Operational Radiological Monitoring Program

Environmental compartment ^a	Sampling location	Sampling frequency	Constituent measured
Air	Yellowcake dryer stack	24-hr sample, weekly	Uranium, Rn-222
Surface water	Surface impoundments ^b and affected drainage	Quarterly	Uranium, Ra-226, Th-230, Pb-210, suspended solids sediment
Groundwater	Selected wells	Quarterly	gross alpha ^c , gross beta ^d
Air	Well field surge tanks	Monthly	Rn-222 or radon daughters
Air particulates	Air quality monitoring sites	24-hr sampling at monthly intervals	Ra-226, Th-230, uranium, particulates
Soils, vegetation	Air quality monitoring sites	Annually	Ra-226, Pb-210, Uranium, Th-230

(a) The water quality in the ore zone aquifer will be monitored also.

(b) Stock watering ponds and disposal ponds.

(c) If gross alpha exceeds 3 pCi/l, a Ra-226 analysis will be performed, if gross alpha exceeds 100 pCi/l, a fluorometric maximum analysis will be run.

(d) If gross beta activity exceeds 50 pCi/l, a Pb-210 analysis will be run.

2.8 EXCURSION CONTROL

Under normal operating conditions the injection and production rates are balanced to ensure that the fluids stay within the production zone as illustrated in Figure 2.6. Generally, this balance is accomplished by withdrawing five percent more lixiviant than is injected, thus, maintaining flow of groundwater into the production zone.

Excursions occur when any of the injected fluid moves outside the mining zone, either laterally or vertically. Lateral excursions within the ore-zone aquifer occur when the hydraulic gradient established by the mining operations shifts away from the well field or from any production wells. If the aquifer is anisotropic with respect to permeability or develops selective permeability directions within the ore zone, local changes or possible reversals in gradient may occur even though the net gradient is toward the well field.

FIGURE 2.6. Individual 5-spot Production Cell Flow Pattern

Monitoring wells and water quality sampling generally confirm that a lateral excursion has occurred and corrective action is needed. Lateral excursions are detected by water quality samples when a marked change in total dissolved solid or some other parameter is noted (see Section 2.7). The suggestion has been made that because of the relatively low rate of ground-water flow in ore-zone aquifers (generally 0.5 m/day) that pressure or water level changes might provide a more immediate means of recognizing a potential excursion (Thompson et al. 1978). Water quality sampling has also been used to detect vertical excursions of fluids into aquifer units above and/or below the ore zone.

Corrective action for verified lateral excursions generally consists of one or a combination of three principal techniques: 1) overproduction, 2) modifying the injection-production balance of the well field or 3) reducing or stopping injection. The purpose of these techniques is to extend the zone of influence of the producing wells to include the fluids that have moved beyond the active mining region. The corrective measures may be applied to the whole well field or locally to a well or several wells.

Vertical excursions occur when the mining fluid has moved into an aquifer lying above or below the ore-zone aquifer. These excursions may be detected by water quality monitoring wells in the overlying or underlying aquifers or by tests designed specifically to test for vertical leakage, i.e., pumping from an overlying or underlying aquifer and noting if any quality changes occur. The source or manner of occurrence of a vertical excursion may be difficult to determine, and may not be the result of a single cause. The corrective action will depend on the causes for the excursion and may require re-cementing of a poor cement job or an adjustment in injection pressures to prevent hydraulic fracturing of confining units or to prevent forced flow

through a semi-permeable confining unit. The effectiveness and duration of excursion control techniques are generally determined by water quality sampling and comparison of results with known baseline water quality parameter of the affected unit.

2.9 GROUNDWATER RESTORATION AND RECLAMATION

After completion of mining, the groundwater must be restored and surface structures must be decommissioned in order to restore the land and groundwater to approximately premining conditions. This section describes the reclamation and restoration methods commonly used.

2.9.1 Groundwater Restoration

Restoration methods are applied to the ore-zone aquifer when the ore is depleted or the operation is terminated. These methods are designed to remove or reduce the effects of the mining operation at the well field and adjacent parts of the aquifer to levels defined in regulatory standards. The ease of restoration depends mainly on the original groundwater quality and hydrology, the mineralogy and volume of the formation, and the exchange characteristics of the ore body with the lixiviant.

Several restoration methods are currently being used. The most direct and widely considered technique is that of simply pumping the residual fluids from the well field area. As the pumping continues, groundwater from beyond the mined area flows in to replace that that was pumped out. The infusion of surrounding, uncontaminated water displaces the lixiviant which is pumped out of the recovery wells. The extent of lixiviant recovery and removal of undesired ions in the aquifer increases with increased groundwater extraction. This procedure, called groundwater sweeping, may pump water up through the injection wells along with the production wells. The process continues until predetermined concentrations of constituents are reached. The water must either be disposed of as waste or it may be treated and recharged to the aquifer at some distant point. The constituents and concentrations in the waste stream are dependent on existing groundwater concentrations and on the constituents in the lixiviant solution. Table 2.14 shows expected ranges in concentration in restoration waste streams from ammonium bicarbonate leach systems. As pumping continues, the waste stream concentrations approach the concentrations found in the groundwater. Sweeping appears to recover nearly all of the lixiviant although certain chemical components may not be returned to pre-mining levels. Its consumptive use of water (20 to 30 times operational levels) may temporarily or permanently deplete the aquifer in areas where groundwater is scarce, and degrade its water quality because of this depletion. Even where it is plentiful there may be some tradeoff in the desirability of total recovery versus minimum use of water (Section 7.2).

The unit used in describing the amount of water required to achieve a given restoration level is called a pore volume. This has been defined as the

TABLE 2.13. Restoration Waste Water Stream for Ammonium-Bicarbonate Leach Systems from Various Stages of the Restoration Process

<u>Constituent</u>	<u>Concentration mg/l</u>
Ca	21 - 400
Mg	54 - 200
Na	210 - 8650
K	3 - 135
HCO_3^-	105 - 14,320
$\text{SO}_4^{=}$	110 - 15,620
Cl^-	230 - 12,750
F^-	0.3 - 14
$\text{NO}_3^{=}$	1 - 19
TDS	710 - 54,100
NH_4^+	2 - 9500
Mo	.42 - 377
V	<.05 - 0.21
U_{308}	3.5 - 403
Ra^{226}	370 - 4100 pCi/l
pH	4.5 - 8.5 standard units

Sources: Thompson et al. 1978, Texas Water Commission 1977b, 1978b,d, USEPA 1979

volume in the host sand initially occupied by water within the outer boundary of the well pattern. Results of computer modeling a particular set of assumptions of restoration showed that groundwater sweeping took 24.4 days and 14.5 pore volumes to approach 100% lixiviant recovery (Riding and Rosswog 1979).

A second and similar restoration technique is called recirculation of recharge or clean water recycle. Recirculation involves the artificial recharge of water. This recycling may be in the same direction as the mining by pumping the water down the injection wells and out the production wells. A variance from this is reverse recirculation where the liquid is pumped into the production well and out the injection wells. An evaluation of the hydrology of the formation at the site would determine whether the forward or reverse method would be most effective. In either case, the groundwater may undergo surface treatment which purifies the groundwater, usually to baseline or better conditions, before it is reinjected back into the wells. This recycling of the water recovers much of the lixiviant without the consumption of as much water as the groundwater sweeping method. It does have a concentrated waste stream from the treatment requiring disposal. The modeling of forward recirculation predicted 35.5% lixiviant recovery in 28 days using the equivalent of 14.4 pore volumes of water. Reverse recirculation using the same set of assumptions predicted 13.3 days to extract 25.8% of the lixiviant solution with a recycling of water equivalent to 6.8 pore volumes.

A different proposed technique would consist of injecting specifically tailored fluids into wells in the well field. The injected fluid would be designed chemically to be most effective for the specific conditions in a particular area. Tests have been performed using treated well field water as well as with solutions containing added chemicals. Results have shown promise but the proposed technique needs further development (Thompson et al. 1978). These special injected fluids may aid in the recovery of hard-to-remove lixiviant ions or the stabilization of elements in the formation. Dissolved uranium and molybdenum concentrations may be difficult to reduce to acceptable levels. Ammonia, commonly used as a bicarbonate carrier in leaching solutions, is one of the hardest lixiviant ions to completely remove following in situ mining. Its properties at low concentration levels are stringently regulated, particularly in Wyoming because of concern about nitrate levels in drinking water. Techniques, such as the use of lixiviant cations known to exchange with ammonia on clays, have been tried to reduce the ammonia concentration within the formation. However, problems with ensuring near total recovery of ammonia have caused some companies to seek lixiviants that pose fewer restoration problems. In some cases, these lixiviants are less efficient.

Other theoretical restoration methods which need technological refinements or additional testing are bacterial and chemical precipitation. Bacterial treatment uses known sulfate reducing organisms to precipitate insoluble heavy metal sulfides. Chemical precipitation may also accelerate stabilization by creating reducing conditions that could precipitate the metal sulfides. Uniform distribution of a reductant appears necessary for this option to work.

Surface treatment of groundwater is mandatory for some restoration methods and is an option for several other restoration methods. A combination of physical and chemical separations are available to extract chemical contaminants and reduce the total suspended solids. Some of these include reverse osmosis, electrodialysis, distillation, direct precipitation, and various adsorption and ion exchange treatments. All these methods produce concentrated contaminant waste streams that require disposal in on-site lined evaporation ponds.

2.9.2 Reclamation

After the completion of mining, groundwater restoration and post-operation groundwater monitoring, all surface equipment such as pipelines and tanks must be disassembled, decontaminated and sent to a disposal site. The processing or administration building may be left to be used by the land owner upon his request, provided that it is decontaminated and the transfer receives regulatory approval. In addition, wells are cemented to within approximately 1 meter of the surface, the casing cut off and the hole backfilled to be level with the adjacent land surface.

All solid waste storage pits and evaporation ponds are emptied of the remaining liquid and solid waste. These wastes are stored at an approved low-level burial site or adjacent mill tailings pond. After the ponds have been cleaned and all radioactive contamination removed, the pond sites are filled, graded, and spread with topsoil. The site is then revegetated with native flora in an effort to return the area to the original conditions.

3.0 PHYSICAL ENVIRONMENT

A brief description of the physical environment developed for a generic in situ plant forms a basis for analyzing the potential environmental impacts from operation of an in situ facility. In situ operations are located in the western part of the United States from Washington to Texas. Impacts of a particular operation are largely site-specific; therefore, the generic site description is given only to illustrate the general physical environment and so that the potential effects of the in situ uranium industry can be assessed. Variations in the physical environment are discussed when they are of major importance. The geology section discusses the method of formation of sandstone uranium deposits and the characteristics of uranium in each early uranium mining district shown in Figure 1.1 (page 1.3).

3.1 CLIMATE

The major climatic regions of the uranium mining districts of the western United States consist of the Western Plateau and the Texas Coastal Plains (Figure 1.1). The weather of the Western Plateau uranium mining region is dominated by the influences of elevation and pressure systems that pass through the area during the year. The climate of the plateau is semi-arid and the seasons are distinct with mild summers and harsh winters. The weather in the Texas Coastal Plains is more moderate and humid. The annual precipitation varies from a low of 8.8 cm for the Colorado Plateau to a high of 51.6 cm for the Texas Coastal Plains. Large monthly and seasonal variations can occur both within and across the uranium mining region with generally higher precipitation at higher elevations. In the winter, storms with lower temperatures and high winds are common in the Western Plateau. Spring and summer storms may result frequently in low intensity dust devils or, infrequently, in tornadoes. The mean annual frequency of tornadoes ranges from 0 in the Colorado Plateau to 16 in the Texas Coastal Plain (USNRC 1979b).

The air quality of the uranium mining region is generally good. However, during high wind conditions, wind erosion may suspend high concentrations of particulates. Low population density, lack of industrial pollution sources, and high dispersive characteristics of the atmosphere of the uranium mining region account for the current good air quality.

3.2 METEOROLOGY

A model uranium mill site is described by the USNRC (1979b). Table 3.1 contains a set of joint frequency data of annual average wind speed and direction for that site which is used to represent a model site for this report. This data represents a combination of wind speed and stability class data from meteorological stations in the various uranium mining areas and, thus, is used here as a basis for the air quality analysis.

TABLE 3.1. Joint Frequency of Annual Average Wind Speed and Direction at Model Mill

	Speed, m/sec						Total
	0-1.5	1.6-3.2	3.3-5.1	5.2-8.2	8.3-10.8	>10.8	
	%	%	%	%	%	%	%
N	2.3	1.4	1.0	0.3	0.0	0.0	5.0
NNE	2.1	1.3	0.8	0.3	0.1	0.0	4.6
NE	2.7	1.4	0.7	0.2	0.0	0.0	5.0
ENE	2.4	1.2	1.5	0.4	0.0	0.0	5.5
E	2.4	1.0	1.1	0.4	0.0	0.0	4.9
ESE	1.9	0.6	0.2	0.1	0.0	0.0	2.8
SE	1.7	0.8	0.3	0.2	0.0	0.0	3.0
SSE	1.5	0.8	0.6	0.1	0.1	0.0	3.1
S	3.5	1.8	1.8	0.7	0.1	0.0	7.9
SSW	2.5	1.5	2.9	1.3	0.4	0.0	8.6
SW	3.7	2.1	3.9	3.8	1.1	0.2	14.8
WSW	4.7	2.8	4.1	3.4	1.2	0.2	16.4
W	2.9	2.1	2.5	1.8	0.5	0.0	9.8
WNW	1.2	0.9	1.1	0.9	0.1	0.1	4.3
NW	0.8	0.6	0.5	0.4	0.0	0.0	2.3
NNW	0.8	0.5	0.6	0.1	0.0	0.0	2.0
Total	37.1	20.8	23.6	14.4	3.6	0.5	100

Source: USNRC 1979b

3.3 TERRESTRIAL ECOLOGY AND LAND USE

In the region of projected in situ leach operations there is a wide range of vegetative community types. The Northern Montana portions of the region are characterized by ponderosa pine and Douglas fir forests. The mid-portion is a desert shrub-grass community, which is comprised mostly of shrubs, such as sagebrush and rabbitbrush and a variety of bunchgrasses. Because of heavy grazing, the proportion of shrubs and grasses may have been altered from their natural distribution. The abundance of shrubs and grasses is dependent on seasonal and annual changes in environmental conditions, such as rainfall. The vegetation in the uranium mining area of Texas consists of cedar and oak trees, brush vegetation and grasses (USNRC 1979b). Throughout the region, where water supplies are available, irrigated agriculture is prevalent.

A great variety of fauna is also associated with each of these areas. The northern and central portion may contain native grazing mammals such as antelope and deer as well as numerous smaller mammals such as ground squirrels and jackrabbits. In addition to these mammals, a diverse bird population exists across most of the region. Avian fauna includes prairie falcon and other raptors as well as numerous small seed and insect eaters (USNRC 1979b). The presence of threatened and endangered species or protected habitat must be determined for each specific site. Plant life in the perennial rivers probably includes periphytic algae, filamentous green algae, and blue-green algae. Some macrophytes may be present. Impoundments and reservoirs contain planktonic and periphytic algae along with several macrophyte representatives in the shallower reaches. Macroinvertebrate populations consist mostly of mayflies, stoneflies, dragonflies, damselflies, beetles, waterstriders, backswimmers, blackflies, midges, and crane flies. Fish species present will depend greatly on the type of available habitat. Common fish sampled in water bodies include trout, catfish, bluegill, carp, bass, sucker, walleye, squawfish, minnows, dace, chubs, shiner, warmouth, and sculpin (Thompson et al. 1978).

Most of the land within the Western Plateau rangeland is used for grazing and is administered by the Bureau of Land Management or private land owners. Small areas are used for agriculture and some of that is irrigated. Various mineral extraction industries are scattered throughout the region including conventional uranium mines and mills (USNRC 1979b).

3.4 GEOLOGY OF URANIUM DEPOSITS

Leachable uranium deposits are found in ancient channel sands that have been covered by more recent sediments. The deposits range from unconsolidated to very tightly cemented, consolidated sandstones and commonly grade into carbonaceous shales and lignites that were deposited contemporaneously. The sand deposits are usually bounded above and below by impermeable mudstones or shales (Thompson et al. 1978).

The uranium deposits are believed to have formed when the uranium was leached from a source material, probably granite bodies, and was transported in a dissolved state by the groundwater. Oxygenated groundwater percolating through the source material oxidized and mobilized the uranium. As the uranium-bearing groundwater moved through the aquifer, it came in contact with reducing conditions. The uranium precipitated along the oxidation-reduction front in what is commonly referred to as roll-type mineralized deposits. Roll-front or roll-type deposit refers to the classic crescent or more commonly the tabular, dish-shaped or irregular deposit. It is illustrated in Figure 3.1 (Thompson et al. 1978).

In addition to lignite and pyrite, the uranium deposits contain numerous other elements with similar chemical properties that were mobilized and deposited under the same conditions as uranium. The most important associated elements are arsenic, selenium, vanadium, copper and molybdenum (Thompson et al. 1978, Henry 1979).

KEY

	OXIDIZED BARREN INTERIOR		URANIUM MINERALIZATION
	UNALTERED SANDSTONE		(SELENIUM MOLYBDENUM) } ERRATIC
	SILTSTONE OR CLAYSTONE		PYRITE

FIGURE 3.1. A Cross Section Showing the Characteristics of an Idealized Uranium Roll-Front Deposit.
Source: Thompson et al. 1978

Some uranium mineralization occurs in most tertiary and older sedimentary rocks in the western and southwestern United States. The major locations of sandstone deposits amenable to in situ leach mining are the Wyoming Basin, the Colorado Plateau and the Western Gulf Coastal Plain of Texas. Other areas in the northern plains and northeastern Colorado may also contain uranium deposits amenable to in situ leach mining (Figure 1.1).

The geology of these major locations is fully described in Thompson et al. (1978). The following section is based in part on that description.

3.4.1 Wyoming Basins

The uranium-bearing rock units in Wyoming are typically fluvial (stream or river deposited) clays, silts, sands and gravels, with scattered layers of carbonaceous or lignitic material. In general, the materials are oxidized above the water table and unoxidized below. The rock material is often unconsolidated to poorly cemented. The uranium ore is generally found between individual grains, as coating on the grains or as thin layers within the host rock.

In the Gas Hills Uranium District, the uranium mineralization occurs in the Puddle Spring's Arkose Member of the Eocene-age Wind River Formation. The Puddle Springs member consists mainly of coarse-grained arkosic (≤ 25 percent feldspar minerals) conglomeratic sandstone with scattered siltstone and shale. The Dry Coyote bed, in the lower Puddle Springs, is a conglomerate with granite boulders and cobbles in a coarse sand matrix, and contains uranium minerals in the sand matrix and as coatings on pebbles and cobbles. The Wind River Formation is overlain by the Wagon Bed Formation consisting of mudstones, sandstones and conglomerates.

The Shirley Basin area contains Eocene-age fluvial claystones, siltstones, arkosic sandstones and conglomerates. The uranium minerals are found in the sandstone lenses and beds in roll-type deposits at the interface between altered and unaltered sandstone. The ore, primarily uraninite, occurs as coatings on grains and in the intergranular spaces.

The Powder River Basin area contains Tertiary (Paleocene and Eocene age) siltstones, sandstones, lignites and coal. The Highland Sandstone Member of the Fort Union Formation is arkosic, poorly cemented and contains organic and carbonaceous material. The uranium ores are generally found in tongue-like extensions of the main sandstone body and occurs in very thin layers or in irregular masses.

3.4.2 Colorado Plateau

The Monument Valley-White Canyon area of southeast Utah and northern Arizona contains Permian and Triassic age sediments to a depth over 1500 meters. Within these sediments, the uranium deposits are found in the Shinarump Member of the Chinle Formation. The Shinarump consists of stream channel and floodplain deposits of sandstone, conglomerate, siltstone and mudstone. Carbonized wood fragments are common and calcite (calcium carbonate) is a common cementing agent. The uranium deposits generally occur in the carbonaceous sandstone and conglomerate beds at the base of the Shinarump Member and occur as typical roll-front deposits but also as lenses or pods.

In the Uravan district the Morrison Formation is the host rock for most of the uranium deposits and consists of mudstones, siltstones, sandstones and conglomerates. The ore deposits are small tabular or pod-like bodies and typical roll-front deposits. Silica, calcite, dolomite and gypsum are common cementing agents. Uranium deposits are generally found associated with vanadium minerals.

The Ambrosia Lake district in New Mexico contains uranium deposits in the Westwater Canyon Member of the Morrison Formation. The Westwater Canyon is fluvial, arkosic sandstone with minor interbedded mudstones and represents a complex of discontinuous stream channel deposits. The uranium deposits are typically layered and occur roughly parallel to the stratification and at all levels in the Westwater Canyon Formation.

3.4.3 Northeastern Colorado

Uranium deposits amenable to in situ leach mining are found in the sandstones of the White River Group of Oligocene age near Grover in northeastern Colorado. The Grover area lies about 38 mi (61 kilometers) northeast of Greeley, Colorado, in the Rocky Mountain Piedmont section of the great plains.

3.4.4 Western Gulf Coastal Plain

Uranium host rocks in the Karnes County District of Texas are typically marine, deltaic-lagoonal and/or barrier bar sands and sandstones containing volcanic ash and tuff with bentonitic clays.

In the Live Oak County District, Texas, the host rocks are fluvial and floodplain sands interbedded with silts and clays.

In the Oakville District in Texas the uranium minerals are found in a carbonate-rich arkose that is essentially free of carbonaceous debris. The uranium ore fills the spaces between grains and coats individual grains. Various uranium-bearing minerals are found in both oxidized and reduced zones. Several trace and potentially toxic elements are also found in these deposits (Henry 1979).

3.4.5 Northern Plains

The Southern Black Hills area of South Dakota and Wyoming contain most of the known uranium deposits in the northern Plains region. The Inyan Kara Group of rocks (early Cretaceous age) is the principal host rock. The Inyan Kara Group consists of stream channel, siltstone, claystone and sandstone. The ore deposits occur primarily in four units, two of which are carbonaceous and two which are noncarbonaceous.

3.5 HYDROLOGY

Most domestic uranium deposits lie in arid or semi-arid climates with varying amounts of rainfall. Surface waters in the vicinity may include ephemeral streams, tributary streams, reservoirs, and small impoundments for livestock watering. Stream flows typically are heaviest in June and July because of thunderstorm runoff, with many of the smaller streams drying up during the summer. After precipitation occasional flash flooding occurs in gullies and channels through the area (Thompson et al. 1978).

The chemical composition of surface waters depends primarily on the watershed nutrients, local mineral formations, seasonal patterns, watershed flow rate, and the type of surface water. Some surface waters contain high amounts of vanadium and moderate amounts of other trace metals.

The groundwater saturates the ore bodies. Throughout the in situ mining region the uranium-bearing sandstones typically occur in thick (1 kilometer or more) sedimentary sequences. The sandstones are saturated with groundwater that moves in response to local and regional hydraulic gradients from recharge areas. Shale, claystone, and siltstone units are typically a part of the sequence, and the water in the ore-bearing sands is generally confined by these units.

Permeability of uranium-bearing sandstone aquifers has been found to be generally less than 10^3 millidarcies (10^{-2} cm/sec) (Thompson et al. 1978). Wells completed in these units generally yield 5 to 10 gallons per minute (gpm) or about 0.3-0.6 liters per second (l/s), which is adequate to supply usual domestic and stock needs (Thompson et al. 1978).

Water quality is variable throughout the various uranium mining areas depending on the depth, distance from recharge areas and probably, to some extent, on the flow rate through the aquifer. Groundwater in potential in situ uranium mining areas of Wyoming and the Colorado Plateau is of calcium/sodium bicarbonate type with total dissolved solids (TDS) of 160-1250 milligrams per liter (mg/l) while, in the Texas areas, groundwater is of the sodium bicarbonate and chloride type with a TDS of 1250-3000 mg/l (Thompson et al. 1978). Trace and heavy metal concentrations are generally within accepted public health limits in most areas but radioactive parameters (radium-226, gross alpha and gross beta) may be above recommended public health standards in samples from wells that contact the ore body. The following discussion is based in part on Thompson et al. (1978).

3.5.1 Wyoming Basins

Shallow groundwater in the Wyoming basins is found under water-table or perched conditions, in which the deeper aquifer systems are confined. The principal source of groundwater recharge is direct infiltration of precipitation or the infiltration of stream flow. In the lower reaches of perennial streams, groundwater is generally the source sustaining the basic flow of rivers throughout most of the year.

Precipitation varies in the Wyoming basins area from 50-90 cm/yr in the forested mountain ranges to 15-20 cm/yr in the western basins. Many of the basins that have either potential for in situ leach mining or where the method is already in use, drain toward the Missouri River system (eastward). The Green River Basin drains southwesterly into the upper Colorado River Basin system.

About 80 percent of the annual stream flow, mostly from snowmelt, occurs from April to July, but for the remainder of the year, stream flow is primarily sustained by effluent groundwater. Total dissolved solids (TDS) content varies considerably during the year in northeastern Wyoming, partly because of the high silt load during high flow times. Most of the surface waters are hard and many contain from 500-2000 milligrams per liter (mg/l) TDS. They are suitable, however, for irrigation and stock use, except for local highly-mineralized areas.

The major use of surface water in northeastern Wyoming is for irrigation which accounts for about 94 percent of the total diversion. The remainder of the diverted water is small amounts for municipal, domestic, stock and industrial uses. About half of the industrial use is by the coal mining and related industries; the other half by the oil and gas, mining, cement and other industries. Water use by the petroleum industry may decline as reservoirs are depleted, but use related to coal mining is expected to increase dramatically.

Groundwater occurs in the Tertiary sediments and in the more recent terraces and alluvial deposits along drainage ways. Some older rock units, such as the Madison limestone, are important regional aquifers. Shallow groundwater is found as both water table and perched aquifers, but the deeper aquifers are confined (artesian) to partially confined. The most extensive water-bearing units are in the early tertiary age material in the central areas of the major basins. The units are typically alternating lenticular sandstones and shales, interbedded with carbonaceous shales. These units are part of the Fort Union, Wind River and Battle Springs Formation and are characterized by abrupt lithological changes and low permeability. Wells commonly yield 18-36 liters per minute (l/min), although occasional wells may yield up to 3,700 l/min.

Groundwater quality varies considerably. In the shallow alluvial and Tertiary aquifers TDS may be from 200 to more than 4,000 mg/l. In general, the fresher groundwaters are hard to moderately hard and contain calcium, sodium, sulfate and bicarbonate as the dominant ions. Chlorides are generally low, except in the deep aquifers and in areas of oil and gas production.

Consumptive use of groundwater was about 9 percent of total local water consumption in 1973, of which more than half was for irrigation. The amount used for irrigation is expected to increase considerably by the year 2000. Industrial use by the petroleum industry for secondary recovery operations will probably decline as reservoirs become depleted. The additional water requirements for the coal and other energy related industries will probably be met in part by groundwater use.

3.5.2 Colorado Plateau

The Colorado Plateau region includes the Ambrosia Lake and adjacent parts of the Grants Mineral Belt, Monument Valley-White Canyon Area, and the Uranium Mineral Belt.

The Grants Mineral Belt is semi-arid with precipitation occurring as brief, intense storms during the summer. In general, there are no perennial streams and surface water is not an important factor.

Groundwater for domestic and stock needs of generally acceptable quality can be obtained from a number of discrete aquifers in the area. Well yields are generally low and away from the outcrop areas where the aquifers are usually confined. In a large part of the mineral belt, the Westwater Canyon member of the Morrison Formation is the principal aquifer, yielding small to moderate amounts of water of generally better quality than that from aquifers above and below it.

The Morrison Formation is overlain by the Dakota Sandstone of Cretaceous age. Well yields are low and TDS is high, therefore, the Dakota Sandstone is not widely used as an aquifer for domestic or stock needs. The Marcos Shale overlies the Morrison Formation and contains some sand units that yield water of fair to poor quality. Later Tertiary volcanic rocks occur in the Grants, New Mexico, area but are not a source of groundwater.

Alluvium and interbedded basalt of Quaternary age yield up to 3800 l/m in the Bluewater-Grants area. The water quality is highly variable with TDS from less than 2,000 to several thousand mg/l.

The groundwater withdrawals in the Grants area are regulated by the Bluewater Underground Water Basin, established by the New Mexico state engineer in 1956. The amount of water withdrawn for all purposes is constant and as uranium mining has grown, the amount required by the industry and public supply has been met by a corresponding decrease in the amount pumped for irrigation. As population and industry grow, a larger percentage will be needed for industry and public supply.

Much of the conventional uranium production has been from wet ore bodies within the Morrison Formation. In some locations, seepage into the mines may account for considerably more water than is needed by the mining and milling processes. This water is pumped out and not used. It is of generally good quality and could be put to beneficial use.

3.5.3 Northeastern Colorado

Uranium deposits occur in the White River Group (Oligocene age) in northeastern Colorado. The uranium deposits are in sandstones and are amenable to in situ leaching. The climate is arid to semi-arid and suitable for grazing and dry farming. Irrigation mainly occurs along Crow Creek and the South Platte River, south of the uranium area.

Surface drainage in the area is southeastward by tributaries to the Platte River. Most streams are intermittent with the exception of Crow Creek. Surface waters are hard to moderately hard with TDS generally exceeding 350 mg/l.

A major source for groundwater is the sandstones of the White River Group, which also contain the uranium deposits. Wells frequently yield up to 120 l/min for stock and domestic use. Locally, yields may be as much as 85,000 l/min where saturated unconsolidated material overlies fractured sandstone.

Unconsolidated Quaternary age materials are found as terrace and stream alluvium along Crow Creek and the lower reaches of other streams. Where these are saturated, they may yield 75,000 to 90,000 l/min to irrigation wells.

The quality of the water from the unconsolidated Quaternary deposits is quite variable in TDS (350 to 2000 mg/l), relative proportions of sodium and sulfate, and may be quite hard. Water from the White River Group is generally of the calcium or sodium bicarbonate type and contains only 250-450 mg/l TDS.

3.5.4 Western Gulf Coastal Plain

Uranium deposits in Texas occur in a belt, parallel to the coast, extending from the Gulf of Mexico about 160 km to the Brazos River. The belt is, in general, a low, nearly featureless plain, with relief of 60 to 100 m. Salt domes are evidenced by occasional low mounds or depressions with small saline lakes.

The area is generally moisture deficient with respect to the amount required by evaporation and transpiration by plants. A number of rivers rise outside the uranium belt and flow through the area to the Gulf. One river, the Lavaca, rises within the mining area. Surface water quality is quite variable with TDS and salinity quite high, up to 250,000 mg/l and several thousand mg/l, respectively.

Groundwater occurs in the Gulf Coast Aquifer--a hydrologic unit consisting of silts, sands and gravels of seven different formations. Fresh water occurs in the aquifer to depths of more than 900 m and large volumes are pumped for industrial, municipal and irrigation uses northeast of the uranium district.

The quality of the groundwater varies from fresh to saline, laterally as well as vertically. The water is often very hard near the surface, becoming softer with depth. Chlorides and sulfates increase toward the south part of the area, and the groundwater may carry dissolved natural gas and hydrogen sulfide. The water is generally not suitable for irrigation but is currently used in untreated form for human consumption because no better supply is available. Of the groundwater used in South Texas, 80 percent is for irrigation--almost entirely in the Rio Grande Valley--and about 13 percent for public and rural water supplies.

3.5.5 Northern Plains

The outcrop of the Inyan Kara Group is about 8 km wide and 21 km long where many of the uranium deposits occur. The climate is semi-arid and precipitation supports only grazing and dry farming.

The Cheyenne River and a tributary, Beaver Creek, are the main streams draining the mining area. Most of the flow is during spring and early summer; the rest of the year flow is variable but generally too low for irrigation. The river may dry up during drought. Quality varies with flow; TDS may vary from 350 to 1,500 mg/l.

Groundwater is obtained primarily from springs and wells in sandstones of the Inyan Kara Group or deeper carbonate (limestone) aquifers. Downdip from the outcrop, the deeper carbonate aquifer becomes confined and the water quality deteriorates in part by solution of anhydrite. Other wells in the formation yield large quantities of saline water and water containing sodium sulfate.

The Inyan Kara aquifer is believed to be in part recharged by upward flow from the carbonate aquifer below. Yields are fairly high but the water is commonly somewhat saline and is often of the sodium sulfate or bicarbonate type.

4.0 INSTITUTIONAL AND SOCIOECONOMIC ENVIRONMENT

Economic, governmental and interest group participants involved in in situ mining in Wyoming and Texas are identified in this chapter, and the activities related to in situ uranium mining in which these groups are likely to be engaged are described. Wyoming and Texas are used as examples because of their different legal status (i.e., agreement vs. non-agreement states) and because these states are the areas which are experiencing the greatest in situ development. Agreement state refers to the provisions under the Atomic Energy Act of 1954 that allow states to designate an agency that will perform the radioactive materials licensing within that state. The participants and activities are identified for each of the five stages of the in situ mining process beginning with exploration and testing and continuing through mine construction and operation to waste disposal and finally restoration. Similarities and differences between the states are noted. For clarity and to emphasize the differences between Texas and Wyoming the governmental participants and activities of each state are described separately.

Table 4.1 provides an institutional overview for each stage of the mining process. Efforts have been made to identify on the chart and in the text potential participants and activities when none currently exist.

4.1 STAGE 1: EXPLORATION AND TESTING

4.1.1 Economic Participants and Activities

Economic participants include landowners or owners of mineral rights, independent or producer-employed geologists, engineers, geophysicists, and drill crews. In the State of Wyoming landowners or owners of mineral rights may include: the Federal government, the state/local governments, and private individuals. In Wyoming, private owners will probably be either ranchers, or Native Americans living on land previously allotted to them by the Federal government. According to USDOE estimates, 11% of the existing domestic uranium reserves are found on Indian lands (USDOE 1978). Forty-two percent of potential uranium reserves are thought to lie on Indian lands as well. Wyoming's Southern Powder River Basin is one region in which uranium is likely to be found on Indian lands.

Uranium exploration and development firms that have already begun efforts to establish in situ leaching facilities, or who expect to in the next 3 to 4 years, are given in Table 1.1.

In Texas land/mineral owners may include the Federal government, state/local governments, and private individuals. Private owners would probably be farmers or ranchers.

TABLE 4.1. Institutional Overview of In Situ Uranium Mining

	ECONOMIC	GOVERNMENTAL	INTEREST GROUP
	Participants -- Activities	Participants -- Activities	Participants -- Activities
STAGE 1: EXPLORATION/ TESTING	<ul style="list-style-type: none"> - LANDOWNERS and OWNERS OF MINERAL RIGHTS lease land or mineral rights - GEOLOGISTS - ENGINEERS - GEOPHYSICISTS - DRILL CREWS--drill exploratory wells 	<p>WYOMING</p> <p>Federal</p> <ul style="list-style-type: none"> - BIA--approves lease of Indian lands - NRC--issues R&D permit - US FOREST SERVICE--permits drilling, roads on its lands - BLM--must permit access roads on its lands <p>State</p> <ul style="list-style-type: none"> - WDEQ, LQD--issues R&D permit, mining permit; WQD--approves above permits - WYOMING STATE ENGINEER--issues withdrawal/observation wells permits - CITY/COUNTY ENGINEERS--issue permits for access roads <hr/> <p>TEXAS</p> <p>Federal</p> <ul style="list-style-type: none"> - US FOREST SERVICE; BLM--as above <p>State</p> <ul style="list-style-type: none"> - RAILROAD COMMISSION, OIL & GAS DIVISION--issues plugging permit 	(Unlikely at this stage.)
STAGE 2: MINE CONSTRUCTION	<ul style="list-style-type: none"> - DRILLERS - MINING COMPANIES--(engineers and unskilled personnel) 	<p>WYOMING</p> <p>Federal</p> <ul style="list-style-type: none"> - NRC--issues source materials license - EPA--regulates construction of wells --sets requirements for public drinking water supply systems - MSHA--oversees health and safety aspects - FISH & WILDLIFE SERVICE--protects habitats of endangered species <p>State</p> <ul style="list-style-type: none"> - (Withdrawal/observations wells permits and mining permits required--see Stage 1) - WYOMING INDUSTRIAL SITING COUNCIL--issues industrial siting permit - WDEQ, AQD--issues air permit to construct and air permit to install mill processing equipment - WDEQ, LQD--issues site equipment staging approval - WDEQ, WQD--issues permits for potable water supply systems and sanitary sewer systems 	<p>WYOMING</p> <ul style="list-style-type: none"> - FRIENDS OF THE EARTH--litigation - WYOMING OUTDOOR COUNCIL and POWDER RIVER BASIN RESOURCE COUNCIL (possible future participants)--may participate in hearings, offer written comment throughout licensing process.)

TABLE 4.1. Continued

ECONOMIC		GOVERNMENTAL		INTEREST GROUP	
Participants -- Activities		Participants -- Activities		Participants -- Activities	
STAGE 2: (Continued)		TEXAS Federal - EPA, MSHA, FISH & WILDLIFE SERVICE, as above		TEXAS - (TEXAS ENVIRONMENTAL COALITION) (possible future participant)--may participate in hearings throughout licensing process	
		State - TDWR--issues in situ mining permit --issues levee construction permit - TDH--issues radioactive materials license			
STAGE 3: MINE OPERATION	SUPPLIERS OF CHEMICALS MINE PERSONNEL SUPPLIERS OF SUPPORT SERVICES FOR PERSONNEL PROCESSORS, CUSTOMERS	WYOMING Federal - NRC--sets monitoring requirements and excursion procedures in source materials license - EPA--prescribes operating, monitoring, reporting requirements for underground injection wells --regulates hazardous airborne pollutants --regulates nonradioactive effluents discharged during mine operation --has jurisdiction over processing unit - MSHA--see Stage 2 State - WDEQ, LQD--regulates mine operation with specifications of mining permits, issu- ing new regs for in situ due in May, 1980 - WDEQ, WQD--developing water quality standards for in situ activities		WYOMING - WYOMING POWDER BASIN RESOURCE COUNCIL --expressed concern about reported excu- sions at Irigaray site. Promised to remain informed about the situation there (Other potential participants for Texas and Wyoming are noted under Stage 2)	
		TEXAS Federal - EPA--as described for Wyoming; issues NPDES permit - MSHA--as described for Wyoming State - TDH--sets monitoring requirements for radioactive materials - TDWR--oversees monitoring of chemicals; regulates mine operation with in situ mining permit --issues NPDES permit			

TABLE 4.1. Continued

ECONOMIC		GOVERNMENTAL	INTEREST GROUP
Participants -- Activities		Participants -- Activities	Participants -- Activities
STAGE 4: WASTE DISPOSAL	MINING CO. PERSONNEL, DRILLERS-- construction of disposal wells, evaporation ponds	<p>WYOMING</p> <p><u>Federal</u></p> <ul style="list-style-type: none"> - EPA--sets requirements for in situ disposal wells (Underground Injection Control Regulations (UIC)) <ul style="list-style-type: none"> --Uranium Mill Tailings Radiation Control Act, regulation addresses disposal using <u>evaporation ponds</u> --regulates disposal of nonradio-active solid waste - NRC--prescribes design requirements for <u>evaporation ponds</u> <p><u>State</u></p> <ul style="list-style-type: none"> - WDEQ, AQD--air permit required for disposal wells and evaporation ponds - WDEQ, WQD--issues subsurface discharge permit for disposal wells <ul style="list-style-type: none"> --issues permit to construct an <u>evaporation pond</u> --issues NPDES permit for surface discharges of treated wastes (required for liquid/solid separation) - WYOMING STATE ENGINEER--issues permits for tailings impoundments, mill settling ponds, mine dewatering ponds, and final impoundments <hr/> <p>TEXAS</p> <p><u>Federal</u></p> <ul style="list-style-type: none"> - EPA--as described for Wyoming; issues NPDES permit (<u>liquid/solid separation</u>) <p><u>State</u></p> <ul style="list-style-type: none"> - TEXAS WATER COMMISSION--grants permit for deep well waste injection - TDH, WATER WELL DRILLS BOARD, RAILROAD COMMISSION--must advise on deep well permit application - TDWR--inspects proposed <u>deep well</u> locations <ul style="list-style-type: none"> --no discharge permit (in situ mining permit) sets requirements for ponds --issues NPDES Permit for discharges to state waters (<u>liquid/solid separation</u>) - AIR CONTROL BOARD--issues air control permit for <u>evaporation ponds</u> 	(Potential participants as listed above)

TABLE 4.1. Continued

ECONOMIC		GOVERNMENTAL		INTEREST GROUP
Participants -- Activities		Participants -- Activities		Participants -- Activities
STAGE 5: RESTORATION AND RECLAMATION	MINING CO. PERSONNEL--pumping of wells, removal of all structures and equipment	WYOMING Federal - EPA--UIC regulations prescribe requirements for well abandonment --UMTRCA regulations address restoration State - WDEQ, LQD--in situ permit addresses restoration requirements - WDEQ, WQD--developing regulations for restoration of groundwater quality		(Potential participants listed above-- protests/litigation likely if land not properly restored, or wells are inadequately abandoned)
		TEXAS Federal - EPA--as described for Wyoming State - TDWR--sets regulations for well abandonment (EPA UIC regulations follow TDWR regulations closely)		

ABBREVIATIONS

Federal

BIA = Bureau of Indian Affairs
 NRC = Nuclear Regulatory Commission
 BLM = Bureau of Land Management
 EPA = Environmental Protection Agency
 UIC = Underground Injection Control
 MSHA = Mine Safety and Health Administration
 NPDES = National Pollutant Discharge Elimination System
 UMTRCA = Uranium Mill Tailings Radiation Control Act

Wyoming

WDEQ = Wyoming Department of Environmental Quality
 LQD = Land Quality Division
 WQD = Water Quality Division
 AQD = Air Quality Division

Texas

TDWR = Texas Department of Water Resources
 TDH = Texas Department of Health
 NPDES = See Federal

Economic activities associated with this stage of the mining process include: leasing the land and/or obtaining mineral rights, purchasing or leasing drilling equipment, and hiring drillers.

Drilling, the primary activity at this stage, is often done by private drilling contractors (Leaming 1979). Drilling equipment may vary with the depth of the mined area. For wells up to 1,000-1,500 feet (305 to 457 meters) deep, portable, water well equipment can be used. For the most part, in situ production wells have been less than 1,000 feet (305 meters) deep (Pers. Com. to R. J. Cole from W. May, Everest Mineral Corp., June 19, 1979). There have nonetheless been some problems in getting a rig and crew together at times (Pers. Com. to R. J. Cole from G. Ortloff, Exxon Minerals Corp., June 18, 1979). However, the in situ technology is especially noted for its ability to tap reserves at depths that conventional mining techniques could not. Thus, in the future, heavier, more exotic or complex equipment, such as oil rigs, may be required and consequently more trouble may arise in obtaining such equipment.

4.1.2 Governmental Participants and Activities

4.1.2.1 Wyoming

The Federal government becomes involved in the exploration and testing stage if it owns the mineral rights on the land to be explored and/or if pilot scale operations are proposed. If the Federal government owns the mineral rights, the mining company must prepare a claim under the 1872 mining law. No fee is charged by the government for the claim or for any minerals removed, though the company must spend approximately \$100 to assess the claim each year. If no minerals are found, the claim can be declared null and void (Davis 1979).

In the event that the potential site is owned by Native Americans, both the U.S. Bureau of Indian Affairs (USBIA) and the individual owner(s) must approve the lease of the land. USBIA approval is rarely, if ever, denied (Robinson 1979).

Because Wyoming does not have agreement state status, a research and development source materials application must be obtained from the USNRC for all pilot scale operations. The USNRC is directed under Title 10 CFR 40 to regulate all source materials. The Research and Development (R&D) permit application must include data gathered from an initial baseline study, which must be submitted in an environmental report (Kasper and Engelmann 1978). The gathering of the data can take anywhere from 3-6 months and the submission of and approval by the USNRC (following a 2-6 month review) can extend the process even further. The application could ultimately take 9-18 months to be approved.

In the event that the proposed site is on U.S. Forest Service land (Department of Agriculture), access roads and fencing typically require their approval. The U.S. Forest Service may issue exploratory mining permits as

well (Wyoming 1978). Similarly, the U.S. Bureau of Land Management (USBLM) participates in permitting access roads on lands they hold (Kasper and Engelmann 1978).

The state issues several permits that cover exploration and testing activities. An operator can obtain a single license that authorizes research and development activities only, or can procure three other permits which authorize not only R&D activities, but mine construction and operation activities as well.

The special license to conduct research and development testing for a 1-year period is issued by the Land Quality Administrator of the Wyoming Department of Environmental Quality (WDEQ). It is renewable and can be denied if the application violates the purpose of the act by which it is authorized. The application for this R&D permit must include a detailed environmental report, and a bond must be posted in an amount equal to the estimated cost of reclaiming the affected land and restoring the affected water (WY. STAT. 35-11-431 to 35-11-436).

The research and development permit is the minimal requirement that must be met to proceed with exploratory drilling. An alternative to this is to obtain a mining permit, that covers the exploratory drilling stage as well as commercial mine construction and operation. This permit is also issued by the Land Quality Division (LQD) of the WDEQ. The application for the mining permit must include a description of the proposed permit area. The permit, once issued, contains certain requirements for the mining operator once the mine is operating (See Section 4.3). A bond must be posted in an amount equal to the estimated cost of reclaiming the affected land and restoring the affected water. The estimated cost is equal to the operator's expected costs (as stated in the permit application) as well as the land quality administrator's estimate of possible cost to the state if the operator fails or the site is abandoned. (WY STAT 35-11-426 to WY. STAT. 35-11-436, WY. STAT 35-11-417.)

Two further state issued permits that cover the mining process from exploration through operation are the observation wells permit (WY. STAT. 41-3-930) and the withdrawal well permit (WY. STAT. 41-3-930). These are both issued by the Wyoming State Engineer.

If a waste water pond were required at this stage, a construction permit would have to be obtained from the Water Quality Division (WQD) of the WDEQ (see Stage 4: WASTE DISPOSAL for further discussion). A permit for sanitary sewage systems may also be required at this stage, and it too is issued by the WDEQ, WQD.

At the local level permits or licenses might be required for zoning changes necessitated by access roads. City and/or county offices would be involved (Wyoming 1978, p. 7-13).

At the exploration and testing stage the state or local governmental participants are, thus, limited to the LQD and WQD of the WDEQ, the Wyoming State Engineer and, under certain circumstances, city or county zoning offices. Applications for R&D licenses or mining permits are made to the director of the LQD. The director has the authority to make the final decision on any permit application. However, he also designates a land quality administrator as his representative on all matters concerning such applications. In situ mining and R&D permits must also be approved by the WDEQ's Water Quality Division. Permits for zoning changes would probably be obtained from the local planning commission or legislative body; the city or county engineer would grant permits for access roads (Kasper and Engelmann 1978, p. 18-19).

4.1.2.2 Texas

The Federal government becomes involved at this stage if it owns the mineral rights on the land to be explored. See discussion of the 1872 mining law under Wyoming, above. The U.S. Forest Service and the USBLM may become involved under certain circumstances (see Wyoming discussion).

The Federal government does not become involved in licensing pilot scale operations in Texas. Texas has been granted "Agreement-State" status by the USNRC under provisions of the Atomic Energy Act of 1954 as amended. It is, thus, authorized to regulate source materials through its own state agencies. The Texas Department of Health (TDH) is the state agency designated by the USNRC to license operations involving radioactive materials (USEPA 1975).

The only state permit required at this stage appears to be a plugging permit. The authorized agency is the Railroad Commission, Division of Oil and Gas (Tex. Civ. Stat. Art. 7621e).

The TDH assumes most of the licensing responsibilities that the USNRC carries out in nonagreement states. While it does not issue any permits for exploratory drilling, a radioactive materials license, required for possession of extracted uranium, may be issued for extraction of a specific amount of ore from a test facility. Separate research and development licenses are not issued at the exploration stage for proven technology (see Section 4.2.3.2).

At the local level, permits or licenses might be required for zoning changes necessitated by access roads. (See Wyoming discussion above.)

4.1.3 Interest Group Participants and Activities

Interest group activities seem to be minimal at this stage compared to later stages. This may be either because fewer formal opportunities (e.g., hearings, formal requests for written comment) for expression of public opinion are available at this stage, or because the groups likely to become involved have not developed strong opinions about a given project this early. According to an excerpt from their May 1979 newsletter, for example, Wyoming's

Powder River Basin Resource Council, a rancher's organization concerned with keeping ranching a viable operation (Pers. Com. to R. J. Cole from G. Ortloff, Exxon Minerals Corp., June 18, 1979), did not initially object to Wyoming Mineral Corporation's application for a permit ". . . because it appeared that in situ mining might have fewer problems than conventional deep or strip mining." (Powder River 1979).

4.2 STAGE 2: MINE CONSTRUCTION

4.2.1 Economic Participants and Activities

In addition to those companies presently involved in in situ projects, or proposing to operate facilities within the next three to four years, drillers would again be participating in this stage of the mining process (Section 4.1.1). In addition suppliers of pumps, pipes, tanks, and other industrial equipment would become involved. They may have already been involved to a limited degree if a pilot site had been constructed during the initial exploration and testing stage. The actual construction of the field facilities and the central plant would be handled at least in part by the engineers of the mining companies and the same personnel who will ultimately run the mining operation.

Economic activities associated with mine construction include: drilling injection wells, extraction wells and monitoring wells; lining and grouting all production wells; installing pumps connected to field gathering tanks; constructing a field processing facility; constructing a central elution plant for the removal of uranium. In some cases the in situ facility may not include a central plant for the processing of the pregnant solution, which will instead be sent to an existing mill elsewhere.

4.2.2 Governmental Participants and Activities

4.2.2.1 Wyoming

The Federal agency that plays the major role in regulating leach mining is the USNRC. Persons engaged in in situ mining in nonagreement states, such as Wyoming, must obtain a source materials license from the USNRC pursuant to 10 CFR 40 (USNRC 1979f). The USNRC currently follows the same procedures for licensing in situ mining as used in licensing a uranium mill (USNRC 1978d). An applicant for this license must supply the USNRC the information discussed in the USNRC Regulatory Guide 3.5 and applications must be submitted.

Under the National Environmental Policy Act of 1969 (NEPA), the applicant is required to supply an environmental report for the USNRC's environmental assessment pursuant to 10 CFR 51. The applicant's information should be as discussed in the USNRC Regulatory Guide 3.8 (USNRC 1978e).

When the applicant has submitted the environmental report (ER) to the USNRC, the USNRC performs its own standard environmental review, culminating in the preparation of a Final Environmental Impact Statement (FEIS). The

license will be granted to the applicant after the Director of Nuclear Material Safety and Safeguards, or his designee, has weighed the "Environmental, economic, technical and other benefits against environmental costs and has considered available alternatives," as presented in the FEIS, and concludes that issuance of the license is advisable. The applicant's facilities and procedures have to be adequate to protect health and minimize danger to life or property (10 CFR 40.32, USNRC 1979f).

In addition to licensing source materials, the USNRC normally regulates in situ mine construction by setting certain requirements for locating the monitoring wells. These include, for example, setting maximum spacing between wells at 122 meters (400 feet), setting maximum well spacing in the direction of the natural groundwater flow at 61 meters (200 feet); establishing the maximum angle between two adjacent wells at any point on the production perimeter to be 75°; and setting the maximum distance from perimeter to monitor well at 122 meters (400 feet). Production and monitoring wells must "Be drilled and cased in a manner preventing leakage between adjacent aquifers." (Kasper and Engelmann 1978). In Wyoming, the LQD has been granted responsibility for setting these requirements (Pers. Com. to D. Keller from W. Ackerman, Wyoming Department of Environmental Quality, Land Quality Division, February 28, 1980).

A second Federal agency that plays a major role in regulating in situ mine construction is the USEPA. Part C of the Safe Drinking Water Act, 42 USC Sec. 300h, requires the USEPA to develop minimum requirements for state programs to protect underground drinking water sources from endangerment by underground injection. Once the USEPA has promulgated the minimum requirements, each state may develop its own enforcement program. If a state fails to develop an adequate program, the USEPA takes over its enforcement responsibilities (42 USC Sec. 300h-1.). Wyoming was one of the 22 states listed, thus far, in the Federal Register by the USEPA as potentially requiring an underground injection control (UIC) program (43 Fed. Reg. 43420.).

The particular permit and substantive standards that apply depend on how a particular well is classified. Since the classifications depend partly on the relationship of the well to an underground drinking water source, the definition of such sources is important. The definition in the proposed rules includes all aquifers that currently provide drinking water or that contain fewer than 10,000 parts per million of total dissolved solids. However, a state may exclude an aquifer that cannot be reasonably expected to supply drinking water (proposed 40 CFR 146.04, 44 Fed. Reg. 23758). Within every listed state, all injection wells must comply with the USEPA's minimum requirements. The regulations establish five classes of injection wells. Of the five established classes, in situ production wells are defined as Class III wells, while in situ disposal wells fall into classes I, IV, and V (Section 4.4.2).

According to the USEPA requirements any existing Class III well operator or owner must obtain a permit for the well within five years of the effective date of the UIC program. No new Class III well may begin to operate after a

UIC program becomes effective unless it has first been permitted (40 CFR 146.31). Specified maps and operating information must be submitted with a permit application. The required information is described in detail in 40 CFR 146.35. The USEPA UIC requirements also impose construction requirements. Each well must be cased and cemented to prevent excursions; constructed with corrosive resistant material; subject to specified logs and other tests that are to be conducted during drilling and construction and documented in a report; and the well field must be bordered by five monitoring wells.

Under the Safe Drinking Water Act of 1973, the USEPA is further charged with the protection of public drinking water supply systems. The USEPA has, thus, set drinking water standards that include a limit of five picocuries per liter radium-226 plus radium-228. Public drinking water supply systems are those with more than 15 service connections or which are used by at least 25 individuals for 60 days per year. Under this definition most conventional uranium mines and mills operate a public water supply system. Presently, in situ operations neighbor existing uranium mines, which means they too are subject to periodic sampling to insure compliance with the USEPA standards (Rouse 1978). In Wyoming, no individual in situ facility has, of itself operated a public drinking water supply system.

While the USNRC and the USEPA, thus, share the major responsibility of regulating in situ mine construction at the Federal level, other Federal agencies may become involved. The Mine Safety and Health Administration (MSHA) oversees health and safety aspects of in situ mining. The Fish and Wildlife Service may also become involved, for example, as it is charged by the Endangered Species Act of 1973 to determine the critical habitat of endangered species. No mining venture (of any sort) may jeopardize any such critical habitat. The law further permits citizens' legal action to enjoin activities in violation of this act or regulations adopted under its authority (Rouse 1978). Other Federal laws potentially affecting in situ uranium mining construction include: The National Historical Sites Act of 1966, and the Fish and Wildlife Coordination Act (Kasper and Engelman 1978, p. 3).

At the state level, several permits must be obtained before mine construction can begin. Three that may already have been obtained at the preliminary exploration and testing stage are: Mining Permit, Observation Wells Permit and Withdrawal Well Permit. While the R&D permit can be renewed indefinitely, it does not authorize commercial activities. Thus, for construction and operation of a commercial mine, the mining permit issued by the LQD (and approved by the WQD) is required. Under certain circumstances construction and completion of wells may be authorized prior to the issuance of a mining permit or research and development license pursuant to WY STAT 35-11-404(g). (See WY STAT 35-11-427.) Additional state permits required at this stage include: an Industrial Siting Permit, an Air Permit to Construct, an Air Permit to install Mill Processing Equipment, Site Equipment Staging Approval, a Potable Water Supply System Construction Permit, a Water Wells Permit, and a permit for a sanitary sewer system (Kasper and Engelman 1978, p. 18-19).

Several different state agencies participate in this extensive permitting process. The Wyoming Industrial Siting Council issues the siting permit (WY STAT Sec. 35-12-101 thru Sec. 35-12-121). The two Air Permits fall under the authority of the Wyoming Department of Environmental Quality (WDEQ), Air Quality Division. The Site Equipment Staging Approval must come from the WDEQ, Land Quality Division. The Water Wells permit, which authorizes the appropriation of water, is issued by the Wyoming State Engineer. The Potable Water Supply System Construction permit is under the jurisdiction of the WDEQ, Water Quality Division, as is the permit for the sanitary sewer system (although the Wyoming State Department of Health shares jurisdiction on the latter). The Potable Water Supply System Permit granted by the WDEQ, WQD (WY STAT 35-11-301) authorizes only the construction of the system. The USEPA must certify the quality of the water for all "public water supply systems" under the Safe Drinking Water Act of 1973. Wyoming does not have primacy in this area. Systems so designated are then subject to monitoring by the State Department of Health (Pers. Com. to D. Keller from T. Mancini, Wyoming Department of Environmental Quality, Water Quality Division, February 27 and 28, 1980).

The Land Quality Division has also been granted responsibility for locating monitoring wells. In nonagreement states this is usually the responsibility of the USNRC (Pers. Com. to D. Keller from W. Ackerman, Wyoming Department of Environmental Quality, Land Quality Division, February 28, 1980).

At the local level, the participants and activities described under the Exploration and Testing Stage would continue to be involved at this stage. In fact, they would be more likely to be active during the construction stage as the development would now be on a far larger scale (Section 4.1.3).

4.2.2.2 Texas

As previously mentioned, Texas has been granted agreement state status by the USNRC, and, thus, regulates all handling of source materials through its own state agencies. Although the National Environmental Act requires that environmental impact statements be submitted prior to any significant licensing actions by Federal agencies, such as the USNRC (See Section 4.2.2.1) there is no requirement as yet that they be developed by license applicants in Agreement States. Even though some states do call for environmental reports (ER) prepared by applicants, recent litigation has exerted pressure on the USNRC to require ER's from all agreement state applicants (Rouse 1978).

Although the USNRC and NEPA regulations do not apply in Texas, the USEPA requirements under the Safe Drinking Water Act do. (See in-depth discussion of these requirements under Wyoming--Government Activities.) Other Federal laws noted in that section as potentially affecting in situ activities in Wyoming may also apply in Texas (i.e., National Historical Sites Act of 1966, and the Fish and Wildlife Coordination Act). The roles of MSHA and the Fish and Wildlife Service are as described for Wyoming as well.

The primary state agencies involved in regulating mine construction are the Texas Department of Water Resources (TDWR) and the TDH. There are two

sets of procedures in Texas statutes related to applications for uranium mines and mills. In situ operations are regulated according to procedures designed for milling applicants (versus mining and milling units). The license review process is subdivided into two different, yet simultaneous, steps: the milling application and the application for a radioactive materials license.

Under step one, the applicant submits an application for an in situ milling permit to the TDWR. Because this permit prohibits discharges into the waters of the state, it may also be called a no discharge permit. The TDWR is authorized to grant these permits under Chapter 26 of the State Water Code. The TDWR sends copies of the permit application to several other state agencies and provides notice of a public hearing in the Texas Register and local newspapers. When the agencies (including the TDH, River Authority, Park and Wildlife, County Health Department, city officials, and other interested parties) return their comments, a hearing is held. A report is then prepared, followed by a public hearing. The Water Resources Board ultimately issues the decision (Kerr 1977).

The TDH is the key governmental participant for step two. The applicant submits a radioactive materials license application to the TDH, which distributes copies to its Radiation Control Branch, including the Environmental Radioactivity Section, the Compliance Section, and the Licensing Review Section. The Licensing Review Section directs comments and questions from all three sections to the applicant and channels the applicant's response back for review. The Licensing Review Section is ultimately responsible for issuing the license (Kerr 1977).

The review process required for TDH licensing differs in certain respects from that followed by the USNRC. In Texas the environmental review is an effort by state agencies identified as having expertise in environmental affairs, whereas the USNRC has a localized body of experts with contractor assistance to perform the review. The USNRC prepares a "Final Environmental Statement", a written summary of its findings, while the TDH publishes an "Environmental Assessment" based on agency verification of information supplied by the applicant (Pers. Com. to D. Keller from D. Lacker, Texas Department of Health, August 7, 1980).

The in situ applicant may also have to apply to the Air Quality Control Board for a permit (TX STAT Tit 71 Art 4477-5 Sec. 3.27). However, according to one source, no permit is required; thus, no further procedures are identified (Kerr 1977).

The specific construction requirements for locating monitoring wells imposed by the USNRC and described above for Wyoming, are also applicable to in situ wells in Texas (Kasper and Engelmann 1978). The TDH and TDWR jointly impose these requirements, originally set by the Waste Resources Department. The TDWR requirements set the monitoring wells at a slightly greater distance from the injection wells than do the USNRC requirements. The USNRC wants their requirements adopted but the TDWR feels that with monitoring wells too close to the mining zone they may miss an excursion (Pers. Com to D. Keller from D. Lacker, Texas Department of Health, October 1974).

One further permit that may be required is the levee construction permit. If mine construction in the flood plain were to divert the stream flow this permit would have to be obtained from the TDWR (Chapter 11 of the Texas Water Code).

4.2.3 Interest Group Participants and Activities

The mine construction stage offers many opportunities for public comment. Hearings are often part of the licensing or permitting process and, as was noted in the section on governmental activities, many permits and licenses are required by Federal and state agencies. The USNRC licensing procedure further invites written comments, and comments on the USEPA proposed UIC regulations are also welcomed. In Wyoming, potential future participants include the Powder River Basin Resource Council and the Wyoming Outdoor Council (a traditional environmental organization).

The Texas licensing process calls for notice in local newspapers of planned hearings on mining activities. There is no evidence as yet of any activity in Texas during this stage. One possible future participant in Texas would be the Texas Environmental Coalition, a traditional environmentalist organization.

As in situ mining becomes more widespread and well known, and as more becomes known about its effects, additional public attention may be focused on it. The channels for support or opposition already exist, and it would be at this stage that public opinion would begin to surface.

Another channel for opposition is litigation. In Wyoming, for example, a suit has been filed by the Friends of the Earth against six government agencies. The suit was precipitated in part by uranium mining activities in the Southern Powder River Basin and was based on alleged violations of NEPA requirements. In the suit, the plaintiffs charge that the Government violated NEPA by allowing companies to drill on Government land without first preparing the proper EIS statements. While a "smattering of site specific statements" were filed, no regional or national program statements were developed. The plaintiffs contend that the cumulative environmental effects of all uranium exploration, mining, and milling activities (yellowcake production activities) must be considered together, noting that 60 mines penetrating the same aquifer have an impact, far larger than that addressed in a site specific EIS. The plaintiffs further insist that any individual mine represents a major action with significant environmental effects requiring an EIS, while the Government has suggested that some individual mines may not require them (Robinson 1979, p. 4).

The mining companies involved in the area sought to enter the proceedings on behalf of "the Government." While the U.S. Department of Justice is handling the "Government's" case, the agencies involved include the USEPA, the USNRC, the USDOE, and the Departments of Agriculture and the Interior.

4.3 STAGE 3: MINE OPERATION

4.3.1 Economic Participants and Activities

Two critical things must be obtained before a constructed in situ mine can begin operation: chemicals and labor. Mine operation then promotes further economic activity. Support services for mine employees and their dependents must be provided, and customers and/or other processors of the extracted ore become involved.

The predominant leachate currently used in in situ mining is a sodium or ammonium carbonate solution. Sulfuric acid has also been tried (Reed et al. 1979). Sulfuric acid is used to adjust the pH in the purifying process and chlorine is needed in the leach solution to kill bacteria (Pers. Com. to R. J. Cole from D. Durler, U.S. Steel, June 21, 1979).

There are already some close connections between those companies that are involved in in situ mining, and suppliers of the chemicals essential to that mining technology. In Wyoming, for example, Western Nuclear, presently exploring the Pumpkin Buttes area for a possible in situ leaching (ISL) facility, also owns a sulfuric acid plant in Riverton (Casper 1979a). Sulfuric acid is a byproduct from the natural gas fields. Rocky Mountain Energy Co. (a subsidiary of Union Pacific Corp.), which has one ISL research facility in Wyoming, is a part owner of Stauffer Chemical Company of Wyoming, a large and expanding trona (soda ash) producer (Casper 1979b). The primary product of trona is sodium carbonate, which is used in the in situ leaching solution. Wyoming is presently the Nation's largest source of trona, with 11.3 million tons mined there last year, and current projections indicating a steady increase through 1985 (Casper 1979c). Getting the necessary chemicals is, thus, not expected to be a problem to in situ operators. Although for some of the mining companies involved in ISL, it may be even easier than for others.

Hiring personnel to operate the facilities may be less difficult than hiring labor for conventional mines. For example, "miners", as they are known to conventional mine operators, are not needed for in situ operations. The in situ technique does not call for the highly specialized skills of hard rock miners. Thus, the current shortages of hard rock miners and other skilled conventional mine workers are of little consequence to in situ plant owners (Pers. Com. to R. J. Cole from G. Ortloff, Exxon Minerals Corp., June 18, 1979).

In situ is, however, a technology so new that there are very few experts. Thus, competition already exists for workers skilled in in situ mining, especially key people in process engineering. Competition is expected to remain high for many years (Cowan and Parkhurst 1980). The personnel that construct and operate an in situ facility are engineers and maintenance/support workers. The unskilled support staff will most likely be recruited almost entirely from nearby towns. Unionization varies more by area than it does by type of mining. Wyoming is not a heavily unionized area. As of October 1977,

20.9% of the uranium workforce was unionized (Wyoming 1978). In South Texas, one source estimates that roughly 10% of the uranium industry is unionized (Pers. Com. to B. Keen from D. Edwards, Atomic Workers Union, Corpus Cristi, Texas, February 28, 1980). There is not much turnover anticipated, especially compared to other mining technologies. In addition to having a flatter skill distribution, in situ techniques require about one half the number of employees that conventional operations would require for comparable production; in fact, most in situ operations will employ approximately 50 people (Pers. Com. to R. J. Cole from G. Ortloff, Exxon Minerals Corp., June 18, 1979) that local populations should supply with little difficulty.

Nonetheless, a certain rise in local population can be expected to accompany in situ mining facilities. Goods and services will have to be provided to incoming employees and their families. Housing, educational and recreational needs will grow. The active economic participants will, thus, include private individuals, local governments or the mining companies themselves. The increased business that the new population represents, the increased social services that it will demand, and the overall increased cost that their presence may cause to the community may well be absorbed by the local merchants and government--more so with in situ facilities, perhaps, than in conventional mining towns. In towns neighboring large-scale (conventional) uranium mines, the mining companies often have no choice but to support the large influx of families precipitated by their operations, since their operations depend on bringing in and maintaining a sizable labor supply. If the established community cannot support the numbers necessary, the mine company must. Company financing, subsidizing or developing of housing and other necessary facilities or services within already established communities would be one plausible scenario. In situ mining does not create the same "do or die situation" as conventional mining. The majority of workers are locals. The relatively small numbers brought in with the facility may put some pressure on the economy and social services of the local town, but not enough to force the mining company to absorb the costs.

In situ operations are economical at very small scales compared to conventional technologies. Thus, as more remote areas begin to be leach-mined, the in situ mining companies may also have to begin to subsidize their workers and their families. Again, the number of people who would have to be supported at each facility would still be relatively small, yet the possibilities for greater numbers of facilities increase radically with the in situ technology. The 1978 Wyoming Uranium Industry Report prepared for the Wyoming Department of Economic Planning and Development (Mineral Division) describes some of the "recruitment and retention measures" already used by mining companies (not ISL) in areas where the nearest towns were up to 60 miles away. These include: company-supported transportation; company-supported communities developed near the mine; (company-guaranteed financing and development of new housing and other facilities in established communities); and inconvenience or travel pay(Wyoming 1978). These would represent some possibilities for future ISL facilities in remote areas.

Once operations have begun and uranium is extracted, two other sets of economic participants become involved--processors and customers. Several types of processors may become involved. With in situ mining it is economical to choose between doing one's own drying, or ending the process at the liquid slurry stage and sending the product to another mill for the final drying steps, thus, taking advantage of excess capacity at close mills. In some cases, the slurry may instead be sent directly to the uranium hexafluoride conversion plant for processing. At present, the market for the slurry product is very small, and it is not considered commercially feasible to eliminate the drying stage (Cowan and Parkhurst 1980). Before the development of ISL, control of the mill meant control of the ore.

The primary customers of the yellowcake are domestic electric utility firms which then arrange for enrichment and fuel fabrication. Approximately 26 of these firms have purchase agreements for Wyoming yellowcake (Wyoming 1978, pp. 4-22).

4.3.2 Governmental Participants and Activities

4.3.2.1 Wyoming

The primary Federal government activities surrounding this stage of the mining process are aimed at detection and control of excursions during mine operation. The licenses/permits that are granted for mine construction include requirements applicable to mine operation. Thus, the agencies that were involved in the Stage 2 licensing process remain involved for Stage 3. In Wyoming these include the USNRC and the USEPA.

The source materials license that must be granted by the USNRC prior to mine construction authorizes processing plant activities and specifies certain monitoring requirements aimed at detecting unwanted excursions of the leaching solution in the wells. The USNRC requires a biweekly recording of water levels and analysis of water samples. Changes in water levels can indicate changes in aquifer hydraulics that generally accompany leachate excursions (Kasper and Engelmann 1978). The USNRC specifies which constituents are to be analyzed on a routine basis, based on an assessment of native groundwater and leachate composition. Samples are compared with background conditions as described in the permit application for deviations indicating possible excursions. The license further requires that the USNRC be informed with 48 hours of the first indication of excursion occurrence (Kasper and Engelmann 1978).

Verification and control procedures must be initiated whenever routine, biweekly monitoring detects any constituent(s) above the upper limit specified in the permit. Excursion control procedures are also set by the USNRC.

Because Wyoming is not an agreement state, the USNRC theoretically retains authority for all source materials. One source reports, however, that the USNRC is leaving groundwater control to the state (Pers. Com. to R. J. Cole from W. May, Everest Mineral Corp., June 19, 1979), while maintaining control

of radioactive materials. Thus, the agency setting upper control limits for excursions, determining which constituents must be analyzed in biweekly water sampling, and receiving deviation notification may in fact be not the USNRC, but the WDEQ (see further discussion below).

In addition to the specified procedures of the USNRC (or its designated representative state agency), the USEPA's proposed UIC regulations prescribe certain operating, monitoring, and reporting requirements for underground injection wells, as authorized by the Safe Drinking Water Act.

The USEPA has further authority over mine operations through the 1972 Federal Water Pollution Control Act (33 USC 1251-1376). This Act provides a comprehensive framework for the regulation of water pollution by the Federal government and the states and sets effluent limitation standards for all pollutants. While radioactive effluents regulated by the USNRC are not subject to regulation under the Federal Water Pollution Control Act, other effluents from the process defined as pollutants under the Act are regulated by the USEPA. These pollutants would include nonradioactive as well as radioactive materials, such as radium, not covered by the Atomic Energy Act.

Discharges of these pollutants require National Pollutant Discharge Elimination System (NPDES) permits from the USEPA, or from a state agency, if the state has been granted primacy in this area (33 USC 1342). The state of Wyoming has been granted such primacy. These permits are to be issued only for discharges that meet the effluent limitation standards developed by the USEPA and established under provision of the Federal Water Pollution Control Act. Under the USEPA's November 6, 1979, regulations outlining NEPA requirements for the USEPA programs, a full NEPA review is required for issuance of any NPDES permits.

Any questions of air pollution are covered by the USEPA under the 1977 Amendments to the Clean Air Act. The Clean Air Act provides a comprehensive framework for the regulation of airborne pollutants by the Federal government and the states through emissions limitations. In December 1979, the Administrator of the USEPA, after review of all relevant information, added radio-nuclides to the list of hazardous air pollutants which could endanger public health, thus, bringing them within the regulatory sphere of the Clean Air Act. Thus, in addition to jurisdiction over subsurface waters during mine operation, the USEPA maintains some jurisdiction over the processing plant due to the possible release of small quantities of radon gas (Kasper and Engelmann 1978). In situ uranium mining is not expected to involve significant air emissions of nonradioactive materials (Section 2.6.3).

In situ operations are further regulated at the Federal level by the MSHA, rather than by the OSHA. In situ operations were part of the interagency agreement that shifted uranium mills from OSHA to MSHA when they are part of a mining operation.

The state and local mining permit and observation and withdrawal wells permits, discussed in the construction section (4.2.2.1), cover mine operation

as well. The mining permit prescribes certain specific requirements for the operating stage. The permit requires that notice of any excursion be directed to the LQD administrator as soon as practicable; authorizes the administrator to terminate or modify the mining operation if an excursion cannot properly be controlled; authorizes changes in water quality criteria for groundwater restoration if it appears to be warranted; prohibits changes in mining technique, method of operation, recovery fluid used, mining and reclamation plans unless approved; and may contain other specified conditions/ requirements to employ the best practicable technology in carrying out the act (WY STAT 35-11-429). This statute further calls for submission of an annual report and maintenance of records describing all monitoring activities (WY STAT 35-11-430).

As mentioned earlier, while the USNRC maintains the authority to regulate source materials because Wyoming does not have Agreement State status, they are leaving water quality matters to the state (Pers. Com. to R. J. Cole from W. May, Everest Mineral Corp., June 19, 1979). At present the Land and Water Quality Divisions share groundwater control responsibilities. The LQD oversees in situ activities overall, issues the necessary mining permits, sets requirements for the monitoring wells and receives notification of excursions. The WQD acts in an advisory capacity for all the above (it must approve all permits) and is presently developing standards for sampling of constituents, upper control limits of excursions, etc. While the WQD must develop the standards, the LQD will supervise their implementation. The upper control limits on water quality to control excursions are set well by well (as opposed to being set for the whole pattern). If a monitoring well exceeds the limit in one element, Federal regulations require a 7-day sampling period, instead of the regular twice a month sampling schedule.

As mentioned above, the WQD would issue any NPDES permit for surface discharges of liquids meeting the USEPA effluent limitation standards (i.e., bleed waters generated during mine operations if they met the standards, or excess waters released while testing pumps, etc.). At this stage, another permit has to be obtained: an Air Permit to Operate, granted by the air quality division of the WDEQ.

4.3.2.2 Texas

At the Federal level, the USEPA has jurisdiction over mine operation as described at length for Wyoming (see above discussion). In Texas the USEPA is still involved in granting NPDES permits, as primary jurisdiction has not yet been granted to the state in this area. No in situ facilities have had to apply for these permits to date (none are discharging into state waters) (Pers. Com. to R. J. Cole from W. A. Steingraber, Texas Department of Water Resources, October, 1979). The USNRC is not directly involved in Texas. The monitoring requirements normally imposed by that agency are instead under the jurisdiction of the Texas Department of Health and the Department of Water Resources (see discussion below). In situ operations are further regulated at the Federal level by the MSHA.

The TDH is the agency designated by the USNRC to license operations involving radioactive materials (USEPA 1975). Maximum concentrations of various radionuclides that are to be permitted in effluents to "unrestricted areas" have been set. "Unrestricted areas" are defined as "Areas to which access is not controlled by the licensee to protect individuals from exposure to radiation and radioactive materials." The maximum allowable concentrations of radionuclides in water effluents to unrestricted areas are set in Appendix 21A to the Texas Regulations for Control of Radiation.

Texas, like the USNRC, requires a biweekly recording of water levels and analysis of water samples. The Department of Health oversees the sampling for radioactive materials, while the TDWR oversees the sampling of all chemicals. Prompt notification of excursions to TDWR is required. Excursion control procedures are as described for Wyoming, although once again the regulating agency is not the USNRC, but the TDWR.

The in situ mining permit issued by the TDWR for mine construction (Section 4.2.2.2) also addresses operating activities and monitoring requirements. The TDWR would also issue NPDES permits in the event in situ operations were to discharge into state waters, i.e., discharge of bleed waters generated during mine operations. (In Texas, NPDES permits must be obtained from both the state and the USEPA.) These discharges would have to meet the USEPA's effluent limitation standards as mandated by Federal Water Pollution Control Act. As mentioned above, no in situ facilities have required these permits as yet.

The Texas Water Quality Board of the TDWR has adopted standards applicable to the surface waters of the state, pursuant to the authority contained in the Texas Water Code Sec. 21.075-.078 as amended by HB 343 (1971). Discharges of radioactive materials are to be limited to the amounts regulated by the Texas Radiation Control Act (TX REV CIV STAT Art 4590f). The 1960 Report on Radioactivity citing background radioactivity levels in the surface waters of the state, as measured by the Environmental Sanitation Services Section of the State Department of Health, is to be the basis for assessing the impacts of radioactive discharges that may be made into surface waters. Radioactivity in fresh waters associated with dissolved minerals is not to exceed levels cited in the Safe Drinking Water Act, unless conditions are of natural origin.

4.3.3 Interest Group Participants and Activities

This is the stage of the mining process that is most likely to precipitate concern, although more formal opportunities for expression of opinion (i.e., hearings) occur during the mine construction stage. The primary interest group activity arising from in situ mine operation has been the expression of concern regarding possible effects of migrations of chemical solutions on aquifers. While there is no evidence of such activity in Texas to date, in Wyoming the Powder River Basin Resource Council noted in their May 1979 newsletter that they were concerned about reported excursions at the

Irigaray site. They recognized that in situ appeared to have fewer environmental problems than conventional mining, but wanted to be certain "...that it is developed in a responsible manner." The Council, thus, promised to "...continue to watch Wyoming Minerals and other companies closely, in order to safeguard Wyoming's groundwater resources." (Powder River 1979). Other environmentalist groups have been cited as expressing "concern," (Barron 1979b) and even "alarm" (Garbutt 1979) about possible contamination of aquifers by leaching agents.

4.4 STAGE 4: WASTE DISPOSAL: CONSTRUCTION/OPERATION--DEEP WELL INJECTION

4.4.1 Economic Participants and Activities

Economic activities and participants would probably be those associated with the construction and operation of injection, extraction, and monitoring wells. Because disposal wells have to be deeper than operational wells, the more complex drilling equipment, such as oil rigs, would probably be required. Production wells, thus far, have been shallow enough to involve only portable water well equipment. Disposal wells would be operated by the company and employees already doing the mining.

One source notes, however, that

"It is unlikely that such wells can be used to any great extent in Wyoming, Utah, or South Dakota . . . most basins, for example, the Madison Limestone, whose base is at a depth of over 10,000 ft (3,000 m), contain usable water. Injection above such depths would be precluded in order to protect this water" (Thompson et al. 1978).

In Texas, however, waste waters are routinely disposed to deep wells. Texas is one of only two states in which disposal wells are currently operating (Thompson et al. 1978).

4.4.2 Governmental Participants and Activities

4.4.2.1 Wyoming

Deep disposal wells are governed by the USEPA as authorized by the Safe Drinking Water Act. The UIC regulations that have been proposed include three classification of wells applicable to in situ disposal wells: those injecting beneath the lowermost stratum containing an underground source of drinking water (Class I), those injecting hazardous wastes into or above strata containing drinking water (Class IV), and those not included in Classes I or IV, which generally inject nonhazardous fluids into strata containing drinking water, including disposal wells (Class V).

Requirements for Class I wells include acquisition of a permit within five years for all existing wells, and prior to construction for all new wells

(40 CFR 146.116). Specified maps and operating information must be submitted with each permit application, as detailed in 40 CFR 146.15. Construction, operating, monitoring, and reporting requirements have been proposed and are spelled out in 40 CFR 146.11-146.14. Requirements for operators of Class V wells have also been proposed, and are set out in 40 CFR 146.52.

Class IV wells are to be prohibited. All existing wells are to be closed within three years of approval of the proposed UIC regulations. Monitoring and reporting requirements are to be prescribed for those wells still operating until they are permanently abandoned (40 CFR 146.43-44).

The USEPA may exercise further jurisdiction under the Toxic Substances Control Act, 15 USC 2601-2629. The Act specifically excludes from coverage: source, special nuclear, and byproduct material as defined in the Atomic Energy Act of 1954 (15 USC 2602). The USEPA could determine that the disposal of other substances through disposal wells, evaporation ponds, or liquid/solid separation may adversely affect the environment or public health. If so, the USEPA could prohibit or otherwise regulate the manner or method of disposal. The USEPA's Best Achievable Technology guidelines for toxic wastes from ore mining are due in Fall 1980 (Pers. Com. to D. Keller from Sylvia Kawabata, Seattle USEPA, March 3, 1980).

At the state level, two permits will be required covering both construction and operation of injection disposal wells. First, the air permit, granted by the WDEQ, Air Quality Division and also required for mine operation, covers this disposal alternative (WY STAT 35-11-201 to 202). Secondly, a subsurface discharge permit must be obtained from the WDEQ, Water Quality Division. This permit, again, is to cover both injection wells construction and operation (WY STAT 35-11-301 to 302).

4.4.2.2 Texas

The USEPA's UIC regulations governing disposal wells (described above) prescribe minimum Federal standards that are to be administered ultimately by the states. Texas is one of four states required to comply with the USEPA program in the near future. According to one source, these four states already impose requirements similar to those addressed in the new regulations (Thompson et al. 1978, pp. 83-84). The USEPA may also exercise jurisdiction under the Toxic Substances Control Act (see above discussion).

Chapter 27 of the Texas Water Code requires that a permit to dispose of waste by well injection be granted by the Texas Water Commission (Sec. 27.011 Texas Water Code). This permit is issued under the Injection Well Act, Ch. 27 of the Texas Water Code.

In addition to a permit application, the applicant must submit:

- a technical report, requiring extensive technical data, to be prepared under the direction of a professional engineer or geologist (treatability studies of alternate methods of disposal must be included, and reasons for rejecting other methods must be detailed)

- a letter from the Texas Railroad Commission stating that well construction and operation will not endanger any oil or gas formation
- a letter from the Department of Health stating that the applicant has obtained a license governing the disposal of radioactive materials, or that such a license is not required.

Once all the information has been submitted, the application is to be forwarded to state agencies and local governmental entities concerned with water quality control, including the TDH and the Water Well Drillers Board. A representative from the TDWR inspects the proposed well location, and a public hearing is held. The applicant must provide notice of the hearing as specified by TDWR rules. A report is prepared following the hearing, and the Texas Water Commission ultimately decides whether or not to grant the permit.

4.4.3 Interest Group Participants and Activities

Based on information accumulated to date, it does not appear that any interest group activities have arisen specifically concerning this stage of the mining process. The potential participants have been described in preceding sections.

4.5 STAGE 4: WASTE DISPOSAL: CONSTRUCTION/OPERATION--EVAPORATION PONDS

4.5.1 Economic Participants and Activities

The primary activity at this stage is the construction of the lined evaporation pond. The participants involved would be those involved in mine construction and operation (see preceding sections).

4.5.2 Governmental Participants and Activities

4.5.2.1 Wyoming

Both the USNRC and the USEPA have control over the design and operation of evaporation ponds for disposal of radioactive wastes. The USNRC prescribes specific design requirements to ensure retention of all radioactive materials (Kasper and Engelmann 1978). The USEPA is promulgating regulations under the Uranium Mill Tailings Radiation Control Act governing the disposition of tailings or wastes resulting from uranium milling activities, including in situ operations. Underground ore bodies depleted by solution extraction operation do not constitute "byproduct material"; however, are therefore not subject to the proposed regulations. Under these regulations, byproduct material from in situ operations "...shall preferably be disposed of at existing large mill tailings disposal sites," in order to "...avoid proliferation of small waste disposal sites" and reduce potential population exposures (Appendix A 10 CFR 40). Appendix A of 10 CFR 40 also establishes technical, financial, ownership, and long-term surveillance requirements for the disposition of wastes. Applicants for source materials licenses for uranium milling (and in situ) operations will have to address this issue in their license applications.

The USEPA, through the Resource Conservation and Recovery Act (RCRA), has jurisdiction over the disposal of nonradioactive solid waste. Application of this Act would subject the mine to recordkeeping, labeling, permitting, and other requirements (42 USC 6922-6925). Calcite removed from the in situ circuit would contain high enough levels of radium-226 and selenium to make it subject to RCRA regulations. A permit would be needed for mining, hauling, and waste disposal (Rouse 1978). The RCRA legislation also provides for development of state permitting programs (similar to the NPDES program) that would regulate the generation, transportation, and disposal of hazardous waste. The USEPA may have further jurisdiction over this disposal alternative under the Toxic Substances Control Act (see the discussion above), and under the Clean Air Act (42 USC 7401-7642).

At the state level, a permit to construct an evaporation pond is required (WY STAT 35-11-301 to 302). This permit is granted by the WQD of the WDEQ. Construction with natural earth materials at the site that have very low water-transmitting characteristics is required where possible. Where not possible, man made synthetic liners or emplaced clay liners are prescribed (Thompson et al. 1978). The Wyoming State Engineer shares responsibility with the WQD for the safety of evaporation ponds as the safety of all impoundments fall within his jurisdiction. Requirements for impoundments and dam safety laws addressed under WY STAT Title 41 (water) and regulations promulgated by the State Engineer under this section call for several kinds of permits applicable to in situ waste disposal operations. These include permits for tailing impoundments, mill settling ponds, mine dewatering ponds and final impoundments (Kasper and Engelman 1978). Finally, the air permit previously mentioned also covers this waste disposal alternative.

4.5.2.2 Texas

The USEPA has some jurisdiction over evaporation ponds through the RCRA and the Uranium Mill Tailings Radiation Control Act (see Wyoming discussion above). The previously discussed Toxic Substances Control Act and Clean Air Act may grant the USEPA further authority during this stage. Also several state-issued permits are required at this stage. The Air Control Board grants an Air Control Permit, as authorized by TX STAT TIT 71 Art 4477-5 Sec. 3.27, which covers both construction and operation. The in situ mining permit issued by the TDWR for mine construction and operation also addresses evaporation ponds. This latter permit, also known as a no-discharge permit, covers discharges into waters adjacent to state waters. (A discharge or NPDES permit would be required if discharges directly into state waters were proposed--see, for example, the liquid-solid separation alternative.) The mining permit prescribes certain specifications for construction/use of the ponds.

Another requirement for this disposal alternative is registration with the TDWR, pursuant to the Solid Waste Disposal Act. At present no permit is required for disposal of hazardous waste on one's own property. However, the TDWR must be notified of the nature and amount of the waste and the disposal method utilized. A TDWR then sends the operator a registration number and

rules and guidelines which must be followed. Waste classifications and unique waste codes are assigned, allowing the Department to keep track of the wastes through required monthly reports. Hazardous wastes sent elsewhere for disposal must be handled in accordance with TDWR instructions. In this case TDWR issues trip tickets to be filled in at various stages in the shipping process. When RCRA regulations are finalized and "hazardous materials" are specified, permits will be required for disposal of certain wastes. If substances associated with the in situ process are defined as hazardous, permits from both the USEPA and the state will be required, until state primacy is granted.

If wastes have to be transported to an evaporation pond at another site, a radioactive waste transport license may have to be obtained from the TDH pursuant to TX STAT TIT 70 Art. 4590f Sec. 14. The Department is not requiring this type of licensing at present.

4.5.3 Interest Group Participants and Activities

Environmentalists have already expressed concern about tailings ponds for wastes accumulated from conventional milling operations. Although the waste disposal ponds used in in situ generally contain smaller volumes and are lined, misconceptions about the disposal pond relative to conventional mill tailings ponds could result in interest group attention, especially in Wyoming where this may be the most viable disposal method.

4.6 STAGE 4: WASTE DISPOSAL: CONSTRUCTION/OPERATION-- LIQUID/SOLID SEPARATION

4.6.1 Economic Participants and Activities

This disposal alternative requires construction of both deep injection wells and evaporation ponds. The active participants would, thus, include participants described for the two preceding disposal options (see previous discussion). Mine operators would oversee the process for separation of liquid and solid wastes.

4.6.2 Governmental Participants and Activities

4.6.2.1 Wyoming

There are no Federal regulatory programs directly applicable to this alternative (Thompson et al. 1978, p. 91). The USNRC guidelines do limit the offsite release of these type of wastes if the radium-226 concentration is more than 5 pCi/l. The USEPA may have some jurisdiction over this disposal alternative under the Toxic Substance Control Act and Clean Air Act (see the two previous discussions. Any discharges to state waters would have to meet the USEPA's effluent limitation standards as established under provisions of the Federal Water Pollution Control Act.

In addition to the previously described air permit to construct a mine, two more permits are required for this form of disposal. A permit to construct

a discharge pond or a subsurface discharge permit would be required, both issued by the WQD, WDEQ (WY STAT 41-3-301). A NPDES permit would be required for any surface discharges of waste liquids treated to meet the USEPA effluent limitations (WY STAT 35-11-301). Both are granted by WQD of the WDEQ.

4.6.2.2 Texas

There are no Federal regulatory programs directly applicable to this disposal alternative. The USEPA may have some jurisdiction under the Toxic Substances Control Act and the Clean Air Act (see previous discussions), and would issue NPDES permits under the Federal Water Pollution Control Act, if discharges were to be made directly into state waters. Thus far, no in situ facilities in Texas have required this permit. If Texas is granted primacy under this act, the Federal NPDES permit will no longer be required.

At the state level two permits would be required: an air control permit issued by the Air Control Board (TX STAT TIT 71, Art 4477-5, Sec. 3.27) and a state discharge (NPDES) permit for discharges to state waters meeting the USEPA's effluent limitations issued by the TDWR (see discussion under Texas, Stage 3). Registration with the TWDR pursuant to the Solid Waste Disposal Act may also be required (see discussion under Texas Evaporation Pond alternative).

4.6.3 Interest Group Participants and Activities

One source points out that public opinion may prevent the further use of water (i.e., for irrigation) that contained radioactive material prior to treatment (Thompson et al. 1978). Tailings ponds have already precipitated some public concern, as well. Ammonia left in the groundwater may cause additional concern. Under the proper conditions, ammonia may be converted by nitrifying bacteria into nitrites and nitrates, which can be quite toxic even in small concentrations, particularly to infants and young children.

4.7 STAGE 5: RECLAMATION/RESTORATION

4.7.1 Economic Participants and Activities

Subsurface restoration techniques that may be attempted include: pumping of selected leach wells, pumping of selected wells in combination with injection into the same or other groundwaters, and natural restoration. These techniques are described in Section 2.9.

Surface restoration involves removal of all structures, pipelines, and other equipment, and the sealing of evaporation ponds and wells (Kasper and Engelmann 1978, p. 28).

The economic participants involved with this final stage of the mining process are those that have been involved in stages 1-4.

4.7.2 Governmental Participants and Activities

4.7.2.1 Wyoming

The USEPA is the primary Federal agency overseeing restoration. The proposed UIC regulations prescribe certain requirements for the abandonment of operational and disposal wells, and the USEPA's proposed criteria for disposal of radioactive wastes (see discussion above) will also apply. The Uranium Mill Tailings Radiation Control Act of 1978, intended to correct the problem of abandoned wastes from conventional milling operations, includes regulations applicable to wastes produced by in situ activities (Williams et al. 1979). (See previous discussion.)

Early restoration requirements called for restoration of water to a composition identical with or superior to original water. Present regulations recognize the difficulty of achieving these standards and are instead based upon native water composition, potable water quality standards, water quality required for probable future uses, and treatability of waters.

The USEPA proposed UIC regulations require that Class I and III wells be abandoned in a manner not allowing migration, and that a performance bond (or equivalent) be posted to assure the availability of resources necessary for proper well abandonment. Existing Class IV wells, as previously mentioned, are to be closed within three years of effective date of the UIC program. Regulations for abandonment of Class V wells may be promulgated in the future (40 CFR 146.14, .34, .44, .52).

The USNRC has some involvement with restoration, as well. The source materials license necessary for mine operation is conditional upon demonstration of successful restoration of a pilot facility (see discussion under exploration).

The WQD of the WDEQ is currently preparing rules and regulations for restoration of water quality. At present, criteria for restoration are outlined in the in situ mining permits issued by the LQD.

4.7.2.2 Texas

The role of the Federal government (USEPA) in Texas at this stage is as described above for Wyoming.

Texas is one of the few states that have stringent regulatory and enforcement authority over well abandonment. One source indicates that the proposed USEPA UIC requirements follow existing Texas regulations very closely (Williams et al. 1979). These are, again, under the jurisdiction of the TDWR.

4.7.3 Interest Groups Participants and Activities

According to a Wyoming Mining Association spokesman, environmentalists are no longer as concerned about land reclamation as they once were. "You don't see the Sierra Club out saying the industry is not reclaiming," he

said. "They're addressing other problems." He further noted that "Except for young zealots out looking for a cause," environmentalists are no longer a burning issue in Wyoming (Barron 1979a).

This may be especially true with reclamation and restoration following in situ activities which do not disrupt the land nearly as much as do conventional mining techniques. On the other hand, inadequately abandoned wells may provide a "connection between poor and good quality groundwater aquifers" or "a conduit for hazardous residual mining fluids or contaminated surface waters, into potable aquifers." (Williams et al. 1979). Thus, those who have expressed concern about possible or reported excursions during operations may continue to remain concerned at this stage.

Texas is noted for its relatively early and strict regulation of this aspect of mining, perhaps reducing public concern about it. However, the large number of improperly abandoned wells in Texas prior to regulation may have sensitized the public to this problem. Reports of excursions may well lead to concern and/or activity. The previously mentioned Texas Environmental Coalition would be one potential participant.

5.0 IMPACT ASSESSMENT

In situ uranium mining has been hailed as an environmentally safe method for extraction of uranium by some advocates and has been recommended as an environmentally desirable alternative to conventional uranium mining methods. This section of the report examines the ways in which in situ uranium mining operations can potentially affect the physical, chemical, ecological, social and institutional environments.

5.1 PHYSICAL ENVIRONMENTAL IMPACTS

Normal construction and operating activities associated with an in situ facility may impact the physical environment and air and water quality in the vicinity of the plant. The impacts on the physical environment that may occur from various construction activities, in most cases, were found to be minor or temporary in nature.

This analysis of potential impacts is based on limited data in most cases which causes difficulty in making analytical evaluation of impacts. The data that is presented in Chapter 2 are often from only one or two sources. Thus, the data are given to represent the probable range or magnitude of values and not absolute values. As more data become available and as technology changes occur, a more detailed analysis of the environmental impacts will be possible.

5.1.1 Air Quality

Nonradiological impacts on air quality will result mainly from construction activities. These effects will be small because the activities are of short duration and produce low emission rates (USEPA 1979).

Construction of an in situ facility and drilling of the well field could affect the local air quality by the formation of fugitive dust and the release of diesel emissions from drilling and construction equipment (Section 2.6.3) (USEPA 1979). Diesel emissions will be minor and of short duration and should be readily dispersed (USNRC 1978c). Dust will be generated as the result of construction and drilling activities. Areas that are not reseeded or otherwise treated to minimize dust emissions could become sources for suspended particulates during high wind conditions (USEPA 1979, USNRC 1978c). In the drier parts of the uranium mining region, the suspended particulate concentrations could locally exceed allowable standards (USNRC 1978c,d).

Air quality at the in situ site is affected during operations by atmospheric releases from the central processing plant, waste storage ponds and process chemical storage (USEPA 1979). Atmospheric releases for typical in situ facilities are given in Section 2.6.3. Nonradiological releases associated with process chemicals are considered negligible, and of such low levels that absolute values are not reported in license documents (USNRC 1979c, Texas Air Control Board 1978, 1979) therefore impacts are also assumed to be negligible or minor.

For facilities that use ammonia as a leach solution or as an agent in precipitating the uranium, routine releases of ammonia or ammonia chloride have the greatest potential for impacting air quality (USEPA 1979, USNRC 1978c). Ammonium chloride formed over the waste pond are likely to rapidly precipitate in the immediate vicinity of the pond and, thus, should have no effect on air quality (USEPA 1979, USNRC 1978c). Under normal wind conditions, ammonia levels are expected to be below $75 \mu\text{g}/\text{m}^3$ at 100 m from the facility (USNRC 1978c). This is well below the threshold limit value for ammonia, the threshold for ammonia odor or the lowest atmospheric concentration of ammonia known to affect vegetation. In several years of operating experience in Texas, no impacts due to ammonia releases have been observed (Cowan and Parkhurst 1980).

Other nonradioactive chemical releases commonly associated with in situ facilities are combustion products from the burning of fuel oil or natural gas in the dryer and HCl and CO₂ releases from process tanks (USNRC 1978c,d). Routine releases of these atmospheric constituents are unlikely to adversely affect local air quality. No impacts from atmospheric emissions have been observed or measured in over 5 years experience in Texas (Cowan and Parkhurst 1980).

Radiological atmospheric releases result from radon-222 emissions from wells and surge tanks and from yellowcake dust that escapes in the drying process. Examples of anticipated radiological emissions from representative facilities with dryers are given in Section 2.6.3. Facilities that ship yellowcake slurry have much lower levels of radiological emissions, with most of the emission being radon-222. In 5 years of in situ operation, no radioactive releases have been measured to be above standards (10 CFR 20, Appendix B, Table II, Column I) at the fence line (Pers. Com. to C. E. Cowan from E. Bailey, Texas Dept. of Health, 1979). For operations without dryers no radiological emissions have been detected and for facilities with dryers only minor amounts have ever been detected (Pers. Com. to C. E. Cowan from E. Bailey, Texas Dept. of Health, 1979). Generally, atmospheric emissions are projected to be less for in situ facilities on a production rate basis than for conventional milling activities (USEPA 1979). Based on these emissions values and dispersion characteristics, the in situ facility's air quality impacts are anticipated to be minor.

5.1.2 Surface Waters

Surface waters can become contaminated during construction activities, during mining operations or after operations, as the result of improper well abandonment. Most in situ activities are designed to have zero or very low discharge of contaminated waste to surface waters. However, in some cases surface waters may receive flows from groundwater through pathways that are at present imperfectly understood. Improperly constructed, operated or abandoned wells or test holes can provide a mechanism for contamination of surface waters as well as natural connections between underground aquifers and surface waters. In addition, accidental releases from failure of evaporation pond dikes or

failed pond liners could result in unplanned releases of contaminants to surface waters during operation or restoration phases.

Impacts to surface water quality during construction will result primarily from the release of sediments, oil and grease from the construction site into neighboring surface waters. The land clearing associated with the construction of the in situ facility can cause more rapid runoff to occur during rainstorms which accelerates scouring and erosion (USEPA 1979). This scouring and erosion would pick up oil and grease from diesel equipment and drilling rigs (USNRC 1978c). Many of the potential in situ sites are located in semi-arid areas where surface water loads of sediments are very high due to high surface erosion (USEPA 1979, USNRC 1978c) and where surface waters are intermittent or located considerable distances from the in situ site. The impact to the surface waters in the vicinity from erosion due to construction is anticipated to be small or negligible because of the small area disturbed at any one time and the intermittent nature and distance to surface waters. No impact on surface water is expected under normal operating conditions because in situ operations produce no discharge to surface waters (USEPA 1979, USNRC 1978c,d).

There is, however, the potential for surface water contamination resulting from migration of contaminated groundwater (USNRC 1978c,d). There are several factors that would make it unlikely that any deterioration of surface water would occur that would result in harmful levels of pollutants. First, current operations are conducted to reduce the possibility of contaminated groundwater migrating out of the mining area. Groundwater is monitored to detect any excursions and procedures are implemented upon detection of an excursion to prevent contamination of groundwater outside the mining permit area (Section 2.8). Second, many scientists believe that if any contaminated groundwater should migrate outside the mining area, the contaminated substances will be adsorbed by clays and other minerals. In addition to removal of contaminants by adsorption, the contaminated groundwater would be diluted to some extent by uncontaminated groundwater. This is an area that needs to be further researched in order to better define the potential for contamination and to reduce uncertainties. Finally, restoration is expected to return any affected groundwater to a level consistent with previous groundwater quality under existing regulations. These factors act to make contamination of groundwater improbable under normal operating conditions and, thus, result in undetectable impacts on surface water (USNRC 1978c,d); however, these factors will need to be evaluated on a site-specific and leach-specific basis. Restoration is an area that also needs to be further researched especially with regard to the potential for conversion of ammonia, sorbed to clay particles, to nitrates and nitrites which could contaminate public drinking water supplies (Section 6.2).

Accidental spills of chemicals could result in temporary impacts on surface waters. Procedures such as berming and lining of waste ponds and loading and unloading of chemicals on concrete pads reduce the likelihood of accidental spills impacting local surface waters (USNRC 1978c,d).

5.1.3 Groundwater

The potential exists for groundwater contamination to result from in situ facility operation. Some of the potential mechanisms for contamination are increased groundwater concentrations of uranium and trace minerals, excursions of lixiviant material beyond the mining zone, sorption of ammonia on clays, accidental spills, well casing failure and leaks from waste ponds.

During the in situ leach operation, groundwater quality within the mined zone will be lowered by increased concentrations of uranium, lixiviant chemicals and associated trace minerals. As described in Section 2.8 normal leaching operations are designed to limit excursions. Even if an excursion occurs several methods exist for controlling excursions. Also, as mentioned in the previous discussion, any chemicals lost during an excursion would interact with soils and the groundwater reducing any potential deterioration (USNRC 1978c,d). Thus, deterioration of the groundwater by normal operations is limited to the immediate mine area and contamination due to excursions is unlikely. However, the need to better evaluate the potential for contamination of groundwater should these operations be ineffective is a major issue facing the technology (Section 6.2).

Contamination of the groundwater by liquid wastes stored in waste ponds is also unlikely under normal operations. Liquid and solid wastes (Section 2.6) are stored in ponds that are lined and monitored for leaks (USEPA 1978c). If a leak occurs, contamination of the groundwater would probably be minimized by absorption of contaminant on clays or other minerals and by the depth to the uppermost aquifer (USNRC 1978c), although the extent to which this factor would act needs to be determined on a site-specific basis. Additionally, accidental spills or leaks from chemicals would also be small and would not adversely impact the groundwater quality because chemical loading and unloading will take place on cement pads (USNRC 1978c).

Restoration methods and standards specifying restoration goals are expected to reduce the possibility of groundwater contamination after mining (USEPA 1979, USNRC 1978c,d). Ammonia is the constituent that presents the greatest difficulty in restoration cleanup and is one of the major constraints on the technology using ammonia-based lixiviant especially since ammonia would potentially convert to nitrate and nitrite which could have serious health effects if they contaminate public drinking water supplies (Section 6.2).

Groundwater contamination could result from casing failures in both the injection and production wells used in mining and from deep disposal wells. Contamination by both of these sources is unlikely because of the strict regulations involved in constructing wells (Chapter 4) and the continuous monitoring requirements (Section 2.7). In over 5 years of experience in Texas, no groundwater supply system has been contaminated by deep well disposal failure (Steingraber 1980) although some localized groundwater contamination has resulted from injection and production well casing failures.

Although consumption of groundwater during mining is small especially when compared to conventional mining, groundwater consumption during mining would be approximately 15-30 gpm (USNRC 1978d, Thompson et al. 1978). Withdrawal of groundwater over extended periods of time could temporarily affect the level of the water table adjacent to the mining zone (USEPA 1979). Groundwater users in the immediate vicinity of the mining area could have their water supplies affected by these withdrawals until mining has ceased and the natural water table has returned to its premining level (USEPA 1979, Thompson et al. 1978).

Restoration methods (described in Section 2.9) require large volumes of groundwater and represent the largest consumptive uses of the groundwater (USEPA 1979, USNRC 1978d). Consumptive uses of groundwater for restoration represent approximately 20 to 30 times that required during mining. These water intensive restoration techniques will have a greater impact on the availability of groundwater than normal operations; nevertheless, after restoration is completed, the groundwater system normally will replenish itself (Thompson et al. 1978). The need for development of less consumptive groundwater restoration techniques is recognized as a major issue facing the technology (Chapter 6).

5.2 ECOLOGICAL ENVIRONMENTAL IMPACTS

The greatest potential for ecological impacts would result from vegetation disturbance and related loss of wildlife habitat during well field development as well as from increased human activity. Atmospheric emissions, and changes in surface water and groundwater quality which were examined in previous sections, are not expected to have a measurable impact on terrestrial or aquatic biota (USNRC 1978c,d). All waste ponds and well fields will be fenced to prevent access by wildlife or domesticated livestock (USNRC 1978c,d, USEPA 1979). Traffic associated with both the construction and operation of the in situ facility will result in a small number of road kills of animals which should not impact local animal populations (USNRC 1978c,d). Human activities at the facility site including noise from machinery may drive away particularly sensitive species but should not result in significant impact on the ecology (USNRC 1978c,d).

The most significant ecological impact will result from removal of flora and fauna at the site of the processing facility and at well fields. The total area disturbed will usually be less than 100 acres (405 hectares) at one time based on data from several in situ facilities (Section 2.3). Most of the land disturbed will consist of the abundant sagebrush/grassland type, grassland savannah or already disturbed croplands, pastures and old fields (Section 3.3). These ecological habitats cover many hundreds of acres. Many acres are already disturbed from original habitat type due to farming and grazing. Therefore, removal of the flora and fauna on the few acres associated with an in situ facility will not create a significant impact (USNRC 1978c,d). To reduce the level of impact, reclamation plans for each area include reseeding with original vegetation and protecting long-lived shrubs and trees (Section 2.9).

5.3 OCCUPATIONAL IMPACTS

5.3.1 In-plant Chemicals

A number of process chemicals have been identified in Table 2.1 as a function of three alternative uranium recovery processes, e.g., sodium bicarbonate leach, ammonia bicarbonate leach and acid leach. Several chemicals are common among the processes. Even though total containment of these chemicals is unlikely, estimates of work area air concentrations have not been identified in Federal or state regulatory records. Therefore, a comparison of some process chemicals with OSHA regulations that must be met by these facility operators is presented in Table 5.1. Because of a lack of OSHA regulations for most of the process chemicals, threshold limit values (TLV) are also given. A TLV refers to airborne concentrations of substances and represents conditions to which nearly all workers may be repeatedly exposed without adverse effects.

5.3.2 In-plant Radon Exposures

The selectivity of the in situ uranium mining process to uranium results in low concentration of radon in the production solution, since radium-226 is only partially soluble in production fluids. Radon present as dissolved gases may be brought up from production wells where they are then accumulated in the surge tanks from which the radon-222 is vented to the atmosphere.

Areas around the calcium clarifier are monitored for radon through the use of thermoluminescent dosimeters (TLDs). Reported values ranged from 0.02 to 0.16 mr/hr in these work areas (USNRC 1978a). This level is less than 25% of the exposure limits in 10 CFR 20.

Grab samples of radon gas collected from over the calcium clarifiers during a 9-month period of 1979 at the Irigaray facility showed radon air concentrations of less than 4×10^{-8} $\mu\text{Ci/ml}$ which is 0.04 working levels. In a recent report to the Royal Commission of Inquiry concerning health and environmental protection for uranium mining, Hunkin (1979) reported that during about eight years of process development and production activities not a single incident has occurred that has required restriction of working activities in any way or any limitation of working hours at any location within these plants.

5.4 PUBLIC IMPACTS

5.4.1 Nonradioactive Releases to the Atmosphere

A variety of nonradioactive materials are released to the atmosphere from in situ leach operations as identified in Tables 2.5 and 2.6. These materials are dispersed into the atmosphere and become greatly diluted with distance from the plant site. Annual average atmospheric dispersion factors ($\bar{X}/Q'$) are

TABLE 5.1. Work Area Guidelines and Standards for the Exposure of Chemicals
(USHEW 1978, ACGIH 1976)

Chemical	OSHA STD		TLV		Other
	(ppm)	mg/m ³	(ppm)	(mg/m ³)	
Ammonia	50 TWA(a)	35	25	18	INV-MUS LD50=245 mg/kg(b)
Ammonium Bicarbonate		-	-	-	
Ammonium Chloride (fume)			-	10	
Ammonium Hydroxide	50				
Barium Chloride (soluble)			-	0.5	
Carbon Dioxide			5000	9000	
Chlorine			1	3	
Hydrochloric Acid			5	7 MAC(c)	
Hydrogen Peroxide			1	1.4	
Magnesium Oxide (fume)		15	-	10	
Nitric Acid			2	5	
Sodium Bicarbonate					IRDS: skn-hmn 30 mg/3D MLD(d) ora]-hmn LDLO: 500mg/kg(e)
Sodium Carbonate					IRDS: skn-rbt 500 mg/24H MOD(f)
Sodium Chlorate					IRDS: skn-rbt 500/mg24H MLD(g)
Sodium Hydroxide				2.0 MAC	
Sulfuric Acid				1	

(a) Time weighted average.

(b) Intravenous-muscle lethal dose to 50% of population.

(c) Maximum allowable concentration.

(d) Primary irritation dose: skin-human, 3 day exposure, mild irritation effect.

(e) Lowest published lethal dose.

(f) Rabbit 24 hr exposure, moderate irritation effect.

(g) OSHA 29 CFR 1910.1000 from Federal register 43(243):59019-19021 "Proposed Rules", December 18, 1978.

calculated using Battelle's XOQ DOQ Program from wind speed and stability data for the generic site which was taken from USNRC (1979b). The $\bar{X}/Q'$ that leads to the maximum ground level concentrations at the site boundary (1/2-1 mile sector) is 5.2×10^{-6} sec/m³ in the ENE direction.

The resulting site boundary concentrations for these materials are compared to applicable regulations and presented in Table 5.2. Ammonium sulfate is expected to be released to the environment in quantities of less than 1.5 tons/yr (1.4 MT/yr). If it is assumed that 1.5 tons/yr were the real value, then the site boundary concentrations would be that presented in Table 5.2. All these chemical releases are many orders of magnitude below existing standards and regulations. At these very low levels, it is not expected that health effects will result; however, a great deal still needs to be learned about the environmental fate of all chemical compounds before the health effects can be fully evaluated at these very low ambient levels.

5.4.2 Radiological Releases to the Environment

Radiological releases to the environment will be primarily radon-222 and uranium-238. Radon-222 emissions to the environment will be limited to the lixiviant circuit, in particular, to the surge tanks that are vented to the atmosphere. Uranium-238 emissions come primarily from dryer stack exhaust.

TABLE 5.2. Site Boundary Concentrations of Nonradioactive Atmospheric Emissions from an In Situ Leach Facility^(a)

	Site Boundary Concen. mg/m ³	ACGIH TLV mg/m ³	OSHA mg/m ³	National Ambient Air Quality Stde, µg/m ³
NH ₃	2.06×10^{-3}	18	35	-
CO ₂	0.234	9000	9000	-
NH ₄ Cl	7.2×10^{-3}	10	-	-
(NH ₄) ₂ SO ₄ ^(b)	2.2×10^{-4}			
	<u>µg/m³</u>			
CO	0.69	-	-	10,000
Particulates	0.14	-	-	75
Hydrocarbons	0.20	-	-	160
NO _x	2.8	-	-	100
SO _x	0.2	-	-	80

(a) Calculated from Data in Tables 2.5 and 1.6 using $\bar{X}/Q' = 5.2 \times 10^{-6}$ sec/m³

(b) Registered food additive and on the United States Food and Drug Administration's "Generally Regarded as Safe" list.

Exxon Minerals Co. established a qualitative correlation between the rate of radon released and the quality of the in-place uranium deposit. For their ore body, they found the dissolved radon-222 content of the lixiviant to average 0.37 $\mu\text{Ci/l}$ with an actual release of 50 to 75% (Stover 1979). Stover (1979) used this radon concentration and a release rate of 75% to estimate the annual radon release rate from the Hobson Project to be about 286 Ci. Since there is no available site boundary distance information as a function of compass direction except one listing the "nearest site boundary to the sources is 525 ft east of the process area," the 147 m distance will be evaluated from the annual average atmospheric dispersion ($\bar{X}/Q'$) calculated using Battelle's XOQ DOQ program. The maximum ground level concentration will be found at 147 m NNW of the facility where the $\bar{X}/Q'$ is $1.2 \times 10^{-5} \text{ sec/m}^3$. Based on a release of 286 Ci, the annual average ground level concentration for radon-222 is $1.1 \times 10^{-10} \mu\text{Ci/cm}^3$ or about 4% of the maximum permissible concentration of $3 \times 10^{-9} \mu\text{Ci/cm}^3$ for exposures to the public (Texas Dept. of Health and 10 CFR 20, Appendix B, Table II, Column 1, USNRC).

Annual average ground level concentrations for radon-222 and uranium-238 calculated from emission rates given in Table 2.7 are $2.9 \times 10^{-11} \mu\text{Ci/cm}^3$ and $5.7 \times 10^{-14} \mu\text{Ci/cm}^3$, respectively. These values are 1% and 2% of their respective standard as given in 10 CFR 20, Appendix B, Table II, Column 1.

As with chemical releases, the release of radon-222 and uranium-238 are well below standards. At these very low levels of exposure, it is not expected that health effects will result; however, there is controversy about the relationship between low levels of exposure and health effects.

5.5 SOCIAL IMPACTS

This section describes the potential institutional and socioeconomic impacts of in situ activities as the technology spreads into new regions or experiences rapid growth in areas where it already exists. Some of these impacts would result from the introduction of any new technology. The legal and organizational impacts described below include examples of these more generic impacts. Other impacts stem from the unique attributes of the in situ technology. For example, in situ operations, as noted earlier in this report, are economically feasible at far smaller scales than other forms of mining. As a result, the small, highly capital-intensive in situ units can be spread into new areas, previously free of nuclear related activities of any sort, with potential political and psychological impacts. Furthermore, the more generic impacts may be exacerbated as a result of these unique attributes. Neighboring states with long histories of involvement with nuclear activities may not provide applicable models for states newly subject to in situ activities. For many of the impacts discussed, examples of impacts that have occurred or are occurring in Texas and Wyoming are given.

5.5.1 Institutional Impacts

Institutional impacts include legal impacts, organizational impacts, and political impacts.

5.5.1.1 Legal Impacts

Legal impacts can include legislation or litigation aimed at settling legal issues arising from the mining technology or its effects. The following is an assessment of potential legal impacts which may occur as in situ mining spreads to new areas, based on experiences with in situ activities in Texas and Wyoming.

- Interpretation of existing laws will be essential. Questions may arise as to whether this form of mining is in fact covered by existing laws. Legislation may be required to resolve legal ambiguities arising from the need to regulate a new technology.
- Existing laws may not be entirely appropriate to in situ activities, and laws exempting or specifically addressing this form of mining may be required.
 - For example, the Texas Surface Mining and Reclamation Act (SB55, (1975)), which recognized the importance of surface mining as well as its disruption of the land, specifically exempts in situ from its provisions. One source notes that this "...demonstrates recognition of the minimal impact of solution mining on the environment." (Hunkin 1979).
- Legislative action may be required to assign agency jurisdiction over in situ activities.
 - In Wyoming, for example, legislative action was required to settle the confusion which arose within the Department of Environmental Quality over which of its divisions was to regulate in situ mining. The Land Quality Division had regulated mining while the Water Quality Division regulated water. The in situ mining process, with its important consequences for the groundwater, appeared to fall under both jurisdictions. The legislature resolved the issue by assigning in situ mining to the Land Quality Division by statute. This statute also clearly outlined permitting procedures and requirements.
- Where a new agency is created to oversee in situ activities or where existing agencies are assigned substantially greater functions or duties, legislative action may be required to appropriate funds necessary for those activities.
- Deviations in state agency requirements or standards from those outlined by Federal agencies may require legal resolution, particularly in Agreement States.
 - In Texas, for example, the state has developed different requirements for the location of monitoring wells than those issued by the USNRC. Disagreement regarding these standards has yet to be resolved.

- The issue of when a regional rather than site-specific EIS would be required may arise.
 - This issue has already arisen in the suit filed in New Mexico by the Friends of the Earth and a group of Navajo Indians. As they pointed out, one mine penetrating an aquifer may not represent a significant hazard to the environment, but sixty mines penetrating the same aquifer might.
- In some states ambiguities regarding regulatory requirements for in situ leaching on Indian lands may require legal interpretation and resolution.
 - Indian tribes as government entities control mineral development on their land through regulations, ordinances, and other specifications promulgated by assorted tribal bodies. Overlapping or conflicting regulations may have to be sorted out.
- Environmental groups seeking to halt or retard uranium mining activities specifically, or nuclear power generally, may choose litigation as a means to that end.
 - Two suits directed at uranium mining activities have already been filed. As is discussed in greater depth above, one effort was made to halt Mobil's in situ pilot project at Crown Point, New Mexico, and a second suit was filed in Wyoming.

5.5.1.2 Organizational Impacts

Organizational impacts can occur on many different levels. New organizations may be formed to promote a given activity or accomplish a certain mission; established organizations may become reorganized in an effort to keep up with new developments, or established organizations may not want to adapt to changes and, therefore, affected against their will. This assessment of potential organizational impacts that may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Special interest organizations promoting the industry may be formed with both political and nonpolitical missions.
 - One new organization in Wyoming is the state chapter of "Women in Mining." While this organization is not concerned with in situ mining alone, it represents women concerned with mining generally. Women in Mining was organized to "promote the mining industry" and to help educate the public about it. Monthly meetings are held, guest speakers are welcomed and a scholarship is to be offered to a high school senior who plans to major in mining. The group ultimately hopes to become involved in lobbying efforts as well (Casper 1979d).

- State regulatory agencies may have to regulate a technology that is entirely new to them. New rules and regulations will have to be drafted, adopted, and codified. For many agencies, a great deal of learning may first have to occur. Uncertainties about the technology, resulting in large measure from its newness, may pose special problems for agencies trying to draft appropriate regulations. Because in situ activities potentially affect air, land, water, and health, several agencies may be affected in each state.
 - In Wyoming, for example, the Water Quality Division has not yet promulgated regulations applicable to the in situ technology, though the LQD has. The WQD is taking far longer to promulgate these regulations than was initially anticipated.
- Regulatory agencies are likely to have new responsibilities. Licensing, permitting, monitoring, and advisory duties may be required of each affected state agency in addition to the development and enforcement of new regulations. In most cases this increased work load will require additional personnel.
 - The new regulations, permits, and standards developed by the Land Quality Division in Wyoming are examples of the kinds of activities that will be necessitated by this new technology.
 - Some states may, furthermore, be required to undertake Federal programs such as UIC more quickly than other states as a result of the expansion of this technology within their boundaries. Texas, for example, was one of four states specified by the Federal government as having to adopt UIC regulations more rapidly than other states, primarily because of past experiences with inadequate well abandonment.
- Costs to the regulatory agencies of preparing to develop and execute these new functions may run high, especially at the beginning. In addition to possibly needing more manpower, regulatory personnel will require training. Unless salaries in the state become competitive with those offered in the private and Federal sectors, the state will not be able to attract experienced personnel. Training is, furthermore, likely to prove a continuing drain on resources as state personnel, having gained skills and on-the-job experience, leave for higher salaries offered by private industry.
- Increased interagency interaction may be required as in situ facilities affect air, land, water, and health. A great deal of close contact and coordination is critical in developing rules and procedures that do not conflict or overlap and that are reasonable to protect society while yielding flexibility to industry. In some cases, close contact may be a continuing necessity, extending beyond the stage of development of rules to each licensing or monitoring action.

- In Wyoming, for example, the Land and Water Quality Division of the WDEQ work closely on every aspect of the in situ process including licensing, monitoring, and enacting appropriate standards and regulations.
- Conflict and confusion for the involved agencies is likely to exist until jurisdiction over in situ is clearly and legally defined.
 - The experience of the Land and Water Quality Divisions in Wyoming prior to legislative action illustrates this point.
- In some cases pressure may be exerted on legislators to create a single coordinating agency authorized to oversee all necessary licensing activities from application through certification.
 - In Wyoming the Industrial Siting Administration recommended in its 1978 annual report that a central lead agency be established to process permit applications for all proposed industrial facilities. It was hoped that a lead agency would lend uniformity to the permit review process which is currently a mass of differing requirements and deadlines from several different agencies.
- In nonagreement states, some agencies may be saddled with responsibilities generally shouldered by the USNRC but informally granted to the state in certain instances. This informal delegation of responsibilities could create administrative ambiguities for the regulating agency.
 - In Wyoming the USNRC has retained for itself responsibility for regulating radioactive materials but is leaving issues of ground-water quality up to the state.

5.5.1.3 Political Impacts

Political impacts include use of the political process to express opinions about the technology or its effects, or represent a given group's desires or interests. The electoral process and lobbying activities are two possible channels for political action that can occur at the local, state, or Federal level. The electoral process can further be broken down to include two sets of participants: voters and candidates. This assessment of potential political impacts that may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Interest groups could oppose the use of in situ technology because of threats to the groundwater, especially in those states in which there is a great sensitivity to issues of groundwater quality (as was the case in Wyoming).
 - Interest groups that have been active thus far, as noted in Chapter 4, include environmental groups, Native Americans, farmers, and ranchers.

- In situ uranium mining may provide a new focus for opponents of nuclear energy and those concerned about radioactive waste disposal. Political opposition could take the form of lobbying to prohibit uranium mining in the state, or protests of specific sites or activities.
- The spread of nuclear-related activities into previously unaffected areas could lead to new instances of collective political action by people opposing such activities "in their backyard."
 - Activities along these lines have already been evidenced in some states, notably Colorado, and have impeded development of any commercial facilities in that state, although in situ mining would technically be feasible on many deposits (Cowan and Parkhurst 1980, p. 40). Public hearings could delay licensing for years and significantly increase costs.
- At the local level, the new activities, operations, and residents may affect the local political scene. New issues may require political action, and new people may run for office. While in situ operations do not bring with them large numbers of new residents (voters), new individuals in the community affiliated with the mining operations may run for office. Voters (new and old) may elect these new candidates based on their presumed experience with the specific issues arising from the new activities. Local elected officials called upon to solve problems arising from the new facilities may be required to learn and execute new types of political actions in order to solve them (see discussion of fiscal impacts, for example).
 - One Texas town that neighbors an in situ facility is considering incorporation (Pers. Com. to R. J. Cole from personnel at U.S. Steel Georges West Plant, June 19, 1979).
 - A Texas mining engineer became the commissioner of a local community (Pers. Com. to R. J. Cole from personnel at U.S. Steel Georges West Plant, June 19, 1979).

5.5.2 Socioeconomic Impacts

Socioeconomic impacts include business impacts, fiscal impacts, psychological impacts, and sociological impacts. Socioeconomic impacts expected to occur from any single in situ facility are likely to be far smaller than those arising from a large-scale conventional mine. However, because in situ mining is economic at far smaller scales than conventional forms of mining, many more areas are likely to be affected. As a result, many in situ projects spread over a region may have a substantial cumulative impact. This regional impact may lack the boom/bust cycles associated with individual large-scale projects, however.

5.5.2.1 Business Impacts

Business impacts are impacts on business operations. The businesses whose operations may be affected include both those within the mining industry and those within communities neighboring in situ facilities. Impacts on mining industry businesses include those affecting the in situ sector alone, as well as those affecting the mining industry as a whole. Impacts on the businesses in the communities are generally those associated with any new economic development. This assessment of potential business impacts that may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Competition for labor and equipment may occur within the mining industry. Competition already exists among in situ mine owners for skilled in situ workers including, for example, process engineers. Similarly, drillers of in situ wells are at present water-well drillers, and labor and equipment of this sort have already been difficult to procure. As in situ wells get deeper, heavier equipment, such as oil rigs, may be required, and stiff interindustry competition is anticipated.
- Businesses and towns neighboring in situ facilities may face competition for unskilled workers. The higher pay scales likely to result may be a financial burden difficult, if not impossible, for some small businesses to bear. Increased demand from incoming families may serve to offset this, however.
 - In Texas, wages range from \$5.50-8.00/hr in the industry, compared to \$2.00-3.00/hr for previously held low level positions. This probably puts a great deal of financial pressure on nonindustry employers of unskilled labor (pers. com. W. M. Mays, Everest Mineral Corp. to C. E. Cowan, May 18, 1979). To many communities, however, the in situ industry has provided a needed source of income with minimal disruption of the community (Cowan and Parkhurst 1980).
 - Business has boomed in the Texas county in which the principal in situ facilities are located. One cafeteria tripled in size (Pers. Com. to R. J. Cole from personnel at U.S. Steel Georges West Plant, June 19, 1979). This growth was, in part, related to in situ uranium mining development. There has not been a great deal of movement of new kinds of business into the area (Pers. Com. to R. J. Cole from personnel at U.S. Steel Georges West Plant, June 19, 1979).
- Overall business impacts are likely to be far smaller with in situ mining than with large-scale conventional operations.

5.5.2.2 Fiscal Impacts

Fiscal impacts include those impacts on governments resulting from efforts to raise revenues that provide basic services. This list of potential fiscal impacts that may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Local governments may experience strains as they are asked to provide basic services to an increasing population. (These might include police and fire protection, road construction and maintenance, water, sewage, recreation, and education.)
 - Live Oak County has applied to the Federal government for boomtown relief; some towns have doubled in size (Pers. Com. to R. J. Cole from U.S. Steel Georges West Plant, June 19, 1979). Neither the county nor the towns have developed ways as yet to make the mining companies pay for the increased costs (Pers. Com. to R. J. Cole from U.S. Steel Georges West Plant, June 19, 1979). The strains on these counties are actually more the result of large-scale, conventional mines and other related energy development than in situ facilities. Any single in situ operation is likely to bring with it a far smaller influx of new residents. As was previously noted, however, the cumulative effect of a number of these facilities on a given region may be substantial.
- Meeting increased demand for traditional services may not be as difficult as having to engage in new activities to meet new needs. Planning and zoning, devising new taxation schemes, seeking state or Federal funds, and generally having to conduct new intragovernmental or government/industry relations are some examples of new needs.
- In situ facilities may contribute proportionately more in taxes than do conventional mining ventures, potentially minimizing the fiscal strains which they might otherwise impose. In situ mining is more capital-intensive than conventional mining projects: a lot more value (in the form of ore) is extracted per person involved. Severance taxes (paid on ore extracted) capitalize on this aspect of the technology.

There is a higher ratio of dollars paid to impacts caused (by number of people employed) by in situ facilities than by the more sprawling labor intensive conventional mines. Under certain circumstances, in situ facilities may contribute enough in taxes to not only offset some of the negative impacts which they themselves promote, but to reverse or counter-balance some of the fiscal strains imposed by neighboring conventional mines.

- Uranium mining facilities pay severance, sales and use taxes, and lease royalties and rentals. The 1977 rate of 5.5% of the value of extracted uranium is distributed to the Permanent Wyoming Mineral Trust Fund (2%), to the state's general fund (2%) and to the capital facilities revenue account (1.5%). In Converse County, \$600,952 was paid in severance tax in 1978 (all forms of uranium mining; Wyoming 1978, pp. 5-9). Since 1969 severance tax revenues have increased more than 30 times due to a 5.5 factor of increase in the rate of taxation. Rental revenues received by the state have increased by more than 72% since 1970, with a great surge occurring since 1973-1974. Royalties on commercial production have shown less consistent

growth. Revenues from land rentals are ultimately distributed to state institutions or Wyoming schools. Sales taxes paid by the industry have increased nearly 1900% since 1974. Use taxes paid by the industry averaged nearly 300% annual growth between 1974 and 1978. (All figures are for the uranium industry as a whole, not solely for ISL facilities.) Local government taxes are also paid by the industry. The local production tax is an ad valorem tax and is based on the value of the real property improvements at uranium development sites (Wyoming 1978, pp. 5-17).

- From 1976-1978, in Texas, the industry paid an average of \$765,000 a year to county and school district governments in the form of property taxes. Other taxes paid by the uranium industry in 1978 totalled \$4,655,000. The indirect impact of these taxes is an estimated \$880,000 annually in local taxes (Leaming 1979).

5.5.2.3 Psychological Impacts

Psychological impacts include changes in perceptions, attitudes, beliefs, and behavior. This assessment of potential psychological impacts which may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Land owners may be more willing to allow this form of mining on their land than other more disruptive forms of mining.
 - One landowner in Texas who held out against open pit mining for 17 years because he did not want his land scarred, agreed to allow in situ development to occur (Pers. Com. to R. J. Cole from W. May, Everest Mineral Corp., June 19, 1979).
- In situ has the potential to change perceptions regarding the hazards of uranium mining activities, especially those associating it with great radiation risks for employees.
- The spread of nuclear-related activities into new areas could cause concern in individuals previously isolated from this highly controversial industry.

5.5.2.4 Sociological Impacts

Sociological impacts include impacts on the structure or nature of communities, social institutions, and lifestyles. This list of potential sociological impacts that may occur as in situ mining spreads to new areas is based on experiences with in situ activities in Texas and Wyoming.

- Radical changes in lifestyles or sociological patterns are not anticipated from any one in situ facility, especially as compared with large-scale conventional mines.

- Economic changes resulting from in situ operations may, in fact, slow down or reverse other sociological changes that may otherwise have occurred such as large-scale migration to urban areas in search of higher-paying jobs.
 - In Texas one source noted that the uranium industry enabled residents of rural communities to earn better salaries without having "...to join the migration of rural residents to metropolitan areas that has put such a burden on the state's congested urban communities." (Leaming 1979).

6.0 IMPEDIMENTS

The purpose of this chapter is to summarize and present critical problems and issues which may act to varying degrees as constraints or impediments to the development and deployment of the in situ uranium mining technology. In this case an issue represents a topic area on which there is considerable debate and controversy that will need to be resolved before effective development can proceed. A list of issues was developed from the literature (Eisenbarth 1979), informal interviews held with regulatory and interest group representatives and data collected at a workshop held in Corpus Christi, Texas, in November, 1979 (Cowan and Parkhurst 1980). These issues and their significance are summarized in this chapter. This list will almost certainly change as experience with the technology grows and as technological advances are made. Nevertheless, the list represents those major, minor, or latent issues and problems currently constraining or impeding development and deployment of the in situ uranium mining technology or anticipated to constrain or impede it in the near future. Major issues are defined as those which are seriously impeding technology development; minor issues are defined as those of less serious consequence and latent issues are defined as those that are not currently impeding development but that could in the future.

6.1 ISSUE SUMMARY

6.1.1 Environmental Health and Safety Issues - Summary

6.1.1.1 Major Issues

- Consumptive use of groundwater.
- Nitrate-nitrite formation in groundwater due to use of ammonia lixivants.
- Ammonia persistence during restoration.
- Acceptable/reasonable standards for groundwater restoration limits and evaluation of restoration capacity.

6.1.1.2 Minor Issues

- Effect of mobilized minerals and adsorbed chemicals.
- Effects of surface water discharge of some waste water streams.
- Large volumes of liquid wastes.
- Practicality of mining deep ore bodies greater than 1000 ft (305 m).
- Geochemical behavioral changes that result from leaching.
- Effects of removal of large volumes of water on the surrounding water table.
- Health impacts of radon emissions.

6.1.1.3 Latent Issues

- Adequacy of solid waste disposal methods.
- Adequate techniques to prevent and control excursions.

6.1.2 Institutional and Socioeconomic Issues - Summary

6.1.2.1 Major Issues

- Uncertainties about standards, criteria and requirements.
- Regulatory requirements and permitting procedures.
- Understanding and knowledge of the in situ technology.
- Exchange of technical and other related information.
- Current enforcement practices.
- Acceptable restoration goals.

6.1.2.2 Minor Issues

- Differing time limits and requirements of permit applications at the state level.
- Relevancy of requirements or justification or basis for standards.
- Duplication or conflict between state and Federal permit requirements.
- Funding for the regulatory process.
- Availability of technically skilled labor.

6.1.2.3 Latent Issues

- Interest group response.
- Potential for development on Indian lands.
- Availability of unskilled labor force.
- Availability of capital.

6.2 ENVIRONMENTAL HEALTH AND SAFETY ISSUES - DISCUSSION

Several issues or unknowns exist related to the environmental impacts and safety of current technological processes that are currently impeding development and deployment of the in situ uranium mining technology. These relate to needs for advancement in the technology and/or better methods for evaluating environmental impacts associated with the current applications of the technology. As would be expected most of these issues relate to some aspect of groundwater quality or groundwater restoration.

6.2.1 Major Issues

The issues presented below are those technical and physical environmental, health and safety needs that are currently seriously impeding development and deployment of the in situ uranium mining technology. One

major issue facing the technology is the question of groundwater restoration; therefore, the major issues discussed here relate to the ability to restore groundwater quality after mining.

6.2.1.1 Consumptive Use of Groundwater

The most commonly employed method of groundwater restoration is groundwater sweeping. This involves removal of groundwater from the mined zone with resulting inflow and dilution by fresh water into the mined zone until the restoration goals are reached. This method is highly water consumptive and can severely impact groundwater supplies in arid areas when uranium mining occurs. Thus, a need exists to develop less water consumptive methods in order to reduce the impact of restoration on groundwater supplies. Reverse osmosis units which remove contaminants and allow reinjection of much of the waste water have been suggested as an alternative to groundwater sweeping; however, these units have been unreliable under field conditions (Steingraber 1980). Development and demonstration of practical and economical methods for reducing the groundwater removal impact during restoration may be necessary before the technology can become viable in many arid areas of the country.

6.2.1.2 Nitrate-Nitrite Formation in Groundwater Due to Use of Ammonia Lixiviants

Currently most in situ mining operations use ammonia bicarbonate-carbonate leach solutions. However, there is a great deal of concern about the potential environmental and public health impacts of ammonia that could be converted to nitrate and nitrite and which would be a potential hazard to water supplies particularly following cessation of mining. Nitrate and nitrite are of great concern because of their potential impacts on human health, especially the potential health impacts on infants. Removal of all the ammonia adsorbed to clay particles during restoration is considered not economically nor technically feasible. Based on these public health and environmental concerns, leach systems that do not use ammonia need to be developed and demonstrated. Nonammonia leach systems that use sodium bicarbonate or sulfuric acid are also known to result in some environmental impacts and restoration problems; therefore, other systems may need to be developed and demonstrated to be technically effective and environmentally safe. The ideal lixiviant would be one that will oxidize the uranium, maintain it in solution by complexation and interact little with the barren host rock. Unfortunately, no lixiviant tested to date is entirely inert to other minerals associated with the uranium (Thompson et al. 1978).

6.2.1.3 Ammonia Persistence During Restoration

Ammonia based lixiviant systems have been used extensively to leach uranium deposits; however, the ammonia adsorbs to clay particles in the ore body and is very difficult to remove. The most common restoration techniques that have been proposed require removal of groundwater from the ore body until the ammonia levels are equal to baseline values. Since groundwater does not contain ammonia, this means removing essentially all the adsorbed ammonia,

which would be very water consumptive and probably not economically feasible. Even if ammonia is left in the groundwater, this does not imply that drinking water is unsafe. Small incremental amounts of ammonia, nitrate or nitrite above baseline may still be acceptable from a legal, public health and safety perspective as long as the concentrations remain within standards. Since many sites have already been leached using ammonia based leaching solutions, methods are needed that are less water consumptive and more economical to restore these areas to an environmentally safe level.

6.2.1.4 Acceptable Reasonable Standards for Groundwater Restoration Limits and Evaluation of Restoration Capacity

Excursion and restoration limits usually are set by using baseline water quality values; however, groundwater has a great deal of natural variability which may not be accounted for in the baseline samples. Also, geochemical changes may occur as the result of removal of the uranium and trace metals that would change the groundwater equilibrium. Thus, a need exists to determine restoration limits which reflect the potential variabilities in groundwater quality and potential geochemical changes that result from leaching. Consideration must be given to potential health and environmental effects resulting from constituents remaining after restoration.

In order to determine the ability to remove a given lixiviant at a given site, pilot restoration demonstration is required as part of plant licensing. Several people have pointed out that, since the ore body has not been mined, the geochemical changes cannot be fully predicted and these pilot restorations may not adequately represent the real restoration situation. Thus, there is a need for definition of methods for establishing restoration goals and restoration capacity that adequately protect the environment and adequately represent the true restoration capabilities.

6.2.2 Minor Issues

Minor physical environmental, health and safety issues are those for which no or only a slight impact on development and deployment of the technology exists. The minor issues represent areas where questions exist relating to the adequacy of existing environmental information on the impacts of the technology.

6.2.2.1 Effect of Mobilized Minerals and Adsorbed Chemicals

One concern that is raised repeatedly by environmental interest groups is that minerals that are mobilized by in situ leaching operations, such as molybdenum, arsenic, and selenium, could result in serious health impacts on neighboring populations who use the groundwater. Many environmental interest groups are concerned about the effect of ammonia that is slowly desorbed from clay particles and the impact of compounds, such as nitrate and nitrite formed from ammonia, on human health. Certain geochemical data suggest that natural geochemical processes within the groundwater may immobilize some of the

minerals and inhibit formation of hazardous chemicals from ammonia. The extent of these processes and the buffering effects need to be understood so as to better study ways of predicting and mitigating environmental impacts from mobilized minerals and desorbed chemicals (Thompson et al. 1978).

6.2.2.2 Effects of Surface Discharge of Restoration Waste Streams

In areas where water availability is a serious concern, environmentally acceptable alternative uses for some of the restoration waste waters could prove to be beneficial to the area. In order to use this water for irrigation rather than disposing of it as liquid waste, the possible environmental effects of surface discharge must be understood and evaluated. The most commonly proposed method for restoring groundwater after mining (Section 2.9) is to remove groundwater from the ore body until the restoration goals are attained. This method, called groundwater sweeping, is extremely water consumptive and much of the water removed, especially in the case of ammonia leach restoration, contains very low levels of toxic minerals and ammonia.

6.2.2.3 Large Volume of Liquid Wastes

Many of the proposed restoration methods produce large volumes of waste water. Development of methods to reduce these waste water volumes would reduce disposal problems and would reduce water consumption. Currently, liquid wastes are disposed in deep wells in Texas and in large waste water ponds in Wyoming. Disposal of the waste water by evaporation may not be possible where evaporation rates are low; therefore, disposal by other environmentally safe methods must be studied. Reverse osmosis, electrodialysis, and anion-cation exchange techniques have been applied to demineralized waste streams; however, these methods are expensive, unreliable and only able to treat 80% of the waste streams (Steingraber 1980). More efficient and reliable methods are needed to reduce waste water volumes and mitigate potential impacts from disposal of large volumes of waste water associated with restoration.

6.2.2.4 Practicality of Mining Deep Ore Bodies Through Demonstration

Many people who are involved with the in situ industry and technology predict that the industry will soon be mining deep ore bodies. Mining of deeper ore bodies will probably involve changes in the technology, since drilling wells to depths over 1000 ft (305 m) intervals may not be economically feasible. The new methods could also have important implications on the control of excursions and on the ability to restore groundwater. Thus, new methods will need to be developed in order to mine deep ore bodies, compared with conventional methods, and examined for potential environmental impacts.

6.2.2.5 Geochemical Changes that Result from Leaching

The leaching of the uranium from an ore body will result in geochemical changes in the ore body; however, neither the extent of these changes nor the

effect that they will have on the ability to restore the groundwater and on the environmental and health impacts of the in situ operation is known. Removal of uranium and other toxic metals, such as vanadium, arsenic, molybdenum and selenium could have a beneficial effect on the quality of the groundwater in the area. However, it is not known if disturbance of the geochemical equilibrium could result in degradation of the groundwater by freeing other elements into the groundwater or if restoration goals could be achieved after the disturbance. Therefore, there is a need to better understand the geochemical changes resulting from leaching in order to determine the beneficial or harmful impacts on the groundwater quality and restoration.

6.2.2.6 Effects of Removal of Large Volumes of Water on the Surrounding Water Table

In situ leaching operations are designed to remove more fluid from the ore body during production than is injected. This results in a drawdown of the water table around the in situ facility that can significantly lower the level of water in surrounding water wells for several miles for larger well fields. During proposed restoration activities, up to 20 to 30 times this amount of water will be removed (Section 6.1). The effect of this drawdown on surrounding water wells, other water supplies and on the regional groundwater flow system need to be examined for potential public and environmental impact.

6.2.2.7 Health Impacts of Radon Emissions

There are radon-222 emissions associated with normal operation of an in situ facility. While the radon emissions are believed to be less of an environmental problem than they are with conventional mining techniques, radon represents the largest radioactive dose potential to occupational workers through the air pathway. Data on radon levels are needed to evaluate the health effect of radon emission on the workforce and on the offsite environment. Less is known about the source terms, environmental pathways and biological effects of radon emissions from in situ facilities than from conventional mining and milling facilities.

6.2.3 Latent Issues

Latent issues represent those areas that are not currently impeding development or deployment of the technology but could become more important constraints as the political and environmental attitudes change.

6.2.3.1 Adequacy of Solid Waste Disposal Methods

Although disposal of the small amounts of solid wastes generated at an in situ facility is not currently a major concern, public interest could provide impetus for developing processes to reduce the volume of solid waste and for developing environmentally safe and efficient methods of waste disposal.

6.2.3.2 Adequacy of Techniques to Predict, Prevent and Control Excursions

During operation, excursions of leach fluid beyond the mining zone can occur. If these excursions were to go undetected and/or uncontrolled, they could result in serious potential environmental or health impact. The causes of excursions are not always known and there is very little ability to predict their occurrence. Better methods for controlling and containing excursions are needed once the cause is determined.

6.3 INSTITUTIONAL AND SOCIOECONOMIC ISSUES - DISCUSSION

Numerous institutional and socioeconomic issues exist that are currently constraining development and deployment of the technology. If the traditional environmental problems can be satisfactorily addressed or mitigated, these institutional and socioeconomic issues will still need to be addressed before the technology could expand to its potential production level.

6.3.1 Major Issues

Many of these issues that are considered impediments relate to the area of interface between the regulators and industrial representatives.

6.3.1.1 Uncertainties About Standards, Criteria and Requirements

Among many regulators, a certain level of uncertainty exists regarding the nature and severity of environmental impacts of chemicals and procedures associated with the technology. This may lead to uncertainty with regard to the new form that standards or regulations should take or to uncertainty regarding the most appropriate level for criteria and standards. As learning occurs and as studies are conducted, criteria and requirements may change in response to the findings. Also, as the technology changes criteria may change.

Among the industry, apprehension exists regarding constantly changing regulations or standards. Regulations often change too fast to allow sufficient rebuttal and are often not appropriate for certain forms of the technology (Cowan and Parkhurst 1980). Keeping up with or responding to meet ever changing regulations takes up increasing amounts of staff time and resources.

Another complication of these uncertainties was noted at the November 1979 workshop. Growth of the industry may be impeded by the reluctance of companies new to the in situ uranium mining technology to initiate operations in the face of unknown future regulations. Workshop participants noted, for example, that regulators could conceivably make regulations so restrictive that compliance would be impossible or too costly. While the uncertainty of the future regulations has not forced out companies already in production, other interested companies have not initiated operations because of these uncertainties.

6.3.1.2 Regulatory Requirements and Permitting Procedures

Inflexible regulatory requirements allow regulators very little discretion in dealing with particular environmental and permitting problems associated with a particular facility. For example, in Wyoming, statutory language allows the Industrial Siting Administration only two decisions on construction either "go" or "no go." There is no conditional go ahead allowed, therefore, when a single part of a permit is incomplete, it could delay the entire project.

Many industrial representatives feel that permitting requirements are too rigid or stringent to allow them to develop new variations on the technology because the regulations contain mandatory methods for doing things rather than allowing the operator the flexibility to choose the methods to meet the regulations. The industrial representatives feel that the company must be able to continually adapt and refine the technology to achieve the best extraction and economics for a particular site. Regulators and interest groups tend to be more conservative and are concerned that the new technological advances may have adverse environmental impacts that need to be regulated.

6.3.1.3 Understanding and Knowledge of the In Situ Technology

Industrial representatives have noted that regulators are not experts in the necessary fields and often do not fully understand the technology which they are regulating. Governmental and industrial representatives agreed that regulators must have adequate information and must be adequately educated about the technology before they can effectively regulate the industry. Basically, industrial representatives are concerned that regulations may be formulated from information gathered about other industries. There was a concern that, if the special needs of the industry were not considered, regulations could be promulgated that would prevent expansion into new geographical areas and impede responsible industrial growth (Cowan and Parkhurst 1980).

The possibility of this worst case happening may be remote. Regulations in Texas have become less restrictive and more flexible in the recent years. Also the USNRC has been licensing in situ facilities for several years and bases all licenses on the most current information available and on past regulatory experience (both state and Federal) with the in situ industry. State agency requirements in Wyoming are in some cases more restrictive than the USNRC requirements (Cowan and Parkhurst 1980).

Additional problems have arisen from outdated information: the industry has problems that the regulators may not yet understand. Because companies are focussing on getting plants on-line and have needed to keep industrial processes secret, they have not spent enough time educating the regulators. The education of regulators and communication with the public was considered by some workshop participants to be especially desirable with the hopes that reasonable regulations may be issued and drastic changes or "tighter is necessarily better" attitudes may be forestalled (Cowan and Parkhurst 1980).

To the extent that these problems (ill informed, not adequately educated regulators) occur, they are further exacerbated by high regulatory staff turnover, reducing opportunities to become knowledgeable in the field. Regulators who have become educated in the technology usually leave or are transferred to a new assignment (Cowan and Parkhurst 1980). Part of the problem is caused by agency structure which results in frequent reorganization and reassignment of personnel. Another contributing factor is the salary differential between state and Federal agencies and industry.

6.3.1.4 Exchange of Information

Regulatory problems and the reactions of environmental groups are due, at least in part, to inadequate or outdated information. First, the technology is undergoing, and probably will continue to undergo, rapid and frequent changes, making constant exchange of information on state-of-the art technology necessary. Second, in situ is a relatively unknown technology outside the states of Texas and Wyoming, where it is applied commercially. Most in situ development and, therefore, most of the information on environmental impacts has been accumulated in Texas. Due to the agreement-state status of Texas, much of the information gathered by industry, regulators, and environmentalists is not readily available to the Federal government or to groups or agencies outside of Texas. In addition the information has been gathered for Texas and may not be totally applicable to other states. Many of the participants at the November, 1979, workshop recognized the need for increased exchanges of experiences and information, perhaps in workshops and conferences (San Juan 1979).

6.3.1.5 Current Enforcement Practices

When a company or in situ operation is found to be violating a permit requirement or causing a measurable environmental impact that the regulatory agency was unaware of, the reaction of the regulatory agencies has often been to increase regulations or delay permits. This adversely affects many nonoffenders. Delays or changes in regulations have numerous ramifications on the industry. Recently, emphasis has been placed on punishing offenders and not punishing the entire industry.

6.3.1.6 Acceptable Restoration Goals

At present the restoration goals are not clearly defined and regulations vary significantly from agency to agency. Restoration is defined as the reduction of the quantity of dissolved minerals within the mined ore aquifer to levels that protect the environment and human health; however, there is considerable debate as to what levels are acceptable or what is necessary to protect public health and safety. Several of the possibilities discussed include:

- Restoration to baseline quality values.
- Restoration to a given amount or percentage above baseline.

- Restoration to values consistent with defined water use category.
- Restoration to better than previous use classification if the previous use classification was due to the presence of the mined element.
- Restoration to within established water quality standards.

Restoration of the groundwater to baseline is the most difficult to achieve and may be technically impossible because of physical-chemical changes in the geochemical formation resulting from uranium extraction and lixiviant ion exchange on the clays. Restoration to other levels, such as previous water use category, is much less difficult technically but depends on the type of lixiviant solution used, confinement of the aquifer and other site-specific parameters.

Therefore, the feasibility of successful restoration depends to a great extent on the levels which are chosen as restoration standards. Very stringent restoration goals may make restoration infeasible, either technically or economically, and impede further development of the technology; on the other hand, adequate protection of the public needs to be assured.

6.3.2 Minor Issues

Minor institutional and socioeconomic issues are those for which no impact or only a slight impact on the development and deployment of the technology exists. As with the major issues, many of these issues concentrate on the interface between regulators and the industry.

6.3.2.1 Differing Time Limits and Requirements of Permit Applications at the State Level

According to the Wyoming Industrial Siting Administration's 1978 annual report, a major problem in the industrial siting process is the "...differing requirements for plans and proposals by various agencies," with some requiring final plans, and others (i.e., industrial siting permit) requiring a preliminary statement. Moreover, some permitting authorities have no time limits while others specify dates for completion of reviews, creating lags and conflicts in project approvals. The long lag time between exploration and the issuance of an operating permit means that prospective producers must anticipate compliance with both existing and future regulations.

6.3.2.2 Relevancy Requirements or Justification and Basis for Standards

In situ mining is like conventional uranium mining only in that it involves extraction of uranium from the ground. In fact in situ is so different from conventional mining methods, especially in the extent of environmental impact, that regulatory and industry participants at the November 1979 workshop agreed that the technology requires specifically designed regulations (Cowan and Parkhurst 1980). Since there is no major disturbance of the ground, mining laws emphasizing reclamation have little application to in situ mining. Further, the problems of injection associated with in situ underground leaching are not covered by most mining regulations. In situ extraction is often

associated with milling because both processes use chemical extraction. However, unlike conventional milling, there is no atmospheric contamination from rock crushers and radon-226 emissions from mill tailings piles or tailings ponds. Thus, regulations covering these processes would also be inappropriate for in situ mining.

In meeting requirements set for conventional mining and milling, in situ operators have, thus, had to:

- Comply with rules for equipment and facilities that are not used.
- Analyze for elements that are not extracted by in situ leaching.
- Undertake environmental studies and collect excessive amounts of data, i.e., detailed terrestrial ecological surveys.

The cost of meeting these requirements frequently ruins the economics of otherwise minable ore bodies. It was suggested by the workshop participants that site-specific considerations should determine standards. Standards that are set arbitrarily and that apply to all sites are often impractical. Furthermore, the workshop participants urged that standards be a set of objectives with the implementation methods left to the discretion of the operator.

6.3.2.3 Duplication of Conflict Between State and Federal Permit Requirements

In Wyoming the water monitoring required by the USNRC is different from that required by the state. In Texas, requirements for the location of monitoring wells differ slightly from those of the USNRC. The distance of the monitoring wells from injection wells is an issue that has yet to be resolved between the USNRC and the TDWR. The TDWR judges that if monitoring wells are placed too close to the injection sites, excursions might go undetected. It is harder for mine operators to keep up with regulations when they are not uniform or when they are in a constant state of revision. Costs and delays in permitting because of the duplicative or conflicting requirements can impede construction of new facilities.

6.3.2.4 Funding for the Regulatory Process

In Wyoming funds for the regulatory process presently come from state general fund appropriations and application fees. As noted in the Industrial Siting Administration's Report, a problem arises regarding funding during periods when no applications are under active review, as well as for more extensive planning and forecasting efforts (i.e., for strengthening state "capabilities toward dealing with 'front end' social and economic problems associated with energy development").

6.3.2.5 Availability of Technically Skilled Labor

In many areas where in situ facilities are operating or are planned there is high competition for those engineers and managers who have experience with

the in situ uranium mining technology and the regulatory process. This competition is likely to remain for many years resulting in high salaries and impeding rapid, responsible growth of the industry.

6.3.3 Latent Issues

Latent issues are those issues which are not expected to impact on the development and deployment of the technology now but which could become major problems if certain factors change in the future.

6.3.3.1 Interest Group Response

Currently, interest group response to development and deployment of the in situ uranium mining technology has shown minor concern in Wyoming and has been positive in Texas. For example, in Texas an in situ facility was permitted by local landowners to mine a uranium deposit where conventional mining had previously been opposed. In one county in Texas, the proposed shutdown of an in situ operation was met with public outcry and a petition to the governor to delay the shutdown. This county, as well as others, have also encouraged expansion of in situ facilities in their jurisdiction. Past experience with public hearings in Texas indicates that very few people attend and that the interest of citizens and many interest groups has decreased as their ideas are incorporated into the licensing process. Local citizens have been interested in learning about the facility but have not opposed construction or operation.

However, there is some industrial concern about future opposition to nuclear power focusing on the front end of the nuclear fuel cycle, which would include uranium mining. Strong antinuclear groups have effectively prevented development in some states containing uranium reserves such as Colorado, South Dakota and Montana. Another example of increased opposition to front end activities in the nuclear fuel cycle is the recent Friends of the Earth et al. suit against Mobil Oil's Crown Point in situ facility in New Mexico (Peshlak et al. 1979).

6.3.3.2 Potential for Development on Indian Land

Indian tribes own substantial deposits of uranium resources. Their rights to these minerals and their governmental institutions derive from treaties, laws, the Constitution, and numerous Supreme Court rulings that uphold their status as "quasi-sovereign" entities. No tribal mineral rights can be sold. Leasing agreements must be approved by the tribe's governing body and the Secretary of the Interior who serves as trustee.

The tribe as a governmental entity further controls mineral development through regulations, ordinances and other specifications promulgated by assorted tribal bodies. The Navajo Division of Labor, for example, issues manpower utilization guidelines that could affect mine construction activities as well as hiring practices. Their Environmental Protection Commission and Land Administration promulgate environmental regulations, pollution control

specifications and other ordinances with which any mine operator would have to comply. These regulatory activities apply in addition to, and/or in the absence of Federal regulatory activities. There may be some overlap, especially in areas regulated by the state, but in all instances development of resources on Navajo lands must meet Navajo regulations (Pers. Com. to D. Keller from A. Tardash, DNA People's Legal Services, Albuquerque, NM, 1980).

There appears to be a great deal of concern about health and safety hazards associated with improper mine management and site abandonment (without reclamation), and Federal or state unwillingness to intercede or assume responsibility for such situations. It is likely that Indian tribes will, thus, not support or facilitate in situ or any other form of mining until they know that someone will assume responsibility for monitoring and clean up activities and for insuring compliance with existing standards (Cowan and Parkhurst 1980).

A positive or negative response by local Indian tribes to in situ mining could have a major impact on in situ development in new geographic areas. Recently, for example, an effort was made to halt Mobil's in situ pilot project at Crownpoint, New Mexico. Seventy-two members of the Navajo tribe and the Friends of the Earth filed a suit against six Federal agencies alleging: (1) that the Mobil in situ project violated NEPA because no EIS had been prepared, (2) that the lease sale underlying the project violated NEPA for the same reasons, and (3) that a regional EIS was also necessary and lacking. In a September 5, 1979, ruling, the motion to halt the project was denied. The in situ project which "...had the purpose of determining whether uranium leaching was feasible in New Mexico" (Peshlakai et al. 1979) was judged to represent an "infinitesimal" threat of contamination to aquifers, a "realistically nonexistent" threat of radiation to the public/workers from radon emissions, "land use impacts...of minimal significance," equally minimal impacts on Navajo culture in general, and "economic and social impacts (which are) overwhelmingly favorable." A full fledged EIS was, thus, judged not to be required. The regional EIS was found to be equally unnecessary in that the various Federal actions in the region were viewed to be "...widely scattered actions by six different Federal agencies, with different programs and purposes...without any conscious overall planning." The lease sale was found to be lacking the proper EIS, but plaintiffs were "...barred by leases from pressing the point of that violation" (Peshlakai et al. 1979). The individual lessor of the minerals rights did seek to have the lease cancelled prior to this litigation, alleging that Mobil violated its terms and that the USBIA had improperly approved it, but that motion was similarly denied by the United States Department of Interior administrative proceedings.

These actions cannot really be taken, however, to represent the feelings of all the Indians towards mining generally, nor in situ leach mining in particular. There is currently no single "Indian position" on these issues (Cowan and Parkhurst 1980). Navajo leaders in the San Juan River Basin in New Mexico, when questioned about their concerns regarding uranium development, noted that it is not viewed as totally unacceptable and could, in fact, lead to benefits for the local Navajos in the form of community improvements and

increased standards of living. However, they were concerned about certain specific aspects of the leasing and mining processes as well as about the manner in which the uranium companies, the USBIA, and the Navajo tribe itself have dealt with the local Navajos. They pointed out that the Navajos have not been sufficiently compensated for damages to their land and property from past uranium developments and that respect for Navajo beliefs and sacred places is lacking. Further, uranium companies have not been open about their intentions and at times some companies have been deceitful. The leasing process is particularly open to abuse in that it is poorly understood by many individual Indians. Navajo leaders feel that it is the responsibility of the companies, USBIA, and the tribe to help clarify lease terms where that is possible. The leaders do point out, however, that an opportunity exists to restore decision-making back to the local level, and that the Navajo want greater control over the impact of uranium development.

6.3.3.3 Availability of Unskilled Labor

Currently, the major portion of the in situ mining labor force, which is unskilled, is drawn from local communities. Since these areas generally have a poor economic base, the in situ industry adds an important economic factor. However, as in situ mining spreads into more remote areas where there is very little population or into areas with large conventional uranium mining operations, the labor may not be available or competition for labor may be very high. This could impede deployment of the in situ technology into these areas.

6.3.3.4 Availability of Capital

The growth of the in situ industry is potentially sensitive to the competitive investment potential of it versus other kinds of energy activities. Because the in situ technology is being developed by subsidiaries of large multi-component corporations or by small independent entrepreneurs, it is supported by financial resources that have many alternative uses. It is unlike the auto industry, for example, in which technological development is financed largely by retained earnings. As a consequence, the development of the technology is very sensitive to the costs of in situ techniques and the demand for uranium.

7.0 CONCLUSIONS

The previous chapters contained discussions of the technology, the physical, ecological, institutional and social environment in which the technology exists, and the impacts and impediments to the technology. This chapter consists of two portions. The first part briefly discusses some of the ongoing research projects and other activities that are addressing the data needs, impacts and impediments previously identified. The objective is to indicate that research and activities are ongoing to address the needs identified and to indicate major gaps in the activities. The Technology Assessment will contain a more complete discussion of the ongoing research and activities. The second part of the chapter contains a brief synopsis of the major findings of the report.

7.1 ONGOING RESEARCH AND ACTIVITIES

The preceeding chapters identify the potential environmental impacts and the impediments to the in situ uranium mining technology. These impacts and impediments serve to familiarize policy- and decision-makers with the major areas in which research or other activities may be needed to mitigate or evaluate impacts or overcome the impediments. This discussion presents some of the major ongoing research and other activities that address these needs. There are probably more research projects, especially by industry, that are not adequately represented in this discussion.

Currently, there are several research projects underway through industrial and governmental sponsorship on methods for groundwater restoration. Among the government sponsored projects, work is being done by Ford, Bacon and Davis, Inc., and Rocky Mountain Geochemical Corporation for the Bureau of Mines which examines the effectiveness of various restoration methods. Carol L. Brierley, of the New Mexico Institute of Mining and Technology, has been exploring the possibility of using bacteria for selectively restoring groundwater by converting absorbed ammonia to nitrite. She has also examined the possibility of using algae to clean waste water streams.

The USBOM and the USEPA have also sponsored research to predict the geochemical changes expected from leaching as well as the effects of migration of leach fluids beyond the mining zone. Included in the USBOM research is development of computer models to predict flow characteristics. Their ongoing research includes development of more complex flow models and use of geochemical models in order to be able to predict the concentration of uranium in the leach solution. The USBOM has published a technical paper describing geochemical changes taking place during acid leaching at a site in Wyoming (USBOM 1979). Several projects have been conducted at the University of Texas at Austin's Bureau of Engineering Research under both government and industry sponsorship that examine the fate of residual ammonia in groundwater. These studies include examination of groundwater transport, ion exchange capacity, geochemical and bacterial interactions with ammonia, and include both model development and field studies.

The development of alternative leach systems to the ammonium bicarbonate system is being undertaken by the USBOM and by private industry. The University of Texas at Austin has received a contract with the USBOM to develop environmentally attractive leach solutions which can be substituted for ammonium-bicarbonate. Several private companies, as part of their research and development effort, have examined and tested alternative leach systems.

Additional research is ongoing at several industrial and governmental research laboratories to improve or better understand current methods of mining. Development of more effective ion exchange materials is one area of research. The USBOM has also conducted research into the potential use of hydraulic bore-hole mining techniques and has developed a hydraulic jet for perforating and stimulating in situ leaching wells. In addition, Mobil Oil is using a pilot facility in New Mexico to test the leaching of very deep ore bodies.

There is, in general, less overt activity associated with overcoming the institutional and socioeconomic issues identified in Section 6.3. There have been three workshops in the last year between industry, government and interest group representatives with the purpose of discussing various aspects of in situ mining and regulations effecting in situ mining technology. In addition, there are several technical conferences each year sponsored by technical societies which serve as forums for discussing the latest technical developments. The opportunities for a broad-based discussion of the technology and regulations are, however, very limited.

7.2 FINDINGS AND RECOMMENDATIONS

The following are findings drawn from the examination of the in situ uranium mining technology, its impacts and impediments.

- The in situ uranium mining technology is a technically feasible method for mining many uranium deposits. In fact, in situ mining may, in many cases, be the only feasible method for mining some ore bodies.
- Due to the small scale at which in situ techniques are economically feasible, in situ developers have more choice as to where to develop. Deposits that were previously uneconomical are now open to them. They are not constrained by the need for highly skilled personnel or by the location of mills.
- The in situ technology is being developed by subsidiaries of large multi-purpose corporations or by small independent entrepreneurs; therefore, it is supported by financial resources that have many other natural outlets. As a consequence, the in situ technology is extremely sensitive to the comparative investment potential of it versus other kinds of energy activities, the cost of in situ techniques, and the demand for uranium.

- Based on available data there appears to be no significant physical or ecological environmental impacts resulting from development and deployment of the technology. There is less land disturbance, less air pollution and smaller volumes of waste associated with application of the technology. There is, however, inadequate data in many cases to do a full analytical evaluation of potential impacts.
- The primary environmental, health and safety concerns are associated with the adequacy of techniques and standards for restoration and with potential contamination of groundwater during and after mining. These concerns are also the primary areas receiving attention by industry, regulatory agencies and interest groups. There is also considerable research directed toward resolving these concerns.
- Because the in situ uranium mining technology is a relatively new technology in most areas, with the possible exception of Texas, and is undergoing rapid changes, it suffers from many of the problems associated with regulation of a new industry. This includes inadequate or outdated information, misconceptions, and regulatory delays.
- Because the in situ technology does not fit neatly into the jurisdiction of existing agencies, it results in several institutional impacts and is at a disadvantage when compared to conventional uranium mining technologies. In situ is similar to mining and also to drilling; it is somewhat like resource extraction and somewhat like resource processing. It is neither completely a land use problem nor completely a water quality problem. Consequently, agencies are particularly slow in developing the regulatory framework to deal with the technology and agencies are forced to resolve jurisdiction problems while learning about the technology.
- Because of the smaller scale of in situ operations and the lack of requirements for a large technically skilled labor force, in situ facilities to date have had positive impacts on otherwise economically poor regions, especially in Texas. There is less boom town development. However, in situ facilities will impact a larger area and a potentially greater population than conventional uranium mining technologies. How these people respond to both the positive and negative aspects of the in situ mining technology may be crucial to the growth of the industry.
- The major impediments to in situ uranium mining development and deployment are institutional. These include uncertainty about standards, criteria and requirements; the limited flexibility of regulatory requirements and permitting procedures, and inadequate exchange of information. All of these major impediments have in common the fact that they resulted from inadequate communication among the regulators, interest groups and industrial representatives.

Based on the analysis to date and the major findings of the report, several broad recommendations can be made. First, there is a continuing need

to evaluate the consequence of in situ development on the environment. Efforts to address potential impacts and to collect data necessary for evaluation of impacts should be encouraged. In light of the ever-changing nature of the in situ technology, it is also recommended that an ongoing or periodic effort be initiated which would reevaluate potential environmental impacts based on changes in the technology. Finally, open communication between regulatory, interest group and industrial representatives should be encouraged in order to facilitate more effective communication of technical and other related information among the groups and to facilitate the evolution of strategies for dealing with institutional impediments.

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9.0 GLOSSARY

ADU	Ammonium diuranate. Approximate chemical composition is given as $[\text{UO}_2(\text{OH})_2 \times \text{H}_2\text{ONH}_4^+]$ salt. ADU is not U_3O_8 .
Aquifer	Porous water-bearing formation of permeable rock, sand or gravel capable of yielding significant quantities of water.
Bleed	A production adjustment technique whereby more fluids are pumped from the production zone than are injected.
Calciner	A heating devise that raises the temperature of a substance to just below its melting point to drive off volatile materials.
Decarbonator	An instrument in which carbon is removed from solution by chemical means.
Drilling mud	A suspension of finely divided heavy material pumped through the drill pipe during rotary drilling to seal off porous zones, flush out chips, lubricate and cool the drilling bit.
Excursion	The movement of lixiviant out of a mine zone as evidenced by measured movement past a trend or monitor well.
Injection well	A well used for injecting fluids into an underground stratum or ore body by gravity flow or under pressure.
Log a well	Continuous recording versus depth of some characteristic datum of the formation penetrated by a drill hole.
Monitor well	A observation well usually located along the periphery of a well field. It is used to indicate containment and/or lixiviant migration beyond the well field boundary.
Pore volume	The volume of water contained in the open space between rocks or soil in the mine zone. Pore volume is used as a measure of the amount of water removed during restoration.

Production well	A well from which lixiviant is recovered for conveyance to the main processing facility.
Redox potential	Voltage difference at an inert electrode immersed in a reversible oxidation-reduction system. It is used as a measure of the oxidation state of the system.
Resistivity	The electrical resistance offered by a material to the flow of current, times the cross-sectional area of current flow and per unit length of current path.
Self-potential	Electrical potential caused by dissimilar conductors in an electrolyte. The self potential is used in prospecting. This method is based on the measurement of natural earth potentials caused by the self-potential effects from ore bodies.
Trend well	Surveillance well for production control and/or monitoring, located between the well field and the monitor wells.
Uraniferous	Of or containing uranium.
Working level	Any combination of short-lived radon daughters (through ^{214}Po) in a liter of air that will result in the emission of 1.3×10^5 MeV of alpha energy. A radon-222 concentration of 100 pCi/l with its daughters in equilibrium corresponds to a potential alpha-energy concentration of 1 working level.
Yellowcake	The final precipitate formed in the mining of uranium ores. Yellowcake is also referred to as U_3O_8 .

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AQD	Wyoming's Air Quality Division
EIS	Environmental Impact Statement
ER	Environmental Report
FEIS	Final Environmental Impact Statement
ISL	In Situ Leach
LQD	Wyoming's Land Quality Division
MSHA	Mine Safety and Health Administration
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupation Safety and Health Administration
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
TDH	Texas Department of Health
TDWR	Texas Department of Water Resources
TLD	Thermo Luminescent Dosimeter
TLV	Threshold Limiting Value
UIC	Underground Injection Control
UMTRCA	Uranium Mill Tailings Radiation Control Act
USBIA	United States Bureau of Indian Affairs
USBLM	United States Bureau of Land Management
USBOM	United States Bureau of Mines
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
USNRC	United States Nuclear Regulatory Commission
WDEQ	Wyoming Department of Environmental Quality
WQD	Wyoming's Water Quality Division

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