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Guidebook on good practice in the management of uranium mining and mill operations and the preparation for their closure

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FOREWORD

Over the past fifty years the uranium industry has moved from a labour-intensive industry to a 'high-tech' and capital intensive industry. Organization of knowledge, manpower and material had to change to meet the demands of several stakeholders inherent to any project and to constantly adapt to technological innovations. Today, the mission of a uranium operation is not only to make a profit while selling yellow cake to electrical power stations but also to address issues regarding safety, health, environment and demands of the regulators and the public and assure the sustainability of the operation. Therefore, the concept of good practice and its applications has been introduced in mining operations. Good mining practice begins with the proper planning and forecasting from the discovery of a deposit to decommissioning of the mine.

This report describes and defines what is considered as good practice in the various activities of a mining operation and provides an overview of the management of a single operation. As technologies are progressing rapidly in the mining industry, and as this industry is transnational, this report emphasizes the importance of training employees at all levels of the organization. This is in their views an important good practice.

The statements on good practice for the various activities of a mining operation will be useful for organizations which are planning to open new mines or intend to modernize ongoing operations. They provide the basic elements for the introduction of good practices. Practical examples are given in the case histories for four different countries. The objective of this publication is not to provide strict rules on the application of good practice but to give general guidelines that can be consulted and used in many different countries.

The authors are from four uranium producing countries. They have diversified experience gained in the development, exploitation and closure of uranium mines in eight countries and have implemented good mining practice during their careers.

This Technical Document is one of a series of IAEA publications covering all aspects of the uranium mining industry, from exploration to exploitation, socio-economic impacts and decommissioning. Reports already published address topics such as feasibility studies (Steps for Preparing Uranium Production Feasibility Studies: A Guidebook, IAEA-TECDOC-885, Vienna 1996), development of regulations (Guidebook on the Development of Regulations for Uranium Deposit Development and Production, IAEA-TECDOC-862,Vienna, 1996) and environmental impact assessment (Environmental Impact Assessment for Uranium Mine, Mill and In Situ Leach Projects, IAEA-TECDOC-979, Vienna, 1997).

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1. INTRODUCTION

Forty years ago the uranium mining industry like the other mining industries was labour-intensive. The methods for exploration, mining and milling were, by today's standards, rather primitive, and environmental concerns were of low importance. The management of uranium mines and mills was simple, the demand was defined, and the prices were reasonably stable until the 1970s.

Since then, the uranium industry has changed considerably not only from labour-intensive to capital-intensive, but also to applying high-technology and taking into consideration the public's ever increasing concern for the protection of the environment and the health and safety of the employees. This development together with the need for sustainability of the industry has led to the introduction of the concept of good practice.

Good business practice in the management of a uranium operation involves all aspects of the activities, from exploration, development, exploitation to its closure and decommissioning. It not only applies to recovery of uranium but also addresses all aspects of safety health and environmental protection.

A prerequisite for good mining practice is to have a group of people with well-defined functions and a common culture, with thorough understanding of technologies and know how to apply them. This group must provide leadership in the various disciplines which becomes the foundation for developing the mine.

In recent years, considerable efforts have been made in the design and planning of uranium projects from feasibility studies to decommissioning concepts before any decision was taken to proceed. This development has resulted in detailed assessments of the economic return with increased benefits for environmental protection and the safety and well being of the employees during the operation.

A project that is not properly managed will definitely run into problems and leads to losses for the operator and damage to the environment. Adequate planning and good business practices used at the beginning of a project are therefore not only important, but also beneficial. The rewards for both the operator and the public consists of competitive advantages, a motivated workforce and the knowledge of proper environmental mitigation and rehabilitation.

2. THE MANAGEMENT OF A MINING OPERATION

A mining operation is an industrial entity whose objective and function is to extract from the earth crust a metal or other substance of economic value and process it to a stage where it can be sold for further transformation. There are several types of mining operations. For mining and milling of uranium a distinction is made between conventional mining and in situ leach (ISL) mining.

A conventional mining operation consists of underground/or open pit operation and a process plant to extract the uranium from the host rock. An ISL operation consists of well fields and a process plant to extract the uranium. The difference between the two methods is that in the first case, a rock containing the uranium (ore) is mined and moved to a plant for crushing and grinding and extraction of the uranium oxide (U_3O_8). In the second case, a leach fluid is injected within a well field into a porous and permeable rock formation which contains the uranium. The uranium is leached from the rocks and the fluid is pumped to surface for recovery of the uranium in a process plant.

In order to establish and implement good practices, a mining company needs to have a correctly structured organization with clear defined objectives, functions and responsibilities at all levels of management.

Expressed in general terms, the management objective is to plan, organize and direct human efforts, knowledge and equipment to efficiently and economically extract uranium from the ore.

The management duties are listed as follows:

- leading, organizing, motivating and coaching
- directing and guiding
- forecasting and planning
- implementing and controlling
- stewardship of resources that are: human, economic natural, technical (machines) knowledge.

The management of a corporation and its related organization structure depends solely on the size and diversification of the company. A company with many diverse activities require more administration than a smaller company with only one project. The structure of a mining company is similar to other industrial organization. This section describes the job and function of the proponent of a conventional mining organization and of the proponent of an ISL organization. Each illustrated organization is designed for a single mining project. Therefore, the overlying corporate structure is not presented and the highest ranking corporate manager is the Vice President for Mining.

2.1. MANAGEMENT STRUCTURE OF A CONVENTIONAL OPERATION

Table I is the organizational chart of a conventional mining operation. A conventional mining operation is divided into four main activities and departments that are: the mining department, the milling department, the maintenance department, and the environment department.

For a single project the overall management is assumed by:

- a Vice President for Mining reporting to the Chief Operating Officer. He directs, control and administers all mining and milling operations. He is responsible for achieving production objectives and for improving the overall cost and efficiency of the operations through careful long and short term planning, budgeting and control.

  This position requires a degree in mining engineering and a solid experience in all aspects of mining including economics and at least 15 years experience in the mining industry.

- a General Manager reporting to the Vice President for Mining. He holds the most senior on-site management position with overall responsibility for cost-effective mine site production, processing, engineering, maintenance and administration. He is also responsible for capital projects and development projects on the property. He develops and implements company policies and procedures to facilitate corporate objectives and implements a strategic plan given by the Vice President. He also provides information for the preparation of a strategic plan. The four departments (Mining, Milling, Maintenance and Environment) report to him.

TABLE I. ORGANIZATIONAL CHART OF A CONVENTIONAL MINING OPERATION

	Vice President, Mining		
	General Manager		
Mine Superintendent	Mill Superintendent	Maintenance Superintendent	Environment Superintendent
			Radiation Safety Officer
	Mine Superintendent		
Mine General Foreman		Chief Mine Engineer	
Mine supervision		Senior Engineer	
		Engineering and grade control functions	
	Mill Superintendent		
Mill General Foreman	Chief Metallurgist		Chief Chemist
Mill supervision	Metallurgists		Laboratory Staff
	Maintenance Superintendent		
Maintenance General Foreman	Maintenance Planner	Utilities	Warehouse
Maintenance Supervisors			

2.1.1. Mining

The mining department comprises the following jobs and functions:

– *Mine Superintendent*

Reports to the General Manager. Supervises and co-ordinates the operation of the mine and related facilities in accordance with company objectives and procedures, and is responsible for meeting commitments in tonnage and quality, waste removal, equipment and manpower utilization. He is also responsible for grievance handling and budget/cost control; supervises operations through second and first level supervisors.

– *Mine General Foreman*

Reports to Mine Superintendent; responsible for the day-to-day scheduling and control of mine site production activities including drilling layout and procedures, safety, training, manpower scheduling, production statistics, fire prevention and grievance handling; supervises operations through first level supervisors.

- *Chief Mining Engineer*

Reports to Mine Superintendent; responsible for mine design (short term and long term mine design) surveying, mine geology and grade control.

- *Mine Foreman*

A first line supervisory position is responsible for direct supervision of mining workforce and deployment of equipment to meet production and safety requirements.

2.1.2. Milling, processing

The milling processing comprises the following jobs and functions:

- *Mill Superintendent*

Reports to the General Manager; responsible for overall management, direction and co-ordination of the mill operations; ensures mill production objectives are met at lowest cost consistent with quality requirements; achieves these objectives by delegating authority to key supervisors in production, quality control, maintenance and other related functions.

- *Mill General Foreman and Mill Foreman*

Same as in mine only for the mill.

- *Chief Metallurgist*

Reports to Mill Superintendent; responsible for application of process engineering policies and practices; improves mill operating performance; reduces waste and delays; promotes cost reduction and achieves a high level of operating efficiency; evaluates current and potential processing methods, plant layouts, material handling, manpower requirements and equipment and material utilization.

- *Chief Chemist*

Reports to the Mill Superintendent; responsible for supervision of Laboratory staff, analysis and testing of raw and refined products, monitoring production processes and advising on changes affecting quality and/or volume or output.

2.1.3. Maintenance

The maintenance department comprises the following jobs and functions:

- *Maintenance Superintendent*

Reports to the General Manager; responsible for maintaining, repairing and servicing all mine and mill equipment, buildings and facilities; authorizes major repairs or modifications and prepares an annual maintenance budget; works on projects involving construction of new buildings and facilities, and alteration and modification of existing areas; liaises with operations group to ensure equipment/mill scheduled down-times are co-ordinated effectively; usually supervises through two levels of line management; prepares a maintenance strategy.

- *Maintenance General Foreman*

  Same as mine and mill.

- *Two Maintenance Planners (one planner for the mill and one planner for the mine in case of a large operation)*

Report to Maintenance Superintendent; responsible for co-ordinating planned mine and mill maintenance, according to established preventive and predictive maintenance programmes and schedules; deal directly with maintenance supervisory/management staff on scheduled shutdowns and equipment rotations.

2.1.4. Environment, safety and health

The environmental, safety and health department comprises the following jobs and functions:

- *Environment Superintendent*

Reports to the General Manager; is responsible for application of all engineering activities involving in identifying and alleviating environmental problems; also directs socio-economic impact assessments; ensures compliance with federal, provincial and local ordinances concerning environmental standards; ascertains levels of pollution and makes recommendations to senior management; coordinates the activities of environmentalists and consultants; in charge of quality assurance and safety.

- *Radiation Safety Officer*

Reports to the General Manager: This position provides radiation protection and safety monitoring for the operations. Inspects and monitors all workplaces for contaminants such as radiation, gases, dusts, explosive fumes and noise. Develops radiation and safety programmes and provides training to the workforce. Ensure compliance of the operations with all regulatory requirements. Maintains radiation and safety records for all employees.

2.2. MANAGEMENT STRUCTURE OF AN IN SITU LEACH OPERATION

Table II is the organizational chart of an in situ leach (ISL) operation. An ISL operation is divided into four main activities and departments that are: the ISL wellfield, the process plant, the maintenance department, the environmental safety/health department. For a single project operation the overall management is assumed by a vice president mining and a general manager in the same manner as for a conventional mining operation.

2.2.1. ISL wellfield

The wellfield department comprises the following jobs and functions:

– *Wellfield Superintendent*

Reports to the General Manager; supervises and integrates production activities of Ion Exchange Plants and Wellfield operations; in accordance with company objectives and procedures and is responsible for meeting wellfield development and production commitments. He is also responsible for budget/cost control; supervises operations through second and first level supervisors.

TABLE II. ORGANIZATIONAL CHART OF AN ISL OPERATION

	Vice President, Mining		
	General Manager		
Wellfield Superintendent	Central Plant Superintendent	Maintenance Superintendent	Environment Superintendent
			Radiation Safety Officer
	Wellfield-Ion Exchange Superintendent		
Wellfield General Foreman		Chief Wellfield Engineer	
Wellfield supervision		Senior Engineer	
		Engineering and grade control functions	
	Central Process Plant Superintendent		
Process Plant General Foreman	Chief Process Engineer		Chief Chemist
Process Plant supervision	Process Engineers		Laboratory Staff
	Maintenance Superintendent		
Maintenance General Foreman	Maintenance Planner	Utilities	Warehouse
Maintenance Supervisors			

– *Wellfield Engineer*

Reports to the Wellfield Superintendent; responsible for wellfield (mine) design (short term and long term), flow and grade control. Co-ordinates work of pulling unit and technicians with Wellfield Foreman; plans and supervises wellfield quality control projects and construction of new wellfields; requires degree in engineering (Chemical or Mechanical) and at least 5 years of experience.

– *Wellfield Foreman*

Reports to Wellfield Supervisor; first-line supervisory position; responsible for the operation of an ion exchange plant, its associated wellfield and land irrigation facility.

– *Workover Foreman*

Reports to Wellfield Supervisor; first line supervisory position; responsible for scheduling and operation of well workover crews.

2.2.2. ISL processing

The ISL processing department comprises the following jobs and functions:

– *Process Plant Superintendent*

Reports to General Manager; responsible for overall management, direction and coordination of Central Process Plant and associated facilities, including volume and quality of production, scheduling of production, quality control, and meeting delivery dates, ensures yellowcake production objectives are met at lowest cost consistent with quality as well as safety, health, and environmental requirements.

– *Process Engineer*

Reports to Central or Process Plant Superintendent; responsible for application of engineering policies and practices, development of new chemical processes and improves to existing processes and products; identifies and develops control mechanisms to improve reliability and efficiency of a plant system; requires degree in chemical or metallurgical engineering.

– *Chief Chemist*

Reports to Plant Superintendent; fully qualified and experienced professional scientist; plans, conducts and supervises assignments involving chemical analyses of materials; reviews progress, evaluates results and recommends changes in procedures; requires advanced university degree in chemistry and four more years of experience.

2.2.3. Maintenance

The maintenance department comprises the following job and functions:

– *Maintenance Supervisor*

Reports to General Manager; responsible for all maintenance including routine, preventive and emergency; responsible for both mechanical and electrical maintenance, cost effectiveness of maintenance programme and planning; responsible for equipment modification; requires degree in mechanical or chemical engineering and four years of experience.

2.2.4. Environment, safety and health

The environment department comprises the following jobs and functions:

- *Environmental Manager (Environment Superintendent)*

Reports to General Manager and separately to Vice President Mining; responsible for detail phases of environmental surveillance,radiation safety, and reclamation programmes at the mine site; conducts plant and field environmental programmes; co-ordinates environmental sampling programme; responsible for compliance with all environmental regulatory programmes including filing required reports; acts as liaison between mine and regulatory agencies; requires degree in environmental engineering or related area.

- *Safety Officer*

Reports to General Manager and to the Environment Manager; administers and co-ordinates the safety and health programme including the associated and ongoing training programmes; responsible for compliance with all occupational health and safety regulatory programmes; acts as liaison between mine and regulatory agency; requires formal training in safety engineering or related field with 3-5 years of related experience.

- *Radiation Safety Officer*

Reports to General Manager and to Environmental Manager; administers and coordinates radiation safety and health physics programmes; responsible for compliance with all radiation exposure monitoring and control programmes; acts as liaison between project and radiation protection regulatory agencies; requires formal training in health physics, a university degree in technical discipline with 3-5 years of related experience.

3. GOOD OPERATING PRACTICE

The key to Good Operating Practice is *planning, scheduling* and *training*. This allows the organization to identify critical issues in advance, to anticipate difficulties, to prevent failures and to control the development, operation, and closure process.

Good practice requires a structural approach towards a prospective project. The process begins at the Exploration Stage with the collection of information for a "Prefeasibility Study" in which a project is described in very general terms. From then on all information is essential for the preparation of a Feasibility Study and Environmental Impact Assessment. These two documents combined give the description and schedule of the project. They include mining and milling (processing) methods, the environmental protection plan for operations, and the conceptual decommissioning of the project. They further discuss the regulatory approval process and the closure of the mine after ore extraction has been completed.

3.1. GOOD EXPLORATION PRACTICE

Exploration is an activity whose objective is to find a viable concentration of minerals that can be later extracted, refined and sold.

There are many theories and methods how to discover uranium mineralization. Exploration for uranium begins with discussions about areas and geological settings which have the potential for uranium mineralization. As a result of these discussions extensive airborne radiometric surveys over those areas will be done.

Encouraging results will be followed up with ground level geological and geophysical surveys. These geological and geophysical surveys can lead to the discovery of mineralized surface boulders, which in turn can indicate the presence of a regional conductor. Further prospecting and systematic drilling in that area will define the characteristic of the mineralization, and assist in the interpretation of the structures and finally lead to the discovery of an accumulation of mineralization.

Exploration drilling from surface through several hundreds of meters of barren rock can give a very inaccurate estimate of the mineralization, and is costly. For those type of orebodies an underground exploration programme is recommended for better delineation of the orebody and better ore estimate.

A general good exploration practice is the conservation of all data collected at the early stage of exploration to be used later for multipurpose. These data are valuable for:

- describing the geochemical background of region
- radiometric mapping to be used for land planning
- surface water quality
- characterization of soil
- measurement of ionizing radiation
- knowledge of the hydrogeological and geotechnical settings is essential for the mining engineer so he can design and plan a mining method which covers beside the excavation nd extraction of the ore, the protection of the health and safety of the employees and the environment.

Other good exploration practices are:

- keep your camp area clean
- manage your drilling with a geostatical method to optimize the number of holes and reduce environmental impact
- clean the holes before logging
- grout the exploration holes with an approved plugging gel or mud after completion to mitigate the hydrogeological impact and to enhance safety in the future operation, as well as decreasing the amount of water flowing through the mine
- coordinate the activities of underground drilling exploration and mining to avoid interference
- segregate topsoil when constructing drill sites
- close pits restore topsoil and revegetate
- maintain adequate permanent storage of all drill cares and data. Electronic forms such as CD disks or diskettes are advantageous.

3.2. GOOD MINING PRACTICE

Mining is a process of efficiently and economically excavating ore material by means of drilling, blasting, digging and transporting it to a surface process facility for further treatment.

Every level of management has to be involved in the implementation and usage of good practices. Good mining practice is demonstrated when the development team addresses a number of technical, health and safety concerns, discuss the impacts of those issues and provide solutions before the work begins. For the selection of a mining method, the following criteria have to be discussed and solutions proposed:

- Adequate radiation protection over the range of different ore grade.
- Compatibility with ground control and minimization of groundwater flow.
- Sufficient flexibility to adapt to different geological setting within the ore zone.
- Capability of producing the maximum ore tonnage or dissolved uranium for ISL projects.
- Optimizing the use of conventional methods and equipment for cost minimization.

In the case of high grade ore bodies, the mining industry is developing innovative "high tech" methods to deal with the health and safety issues resulting from the elevated radiation levels. There are only two high grade ore underground developments in the world (McArthur River and Cigar Lake projects in Canada). The mining methods planned in these mines are "non entry" methods like jet boring and raise boring using ground freezing or grouting to stabilize the ore and host rock. A description of the McArthur River Mine design is given in the case histories.

Examples of good mining practice for underground mines are:

- Proper ventilation systems where once through flow ventilation will avoid radon problems. This means that fresh air can go only once through a working place and is immediately exhausted.
- Storage of acid generating rocks and low grade ore in specific lined storage areas.
- The clear establishment of cut-off grade according to economic situation.
- Good lighting.
- Good communication.
- Clean working places.
- A clear and logical reporting system.

3.3. GOOD MILLING PRACTICE

There is a variety of milling processes available for processing uranium ore. Depending on the mineral composition of the ore one can chose from acid leaching to carbonate leaching combined with ammonia, strong acid, or hydrogen-peroxide precipitation methods. Good milling practices are demonstrated when an operator addresses not only the technical problems, but also extends the concerns to the health and safety of its employees and the impact of the operation on the environment.

Good milling practices include:

- Minimization of extraction and recoveries; set process standards.
- Minimization of reagent consumption.
- Addressing all material handling aspects of the process.
- Minimization of waste.
- Preventive and predictive maintenance to minimize breakdowns.
- Easy access to equipment for maintenance.
- Establishment of standards for the mill operation and radiation protection.
- Training of manpower to follow the standards and gain full understanding of the process.
- Flexibility to adapt to changes without negative impact on the process.
- Minimize employee exposure to radiation and other health and safety risks.

3.4. TRAINING AS GOOD OPERATION PRACTICE

One of the biggest assets a company has is its employees. When you value your employees, you strive to be an employer of choice. To support this vision, a commitment is to be made to train and develop employees. Workshops and learning opportunities should be designed to support this vision and for corporate values: excellence, people, integrity and environment. The corporate education and training department is a unit in the Human Resources and Corporate Relations Division that provides specialized training design and delivery support to the corporation and its various business and operating units.

Training is expensive. For example, the average annual per capita expenditure on training in the Canadian mining industry is about $1100. Training is an important aspect of good operating practice.

In general, there are three areas of employee training:

- Pre-employment training.
- Site-based training.
- Corporate training.

3.4.1. Pre-employment training

When commitments are made to employ residents of remote mining operations, pre-employment training programmes in these communities are important to the employment selection process. Capable candidates for employment are identified and the general knowledge level of the local community is enhanced. These initiatives are normally funded through master agreements with various government agencies.

3.4.2. Site-based training

New employee orientation

All new employees (including site-based contractor employees) complete an extensive orientation training process upon initial hire. This orientation includes information about the company, its various operations and basic employment policies. Employees also receive an introduction to their job, as well as a tour of the entire plant and site support services.

Extensive information and training is provided during this period on topics related to workplace safety, accident prevention, and radiation protection, as well as a host of other safety and environmental protection issues.

Environment and safety training

All employees receive training on-the-job or specialized training in environmental protection and occupational health and safety to ensure they are working in a productive and safe manner. These training activities are ongoing and form a central part of every employee's development and protection.

Job-specific safety training is provided to all operations personnel. Topics range from the use of personal protective equipment, workplace hazardous materials information (WHMIS) and dangerous goods transport, to more job-specific training like electrical lock outs, confined space entry, crane and sling training, etc. All employees working in an industrial setting are required to complete standard first aid and cardio-pulmonary resuscitation.

Radiation protection

Of particular concern to a company are issues related to radiation protection. Every employee begins their radiation training immediately upon hire, and is provided with ongoing and regular updates and reviews. The purpose of the radiation training is to maximize employee understanding of radiation issues and to ensure that the reduction of radiation exposure is a core responsibility of all employees.

Due diligence

To ensure that all supervisors throughout the corporation understand their responsibilities in the protection of the environment, and worker health and safety, due diligence training should be implemented.

First aid and CPR

All employees working in an industrial setting are required to complete standard first aid and cardio-pulmonary resuscitation

Emergency response, mine rescue and firefighting

All sites should have trained emergency response teams that receive advanced training in first aid and CPR. Specialists in mine rescue should also be available at all operating sites should an injury or accident necessitate a rescue. As part of their training it is common for these teams compete against teams from other mining operations in annual mine rescue competitions.

All employees receive basic firefighting, and every site has a team trained in advanced firefighting techniques and procedures.

Mill and plant process operations training

Extensive training is provided to all operations employees. Using a combination of hands on training, mentoring and computer based learning, mill operations employees are moved through a multi-step training progression that encompasses 20 different positions. The time required to complete the programme is several weeks (18 weeks for example).

In addition to training in the different plant operations the mill and plant operators also complete training in the operation of a variety of equipment including forklifts, cranes, high pressure washers, ramrods, and pumps, as well as the processes for sampling, safety, instrumentation, and computer operations.

Mine operations training

The primary training in mine operations includes mobile equipment operator training. The mine equipment operator progression has 5 steps and covers the full range of mobile equipment including loader, haul truck, grader, dozer, crane, backhoe, scraper, and hydraulic shovel.

Other progression training in the mine department is provided for driller/blasters, and dewatering technicians.

Underground mining

As the operation shifts from open pit to underground, skill training in underground mining will be implemented. This training will be entirely site-based and divided into basic and advanced underground mining. Basic underground mine training will focus on safety, ventilation, mobile equipment operation, blasting, rockbolting and screening and other basic conventional mining skills.

The advanced mining programme will consist of training in conventional techniques such as drift development, stoping, underground drilling, raise mining, and long hole drilling. Training in non-conventional techniques is also developed and implemented. Modules include raise, jet and box-hole boring, and mechanical drift mining.

Trades and technical training

Apprenticeship training is provided in three trades: industrial mechanic, heavy duty mechanic, and electrical trades. Technical progression training is provided in geological, chemical and environmental technologies. As well, technicians, technologists, and professionals are encouraged, with the support of the company, to pursue their own technical upgrading through professional associations, provincial institutes and universities.

3.4.3. Corporate training

A corporate training programme is divided into several streams: productivity improvement, communications, team learning, personal development, supervisory/management development, and executive development. A mobile computer training laboratory to facilitate computer skills training throughout the various operations is advantageous.

Every two years a corporate curriculum should be reviewed, updated and communicated to all employees through a published calendar. Employees, along with their supervisors, should select from a list of workshops which reflect the values and business needs.

In addition, the training unit designs and delivers other corporate training to meet specific emerging corporate needs. These programmes included training associated with corporate incentive plan and performance management programme.

3.5. RADIATION PROTECTION PROGRAMME

Radiation is an important part of any uranium mining operation. One of the main references for radiation protection are the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, jointly sponsored by FAO, IAEA, ILO, OECD/NEA, PAHO and WHO, and published by the International Atomic Energy Agency in 1996. This publication provides the basic requirements for protection against the risks associated with exposure to radiation. The standards are intended to serve as a practical guide and their use should be considered as an integral part of good practice.

3.5.1. Health physics management

The mining company should commit to a policy which will accomplish the objectives of its mining operation with a minimum radiation exposure to its employees, the public and the environment. It should have a documented commitment to a radiation protection programme designed to keep exposure as low as reasonably achievable (ALARA) which includes the following:

- A full time Radiation Safety Officer (RSO) at the site;
- Dissemination and posting of information and policy statements on health physics and occupational safety;
- Annual ALARA audits of the health physics safety programme;
- A facility Health Physics manual;
- Annual radiation safety refresher training.

The Radiation Safety Officer (RSO) will plan and administer the ALARA audit and radiation safety training programme. The RSO will have authority to review and concur on plans for new equipment or changes in processes or procedures that could adversely impact radiation safety or the ALARA programme and the authority to enforce regulations and corporate policies that affect any aspect of these programmes.

The Radiation Safety Officer (RSO) will report directly to the General Manager as well as to the Environmental, Safety and Health Supervisor on matters dealing with radiation safety. The RSO will have the responsibility for assuring that all in-plant and environmental radiation surveys and employees exposures are properly measured, calculated, documented and recorded. The RSO will perform facility inspections to assure compliance with regulations and review facility work orders to assure prescribed radiation safety procedures are followed. Within the RSO's normal work schedule, he will conduct a daily walk through inspection of the facility. The RSO will review facility operating and monitoring procedures annually for compliance with radiation safety policies and regulatory compliance.

3.5.2. Standard operating procedures

Standard written operating procedures should be established for all operational activities involving radioactive materials that are handled, processed, stored, or transported by employees. The procedures shall enumerate pertinent radiation safety procedures to be followed. Written procedures shall also be established for in-plant and environmental monitoring, bioassay analysis, and instrument calibration for activities involving radiation safety. A copy of the written procedure shall be kept in the area where it is used. All procedures involving radiation safety shall be reviewed and approved in writing by the RSO or another individual with similar qualifications prior to being implemented. The RSO shall review and approve the operating procedures annually.

3.5.3. Personnel TLD monitors

External personnel dosimeters, either thermoluminescent dosimeters (TLD) or film type dosimeters will be worn by all employees who work in or routinely enter the product (yellowcake) drying and packaging controlled area.

3.5.4. Bioassay programme

As a means for detecting and measuring the ingestion of natural uranium by employees, a urinanalysis or bioassay programme should be implemented and be maintained at the site. Urine samples are analyzed for their uranium content. In addition samples containing an excess of 5 micrograms of uranium as U per milliliter should also be analyzed for their protein content. The programme includes a baseline urinanalysis for all permanent employees prior to their initial assignment at the facility and monthly urinanalysis for those employees who routinely work in the recovery plant controlled area.

The bioassay results shall be carefully reviewed and appropriate actions will be taken if the results exceed predefined levels, and are determined to be correct. If there is doubt as to the correctness of a bioassay result, an investigation should be initiated which may include a conference with the affected employee and or his/her immediate supervisors.

3.5.5. Exposure calculations

Calculation of internal exposure to radon daughters and natural uranium shall be made for those employees who routinely work in the product drying and packaging controlled area based on a time weighted average (TWA) incorporating both occupancy times and average airborne working levels or activity concentration. If occupancy times are established as an average for any category of workers, an annual time study shall be conducted for that category of worker to determine the basis for the average occupancy periods used.

If any workers reaches or exceeds 25% of the maximum permissible exposure limits, the RSO shall initiate an investigation of the employee's work record and exposure history to identify the source of the exposure. Necessary corrective measures shall be taken to ensure reduction of future exposures to as low as is reasonably achievable (ALARA). Records shall be maintained of these investigations.

3.5.6. Protective equipment and procedures

All process and maintenance workers who work in yellow cake areas or work on equipment contaminated with yellow cake should be provided and required to wear protective clothing including overalls, boots or shoe covers. Workers who package yellow cake for transport should also be provided with gloves. Before leaving the change area, all process workers involved in the precipitation or packaging for transport of yellow cake, shall, at a minimum, monitor their hands and feet using a calibrated alpha survey instrument. In addition, spot surveys shall be performed for alpha contamination at least quarterly on all workers leaving the recovery plant area. The monitoring results shall be documented and maintained on file. Eating shall only be allowed in administrative offices and designated lunch areas that are separated from any process areas.

3.5.7. Facility radiation surveys

The radiological monitoring programmes include alpha, gamma, air sampling programmes. Alpha contamination surveys of the eating and change areas will be conducted weekly and surveys of the facility laboratory and offices should be conducted monthly.

Surveys for natural uranium and radon daughters shall be performed monthly in the recovery plant areas at predetermined locations. Gamma radiation surveys shall be conducted quarterly in the mill or processing plant at predetermined locations. A continuous passive radon detector, located at the downwind recovery plant site boundary, shall continue to be analysed quarterly. All equipment, materials, and/or packages must be surveyed for radiation contamination prior to release from the restricted area.

3.5.8. Management audit and inspection programmes

Good management practice includes regular auditing of the health physics programme which should be carried out in accordance with written company procedures. Auditing will be performed by the facility RSO. These audits will be conducted at least annually. Copies of the audit reports will be sent to corporate management, as well as to the local management, for corrective action as appropriate.

3.6. ISL METHODS

Evaluating the suitability of an orebody for uranium extraction via ISL requires information regarding the accessibility of the uranium mineral and its solubility in a leaching solution. The orebody should be situated below the natural water table in a permeable zone, likely a sandstone. This location allows for hydrologic control of leaching solution during the mining and facilitates restoration of the groundwater quality following completion of mining.

Selection of the lixiviant of leaching solution is a key factor in designing an ISL operation. This selection is driven by uranium recovery efficiencies, operating costs, and the ability to achieve a satisfactory groundwater quality restoration. The primary choice is between a sulfuric acid lixiviant and a bicarbonate–carbonate lixiviant. In general acid systems would not be considered for carboneous deposits because of high acid consumption. Sulfuric acid systems have long been used in eastern Europe and Asia while carbonate systems are preferred in the USA. Acid systems are now being tested in Australia or ore bodies which reside in saline aquifers.

4. ECONOMIC CONSIDERATION

4.1. URANIUM MINERALIZATION AND ITS VIABILITY

After the initial grass-root exploration work, which discovered a concentration of uranium mineralization, a geological exploration data base has to be established to evaluate and plan further actions.

When the database indicates that sufficient reserves have been identified to warrant proceeding with an extended exploration programme, a detailed in-fill drilling programme of a representative portion of the deposit is the next logical step to improve reserve accuracy, confirm ore continuity and delineate mineralization limits and geological structures for a possible mine design.

It may be technically difficult and prohibitively expensive to carry out the in-fill drilling programme from surface; the in-fill drilling is often most effectively carried out as part of an underground exploration programme. Upon completion of this extended programme, it is important that a detailed study is prepared in which the feasibility and viability of the ore deposit is confirmed.

The Feasibility Study which is a good management practice shall review the geological ore reserves using both, the initial and extended exploration drill information, compare the results from both drill campaigns, calculate a minable ore reserve base, determine the mining methods, mine development requirements, consider surface facilities, site access and infrastructure needs and consider the design of a mill and waste management facility.

The Feasibility Study shall make provisions for the identification and mitigation of all possible impacts on the biophysical, socio-economic and human resource environment. Such impacts include, but are not limited to, the following:

- Radiation protection, monitoring and exposure (utilizing ICRP 60 with a 4.0 Working Level Month, WLM limit) for all sources (emanation, gas dust, etc). The ALARA principle must be applied to all exposure scenarios.
- Hazardous chemicals storage, transportation, emergency response contingencies, first aid, material handling and labelling.
- Handling of water from all contaminating sources including open pit and underground areas, stockpiles, mill, drys, camps, etc. Minimization of water contamination to meet government regulations.
- Treatment of all contaminated water to meet discharge limits. Maximize water recycling to meet regulatory requirements.
- Disposal of hazardous waste (i.e., waste oil), industrial and domestic waste handling and disposal.
- Fate of all ore and waste materials on surface and their potential for short and long term impacts (i.e., acid mine drainage, leaching of deleterious substances, radiation, fugitive dust, etc.).
- Socio-economic impacts (including heritage resources); this includes public meetings to inform and educate the local population on project plans and expectations.
- Bio-physical impacts (i.e., wildlife, aquatic environment, air quality, water quality, rare and endangered species, land disruption, etc.).
- Movement of all water on site, both surface and subsurface, and its potential for contamination.
- Decommissioning and reclamation of all facilities.

The Feasibility study shall identify all regulatory requirements of the various agencies and the impact of each requirement on the project in terms of engineering, scheduling and cost. It shall further determine the construction and development schedule, manpower levels, capital and operating costs. A financial sensitivity analysis for the feasibility study shall be prepared following "Good Mining and Business Practice", and shall meet all regulatory requirements. Discounted cash flow techniques are commonly employed in the financial studies. The project shall be designed at optimal cost with due regard for the project life.

In view of the difficulties to forecast the price of uranium to be used for the study, the financial analysis should be carried out on a break-even basis after taxes and royalties to determine the price of uranium required to yield a zero NPV at discount rates of 10%, 13% and 15%.

When all this has been done, the viability of a project can be established with minimized risks and identified areas of uncertainty.

5. PREPARATION FOR CLOSURE

It is in the interest of all new mines that they develop closure plans that protect human health and the environment, prior to proceeding with the project. It is also with interest of the mining company that, wherever practical, rehabilitation work be carried out during mining operations, and the amount of rehabilitation work after closure of mining be kept to a minimum.

Preparing an acceptable closure plan, prior to the development of a mine, at the time of permit application, is an interim plan. The plan is based upon forecasts and projections. The life and operation of the mine may change. Hence, the closure plan should periodically be re-evaluated as the operation goes on.

5.1. PREPARATION FOR THE DECOMMISSIONING AND CLOSURE OF A URANIUM MINE

Prior to developing a closure plan, it is necessary for a company to review its policy in relating to decommissioning and reclamation. This can be done by preparing a list of principles under which the closure will be effected and with which decisions can be made. This review process can result in a Code of Practice which can state:

"Upon the permanent cessation of operations, the site will be abandoned in a safe, stable and aesthetically pleasing state. Stabilization procedures will be undertaken to prevent and/or reduce the migration or erosion of waste materials and reduce the potential for inadvertent exposure to members of the general public."

An example of decommissioning principles follows:

- The effective dose equivalent to any person at any time should comply with regulatory limits.
- Any exposure arising from the site should be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- Standard good engineering practices are to be used even with optimization analyses suggest that lesser efforts may be sufficient.
- The annual quantities of radioactive and non-radioactive constituents released to the environment after closure should not exceed the corresponding releases that occurred during the operating phase.

The decommissioning of a site would include:

- From open pit and underground workings, all salvageable materials will be collected or brought to surface and removed from the site.

- All remaining chemicals, reagents and fuels will be removed from the site and for safe disposal, or, preferably, re-use or recycling.
- Other deleterious material (acid generating waste rock, mineralized core, etc.) will be disposed of in the tailings pond, or underground, used to fill the lower portion of the shaft, or at another approved site.
- Shafts will be filled with non salvageable waste, and these and any other openings to surface will be capped to prevent injury to humans or animals.
- All man-made materials not disposed of at the site will be removed from the site for disposal, re-use or recycling as appropriate.
- Water treatment ponds will be filled and contoured.
- All surface areas, the airstrip and roads not required for post-decommissioning monitoring would be contoured and scarified as appropriate.
- All buildings and other structures, when not salvaged, will be removed, burned or buried. Concrete foundations are to be removed wherever possible, but may be left in place if approved by the regulatory agencies.
- Contaminated machinery and materials would be collected and disposed of.
- Culverts, bridges, docks and any water diversion will be removed to restore normal waterflow to the site.
- Re-vegetation will be done as required.
- A monitoring programme will be conducted to ensure that the site is left in a non-polluting, stable state.

All these decommissioning activities should be discussed with and approved by the regulatory agencies. The activities may spread over a number of years.

5.2. DECOMMISSIONING AND CLOSURE OF AN ISL OPERATION

The objective of the decommissioning and closure plan is to return the affected surface and groundwater to conditions such that they are suitable for uses for which they were suitable prior to mining. The methods to achieve this objective for both the affected groundwater and the surface are described in the following sections.

5.2.1. Groundwater restoration

5.2.1.1. Water quality criteria

The objective of the aquifer restoration plan will be to return all affected groundwater to a condition such that its quality of use is equal to or better than, and consistent with, the uses for which the water was suitable prior to the operation by employing the best practicable technology. To achieve this objective, the primary goal of the restoration programme will be to return the condition and quality of the affected groundwater in a mined area to background (baseline) or better. In the event the primary goal cannot be achieved, the condition and quality of the affected groundwater will at a minimum be returned to the pre-mining use suitability category.

The final level of water quality attained during restoration is related to criteria based on the pre-mining baseline data from that mining unit, the applicable use suitability category and the available technology and economic conditions at the time of restoration. Baseline shall be the mean of the pre-mining baseline data, taking into account the variability between sample results (baseline mean plus or minus tolerance limits, after outlier removal).

5.2.1.2. *Restoration criteria*

The restoration criteria for the groundwater in a mining unit will be based on the mining unit production-injection wellfield as a whole, on a parameter by parameter basis. All parameters are to be returned to as close to baseline as is reasonably achievable (ALARA). Restoration target values should be established for all parameters affected by the mining process. The restoration target values for the initial mining units should be the mean of the pre-mining values. If during restoration, the average concentration of a parameter in the designated production area wells of a mining unit is not reduced to the target value within a reasonable time, a report describing the restoration method used, predicted results of additional restoration activities, and an evaluation of the impact, if any, that the higher concentration has on the groundwater quality and future use of the water should be prepared. This report becomes the technical basis for determining if the higher concentration of a particular species should be accepted as an alternate restoration.

5.2.1.3. *Restoration method*

The primary restoration technique will be a combination of groundwater sweep and clean water injection. Groundwater sweep involves withdrawing water from selected production and injection wells which draws uncontaminated natural groundwater through the leached area displacing the leach solutions. Clean water injection involves the injection of a better quality of "clean" water in selected wells within the production area while pumping other production and/or injection wells which again displaces the leaching solutions with the better quality water. The source of the clean water may be from an electrodialysis unit (EDR) or reverse osmosis (RO) type unit, water produced from a mining unit that is in a more advanced state of restoration, water being exchanged with a new mining unit being placed in operation, or a combination of these sources. Water withdrawn from the production zone during restoration will first be processed through an ion exchange unit to recover the uranium, then will be treated and reused in the project, treated and discharged with regulatory approval, or routed to a holding pond for future treatment and/or disposal.

Chemical reductants are beneficial because several of the metals which are solubilized during the leaching process are known to form stable insoluble reduced compounds, primarily as sulfides. Primary among such metals is uranium which occurs at the site because of the naturally occurring reduced state of the ore body. The introduction of a chemical reductant into the mine zone at the end of mining phase is designed to expedite the return of the zone to its natural conditions and to return as many of the solubilized metals to their original insoluble state as possible. By effecting this partial restoration directly within the formation (in situ), the external impact of groundwater restoration is minimized.

The chemical reductant would be added above ground to the clean water stream being injected into selected wells. The reductant should be a sulfur compound such as gaseous hydrogen sulfide (H_2S) or dilute solutions of sodium hydrosulfide (NaHS) or sodium sulfide (Na_2S). Dissolved metal compounds which are precipitated by such reductants include those of arsenic, molybdenum, selenium, uranium, and vanadium. All of these may be present in concentrations above baseline levels at the conclusion of mining.

The reductant would be introduced during the midst of the restoration process because the introduction of sulfur and sodium increases the total dissolved solids (TDS) level of the injected fluid. once the reducing conditions are re-established, an oxygen free clean water can be injected to effect the final reduction in TDS. If gaseous hydrogen sulfide is chosen for use, a programme for its safe handling would be prepared and submitted to the appropriate agency prior to its use.

5.2.1.4. Restoration sampling

When sampling results indicate that restoration has been achieved, the designated production area wells will be sampled and analysed for the full suite of parameters listed in Table III. If the data confirm restoration is complete this will initiate the stability demonstration period. In the stability demonstration period the full suite assays will be repeated for those same wells at approximately the six month and one year periods. Between these periods the wells will be sampled at six week intervals with the samples analysed for a short list of key parameters developed for that specific mining unit. This sampling plan will provide for a minimum of nine samples within a one year period to demonstrate restoration success.

TABLE III. BASELINE WATER QUALITY PARAMETERS

MAJOR IONS (mg/L)
Calcium
Magnesium
Sodium
Potassium
Total carbonate
Bicarbonate
Sulfate
Chloride
Ammonium
Nitrite + nitrate
Fluroide
Silica
TDS
Alkalinity
pH
TRACE METALS (mg/L)
Arsenic
Boron
Cadmium
Chromium
Iron
Manganese
Molybdenum
Selenium
Uranium
Vanadium
Zinc
RADIOMETRIC
Radium-226
Radon-222

When the sampling data indicates that the mining unit aquifer has been restored and stabilized, a report documenting this should be filed with the appropriate regulatory agencies along with a request for certification of restoration. Plugging of wells and surface reclamation of the mining unit will commence after receipt of restoration certification.

During restoration, sampling of monitor wells for that mining unit will continue at the same frequency and for the same parameters as during mining. However, during stability monitoring the monitor well sampling frequency will be reduced to only once every two months and the sampling will be terminated at the end of the stability demonstration period. Unless requested otherwise and approved by the applicable regulatory agencies, the production area wells in a mining unit to be sampled for determining restoration and stability shall be wells used for collecting pre-mining baseline data for that unit.

5.2.1.5. Well plugging procedures

Wells no longer needed for operations or restoration and stability demonstration will be plugged. The pumps and tubing will be removed from the wells and each well will be filled from total depth to within five feet of the surface with an approved abandonment mud or a cement slurry. The casing will then be cut off a minimum of two feet below the surface and a cement plug will be placed at the top of the casing. The area will then be backfilled, smoothed to blend with the natural terrain, and reclaimed as specified in the approved surface reclamation plan.

5.2.2. Surface reclamation and decommissioning

All lands disturbed by the mining project should be returned to their pre-mining land use of livestock grazing and wildlife habitat unless an alterative use is justified and is approved by the regulatory agencies and the landowner, i.e. the farmer desires to retain roads or buildings. The objectives of the surface reclamation effort should be to return the disturbed lands to production capacity of equal to or better than that existing prior to mining. The soils, vegetation and radiological baseline data will be used as a guide in evaluating final reclamation.

5.2.2.1. Surface disturbance

The primary surface disturbances associated with ISL are the sites for the recovery plant and evaporation ponds. Surface disturbances also occur during the well drilling programme, pipeline installations, road construction, and pumping station construction. These disturbances, however, involve relatively small areas or have very short term impacts.

Disturbances associated with the evaporation ponds, ion exchange satellites and field header buildings, will be for the life of those activities and topsoil should be stripped from the areas prior to construction. Disturbance associated with drilling and pipeline installation will normally be limited, and should be reclaimed and reseeded in the same season. Vegetation will normally be reestablished over these areas within two years. Disturbance for access roads will be also limited.

5.2.2.2. Topsoil handling and replacement

The soil disturbances caused by the mining operation should be kept to a minimum. Topsoil from the mine site is stockpiled and the piles seeded with a cover crop to control erosion. Topsoil from future disturbance areas such as evaporation ponds should be removed and stockpiled. The stockpiles will be located, shaped, seeded with a cover crop and crimp mulched to minimize loss to erosion. Topsoil signs should also be placed on each topsoil stockpile to prevent misuse of the stockpile.

Within the wellfields, topsoil should be removed from new access roads and pumping station building sites and stockpiled as discussed above. If unanticipated high traffic roadways are developed, the top soil on such roadways would be subject to the same programme of removal, stockpiling, seeding and mulching to control erosion. For areas where only limited temporary disturbance occurs, such as for well sites and pipeline construction, the topsoil should be bladed to one side and then respread over the area as soon as construction is completed. These areas should be stubble mulched as soon as practical. If topsoil stockpiling or re-topsoiling of an area is completed in the winter or spring, a stubble crop of oats should normally be planted with the final grass seed mix or a longterm cover seed mix planted in the stubble in the fall. The long term cover grass mix will be used to protect topsoil stockpiles and/or re-topsoiled areas which are expected to remain in place for longer than one (1) year prior to final seeding. These will provide the needed protection for the topsoil and will minimize losses to wind and water erosion.

Additional measures taken to protect the topsoil in the wellfield areas will be to restrict normal vehicular traffic to designated roads and keep required traffic in other areas of the wellfield to a minimum. Disturbed areas in a wellfield not needed for normal access will be seeded with a cover crop as soon as practical to minimize erosion.

After contouring for final reclamation has been completed, the remaining access roads or hard packed areas will be ripped prior to topsoiling. Topsoil will then be spread evenly over the disturbed areas and will be seeded with a cover crop of oats. Final contouring will blend with the natural terrain and will establish drainage and eliminate depressions that would accumulate water.

5.2.2.3. Revegetation practices

During mining operations the topsoil stockpiles, and as much as practical of the disturbed wellfield and pond areas will be seeded with a cover crop to minimize wind and water erosion. After topsoiling for the final reclamation, an area will normally be seeded with oats to establish a stubble crop then reseeded with grasses the next growing season using an approved mix of live seed.

Vegetation in larger reclaimed areas will be protected from livestock grazing by fencing the livestock out until the newly established plant community is capable of maintaining itself under normal management practices. No major attempt will be made to exclude wildlife; however, livestock fencing will be used.

Periodic inspections of the newly reclaimed areas should be made within the first two growing seasons to check and record the success and progress of the reseeded plant community. Data collected during these inspections will be used to determine when the reseeded areas will be ready to sustain controlled livestock grazing and for the final evaluation of reclamation success.

Criteria for determining the success of the reclamation efforts should include (1) post-mining vegetation cover and production equal to that on an appropriate comparison area,

(2) species composition and diversity capable of supporting the planned post-mining use, and (3) a reclaimed vegetation community able to sustain grazing pressure at a rate equal to that of the surrounding native areas. All of the above should be achieved for a period of two consecutive years prior to release of the land for iron-mining uses.

An extended reference area should be established which will include the primary vegetation types to be disturbed. This area becomes a reference for measuring the relative quality and quantity of vegetation established during reclamation.

5.2.3. Site decontamination and decommissioning

When groundwater restoration in the final mining unit is completed, decommissioning of the recovery plant site and the remaining evaporation ponds will be initiated. In decommissioning the recovery plant, the process equipment will be dismantled and sold to another licensed facility or decontaminated. After decontamination. materials that will not be reused or that have no resale value, such as building foundations, will be buried on-site.

The plant site will then be contoured to blend with the natural terrain, surveyed to ensure gamma radiation levels are within acceptable limits, topsoiled, and reseeded per the approved reclamation plan. After all liquids in an evaporation pond have evaporated or been disposed in a licensed facility, the precipitated solids and the pond liner will be removed and disposed of in a licensed facility. The area will then be contoured to blend with the natural terrain, surveyed to ensure gamma levels are not exceeded, then topsoiled and reseeded per the approved plan.

Gamma surveys will also be conducted during the decommissioning of each mining unit. Site decontamination and decommissioning are regulated by the competent authority of the countries that provide guidelines to the mining operators.

5.2.4. Final contouring

Recontouring of land where surface disturbance has taken place will restore it to a surface configuration which will blend in with the natural terrain and will be consistent with the post mining land use. No major changes in the topography should result from ISL mining operation.

5.2.5. Reclamation cost estimate

A detailed reclamation cost estimate must be prepared for all aspects of the project. A 15% overall contingency is applied to the total cost estimate. The estimate should be updated on an annual basis for submittal in the annual report.

6. CONCLUSION

The contents of this book are guidelines for uranium mining and in situ leaching operations. It calls upon twenty years of industry experience to identify the best means to prepare, operate and close a uranium mine. It is not intended to be an encyclopedia or handbook on mining but it should serve as a framework or structure for organizations which are preparing new mines.

The key to Good Practice is planning which allows the organization to identify critical issues in advance, to anticipate difficulties, to prevent failures, and to control the development, operation and closure processes. Following the guidelines described will assist in creating a mine where the health and safety of its employees and the public are protected, the environmental impact of its activities are addressed, and the economical benefits are achieved.

7. CASE HISTORIES

7.1. CANADA: THE McARTHUR RIVER PROJECT

The McArthur River deposit is one of the largest, high-grade uranium deposits in the world. Geological reserves are estimated at 416 million pounds (160 000 t U) at an average grade of 15% U_3O_8. To put this quantity of uranium into perspective, 416 million pounds would supply all of Saskatchewan's electricity needs for about 500 years.

To put this grade of reserves into perspective, Key Lake, currently the highest grade uranium operation in the world, contained reserves of 182 million pounds at an average grade of 2% U_3O_8.

7.1.1. Mining method selection

At the outset of the mining method selection process, no mining method should be eliminated for an orebody. However, a number of conventional and unconventional mining methods can be readily eliminated, because they require personnel to enter the production area, and are incompatible with grouting and freezing techniques or incompatible with geological settings.

Methods eliminated because they require manned entry, included undercut and fill, cut and fill, drift and fill, room and pillar and shrinkage stopping. Methods incompatible with grouting and freezing include block caving, sublevel caving and hydraulic mining. Methods incompatible with geological settings include auger mining, horizontal raiseboring, uphole blasting from the drift under the ore zone and remote roadheader mining.

In our case, this leaves seven potential mining methods for consideration in the detailed selection of the method.

- Blasthole stopping including vertical crater retreat.
- Raiseboring
- Remote raisebore stopping
- Jet boring
- Boxhole boring
- Remote boxhole stopping
- Remote boxhole stopping with "Viscaria" raise mining.

All of the above mining methods have the potential of being used in our example should ore grades and ground conditions be suitable. The current preferred options are boxhole boring, raise boring and the related boxhole stopping and at Cigar Lake are ore freezing, jet boring and cemented backfill.

The mining of high grade ore makes it necessary to design a ore handling system, which minimizes exposure and opportunities for spillage. These facilities can range from mechanical systems, which would provide poor radiation and spill protection, such as conventional load-haul-dump mining from a drawpoint and standard skip arrangement to surface, to a contained remote controlled system.

Conveyor transport was evaluated, but was felt to contribute high radioactive contamination levels from dust. Containers for broken ore were considered, but suffered from a large number of technical and logistic problems.

The idea of containment is the best solution for dealing with high grade ores. A slurry product (crushed and ground rock plus water), can be satisfactorily contained within pipelines and pumped to surface through dedicated boreholes, avoiding any potential to contaminate a production shaft. This means the construction of underground crushing and grinding facilities, which is not uncommon in the mining industry. Large positive displacement pumps, capable of delivering sufficient volume, will pump the slurry to surface, utilizing pressures up to 14 000 kpa.

Other areas where good mining practice is important are: ventilation where once flow through ventilation will avoid radon problem.

- The acid generating rock, waste rock and ore have to be separated in storage areas.
- The establishment of the cost of production area.
- The clear establishment of out-off grade according to economic situation of the market.
- Good lighting.
- Good communication.
- A clear and logic reporting system.

7.1.2. Milling

In this example a complex ore with diverse mineralogy is used. The principal uranium minerals being pitchblende, sooty pitchblende and coffinite. These are accompanied by graphite, sulphides, arsenides and arseno-sulphides together with minor amounts of lead, zinc, copper, molybdenum, cobalt and vanadium. The process for this ore uses acid leaching with ammonia stripping.

This milling process was designed to produce uranium oxide (U_3O_8) from the ore, ammonium sulphate fertilizer as by-product and releasable effluent. The design of the mill incorporates features which allows it to produce at variable rate from a wide range of complex mineralized ores. The process consists of six main steps. Each step is essentially a separate plant that is intimately linked with each of the other plants in that solutions and slurries flow back and forth between them. The six main steps are:

- grinding
- leaching
- washing
- solvent extraction
- yellow cake precipitation
- bulk neutralization.

It should be noted that all of the processing, except the final product drying, is carried out in aqueous medium. The transportation of materials through the process is achieved by pumping the solutions through pipelines.

7.1.2.1. Grinding

The grinding circuit consists of two separate grinding stages. The first stage consists of a semi-autogenous grinding (SAG) mill operated in open circuit, which reduces the run of mine ore to particles about 10 mm in diameter. The second stage, a ball mill circuit, further grinds the ore to less than 0.5 mm in diameter. This slurry is pumped through a pipeline to the main process facilities.

7.1.2.2. Leaching

Leaching the uranium from the ore is accomplished by using sulphuric acid and oxygen in a pressurized autoclave system. The ore slurry from grinding is discharged into pachucas that *provide surge* capacity between the grinding and leaching plants. The pachucas are operated on a batch basis with a pachuca being completely filled, sampled and assayed before being fed to leaching. The slurry is pumped from the pachuca at a controlled rate to the primary leach stage where it is mixed with the acidic overflow solution from the washing circuit. This mixture then flows to the primary thickener. The overflow solution from this thickener is called pregnant solution and is pumped to the solvent extraction plant. The underflow solids from the thickener are fed to the secondary leach circuit.

The secondary leach circuit consists of a series of autoclaves in which the ore is reacted with sulphuric acid and oxygen at an elevated temperature (60°C) and pressure (580 kPa). The underflow from the primary thickener is pumped to a mix tank to which concentrated acid is added. This acidic mixture is then pumped into the pressurized autoclaves where it spends about 5 hours with oxygen being purged through the mixture at the elevated pressure. Temperature is provided by the reaction heat. The slurry discharges from the autoclaves through a special pressure let-down valve and is fed to the washing circuit.

7.1.2.3. Washing circuit

The solids discharged from the autoclaves are washed in an eight stage counter current decantation (CCD) circuit. Water is added to the last stage in the circuit. The solids flow through the eight thickener stages and are sequentially washed by the water at each stage. After the eighth washing stage the solids slurry is neutralized with lime and pumped to the tailings storage area. The wash solution flows from the eighth stage to the first stage going counter current to the solids. The overflow solution from the first stage is mixed with the incoming ore in primary leach as was previously described.

7.1.2.4. Solvent extraction

The pregnant solution from the leaching circuit is fed to a solvent extraction circuit. This process consists of several extraction stages where the uranium is selectively extracted into an organic phase, several scrub stages where the organic phase is rinsed with acidic water and several strip stages where the uranium is stripped from the organic into an ammonium sulphate solution. This is called the loaded strip solution. The organic phase, which consists of 6% amine and 2% isodecanol dissolved in kerosene, is rinsed with water after leaving the strip circuit and is then fed back into the extraction stage. Ammonia is added in the strip circuit to control pH.

The waste solution from the extraction stage (raffinate) is pumped to the bulk neutralization circuit for waste treatment. A small portion of this stream can be recycled to the washing circuit to conserve acid. The loaded strip solution is treated in another solvent extraction process to remove molybdenum from the solution before it is pumped to the yellow cake circuit for product recovery.

7.1.2.5. Yellow cake and crystallization

The uranium is recovered by adding ammonia to the loaded strip solution in an agitated tank. This causes the dissolved uranium to precipitate as ammonium diuranate. The resulting slurry is then fed to a thickener and subsequently a centrifuge to remove the bulk of the solution. The solids from the centrifuge are fed into a multi-hearth furnace to convert the ammonium diuranate to dry uranium oxide (U_3O_8) product. This product is packed in steel drums for shipment.

The overflow solution from the thickener is filtered and fed back to the solvent extraction circuit. A small stream of barren strip solution is fed to the crystallization circuit for removal of ammonia as ammonium sulphate crystals. The crystallization circuit consists of two evaporators and a crystallizer, in which the water is progressively evaporated. This results in crystals being formed. The crystals are separated from the liquor in a centrifuge, dried in a fluid bed dryer and stored for shipment.

7.1.2.6. Bulk neutralization

Waste streams from solvent extraction plus contaminated water from various sources at the site are fed to the bulk neutralization process. There are three stages in the process. The first is neutralization of the acid in the raffinate, followed by radium and arsenic removal and finally effluent pH adjustment.

The first stage is carried out in several pachucas to which lime is added to give a pH of 7. The solids precipitated in this first stage are separated from the solution in a thickener. The underflow solids slurry from the thickener is combined with the waste solids stream from the washing circuit. The overflow solution from the thickener is subsequently treated with barium chloride and lime to a pH of 11 to remove radium and trace amounts of arsenic, nickel and magnesium. This is done in a series of mechanically agitated reactors. The precipitated solids from this stage are removed in a thickener and are also combined with the waste solids stream. The overflow solution from the thickener is then treated with sulphuric acid in two stages to reduce the pH to neutral. This effluent then flows to the environment via a monitoring pond sampling and release system.

The waste solids stream is treated with lime to produce an alkaline slurry (pH > 10) which is then pumped to the tailing disposal area. The solids settle in that area and the contaminated water is collected as supernatant and returned from the tailing pond to a water reservoir at the mill site for further treatment.

7.2. CZECH REPUBLIC: APPLICATION OF THE ISL METHOD AT THE DEPOSIT IN STRÁŽ

7.2.1. The well grid and well density

In the first years of existence of the chemical extraction between 1967 and 1972 mostly isometric polygons, at the beginning hexagons, later squares of production wells were constructed. As in these times the methods used to secure the capacity maintenance of the injection wells at the required level were not yet developed and the yield of the production wells highly exceeded this capacity, the polygons were constructed with a central production well and the injection wells were arranged at the circumference and located at the apices and the centres of edges of the chosen shape. The theoretical proportion between injection and production wells in an infinite well grid with hexagonal shapes would be 5:1 and with an arrangement in squares 3:1.

In the following years the scheme of hexagonal grids was abandoned and the newer leaching fields were designed with square nets of wells in which the injection and production wells alternate and are in a numerical proportion of 1:1.

After the assessment of the negative influence of the depression cone of the dewatered mining field of the deep mine the square well grids appeared to have an only low appropriateness. A great part of the injected leaching solution did not flow to the nearest production well but was transported to greater distances, often also out of the contours of the leaching field and sometimes also out of the territory of the chemical extraction; often they also penetrated outside of the ore body in its top layers. This resulted in losses of chemicals (neutralization by ballast components) and also of uranium (by precipitation from the solution outside of the ore layer). The solution was found in a transformation of the well grid to rectangular shapes and gradually linear schemes in which the rows of wells of the same polarity are at distances many times greater than the distances between wells in the rows were developed. These grids were applied since 1979.

Another change in the well grids was caused by the transition from the pumping of extracting solutions by air pumps (airlift) to the application of stainless steel submersive pumps. The main accompanying change was the need of greater diameters of the boreholes and an increase of the costs of the drilling process including also the construction of wells with stainless casing. Also the efficiency of the production wells increased.

These changes resulted in an enhancement of the relation between injection and production wells to 16:1. Since 1984 leaching fields with linearly arranged injection wells (distance between the wells 11 m), and with production wells in distances between 60–120 m in the rows are operated. The distance between the rows is 100–150 m.

Even later the outlines of the leaching fields were partially adjusted to the shape and accessibility of the terrain and accommodated to the geological conditions with shapes of irregular polygons with narrow injection wells at the periphery and a "central" large-dimension well.

7.2.2. Construction of wells

- Narrow boreholes, drilled in the Turonian aquifer, were constructed with doubled casing columns.

- Large-dimension boreholes had been projected for the solution of a rational pumping regime particularly in regions with relatively lowered Cenomanian water level. By their implementation the specific consumption of electric energy of the pumping decreased approximately an one half.

7.2.3. Recovery

The recovery of the uranium leaching process at the deposit of Stráž varies highly. This process parameter is continuously checked in the individual leaching fields starting at the beginning of the operation till its abandonment. The value of recovery depends particularly on the working period of the field, the circulation rate of the solutions, the sulphuric acid concentration in the leaching solution and the mineralogical composition of the ore in the leached deposit layer. It is for this reason that the values of recovery of the individual fields are not comparable. As an illustration it can be mentioned that the recovery in the individual fields in the area of the Stráž deposit are between 25 and 89%.

The recovery of the leaching process is to a considerable degree dependent on the concentration or dosage of sulphuric acid. On the basis of the knowledge acquired during exploitation, a theoretical relation between the course of recovery and the dosage of sulphuric acid had been developed.

The annual uranium production from the Stráž deposit was about 700 t during a long period, and was maintained by the gradual extension of the mined deposit area. Only after 1991 an abrupt decrease occurred which was caused by the overall situation on the uranium market, the new economic conditions and the change of strategy in the Czech Republic when it was decided that the uranium production will be lowered to a level covering only the requirements of the Czech nuclear power production.

7.2.4. Surface technologies

After the solution had been pumped to the surface the contained uranium is separated from the leachate in a processing complex constituting the so-called chemical station.

The leachate flows through sorption columns and uranium is separated on a strongly basic anion exchanger "Varion AP" which, in the given environment, has favourable properties as regarded from the point of view of the sorption selectivity for uranium. The solution without the extracted uranium, after a readjustment of the concentration of sulphuric acid and, if necessary, of nitrate concentration (nitrate serves as oxidant) is injected back into the underground as leaching solution.

The uranium fixed on the ion exchanger is redissolved by elution with a dilute solution of nitric acid and precipitated by ammonia as a chemical concentrate which is designed as ammonium diuranate. After dewatering of the generated suspension and drying, the final product of the chemical extraction mine is produced.

7.2.5. The hydrobarrier

In the second half of the sixties two different technologies started to develop — the classical deep mining and the in situ leach (ISL) method.

The extensive dewatering of the Cenomanian water-bearing aquifer to meet the requirements of the deep mine started at the same time as the development of the ISL method. Gradually it became evident that the existence of these two methods requiring entirely different conditions, created problems as acid solutions from the area of the leaching fields entered the dewatering centre.

This problem was settled by the construction of a so-called hydraulic barrier between the ISL mine and the deep mine. An artificial subsurface pressure dividing the Cenomanian aquifer was generated and prevented the acid leaching solutions to escape the space of the chemical leaching in the direction to the deep mine. The progress in the construction of the hydrobarrier, however, did not proceed with a sufficient speed and its follow-up operation had not been conducted in an appropriate optimal regime. Thus, the hydrobarrier did not fully meet its purpose, and acid solutions leached out of the limits of the chemical leaching area into the field of the deep mine.

An "advanced underground drainage system" and the construction of treatment plants for the processing of the collected acid mine waters was carried out. As a supporting measure, pumping centres in the area of the Straž block were constructed to maintain a secure pressure head of the Cenomanian aquifer in the area of the chemical extraction.

7.2.6. The impacts of the operation of the chemical extraction mining

One of the results of the exploration, mining and processing of uranium ores in the region of the North Bohemian Cretaceous is an extensive impact on the natural environment. The main centre of environmental problems is the existence of a vast volume of contaminated underground water in the upper Cretaceous aquifers of the Stráž deposit and its surroundings.

The extent of contaminated water was enhanced by the situation which arose during the development of the mining area in the western part of the Stráž block which was considered in the extensive development of two co-existing extraction techniques which mutually adversely affected each other: the chemical extraction and the classical deep mining. The main causes of this situation can be seen in the following:

- an underestimation of the geological structure and of the complexity of natural mechanisms in the hydrogeological structure of the Stráž block resulting from an inappropriate evaluation of the results of geological exploration activities and the following underestimating of the technical mining conditions,
- an insufficient knowledge of the technical properties of the leached ores,
- the absence of thoroughly assessing research at the very beginning of the evaluation of the method.

At the Stráž deposit in an area of approximately 24 km^2 an amount of about 270 million m^3 of contaminated underground water containing an overall amount of approximately 4.8 million tonnes of dissolved solids. The major contamination is concentrated in the Cenomanian aquifer (about 99%), the rest is irregularly distributed in a great volume of the Turonian aquifer (in approx. 80 million m^3).

The impacts of the chemical extraction of uranium at the deposit Stráž on the surface environment became evident mainly during the first stage of the development in connection with the establishment of the leaching fields. The operation of the leaching field alone did not result in any damage of the surface ecosystems.

7.2.7. Restoration project

Over the years the acid solutions and leaching products spread into a large volume of underground water and, in connection with the closing-down of the uranium production, therefore, it is necessary to clean the contaminated water. The main task in the restoration of the Stráž deposit is to remediate the environmental impacts of the ISL technology of the Cretaceous aquifers.

Extensive laboratory research, geological and geophysical exploration work was carried out in connection with this task. New mathematical models had been developed for the evaluation of the hydraulic and hydrochemical situation in the deposit and also for the economic assessment of the restoration process.

The targets of the restoration of the deposit are as follows:

- gradually reduce the content of dissolved solids in the Cenomanian water to a level as low as the environmental limit
- gradually reduce the content of dissolved solids in the Turonian water to the quality required by Czech water quality standards. This means to reduce the contamination almost to the preoperational level.

The restoration of the Cenomanian aquifer is planned in two steps. The first step aims at achieving a hydraulic underbalance in order to obtain a full control of the underground contaminated solution including:

- a control of the ISL process not allowing the precipitation of solid matter in the ore body
- elimination and plugging of the wells
- the preparation of the well grid for the new system of pumping and injection
- to secure the removal of dissolved uranium from the solutions all the time
- to start the operation of the evaporation plant (the first stage of the desalination plant)
- the back injection of the concentrate from the evaporation plant into the central part of the deposit.

The second step will start the removal of dissolved solids from underground. It will include:

- the construction of the second stage of the desalination plant (treatment of the products of the first stage)
- a controlled pumping of the solutions in order to make the best use of the full capacity of the treatment plant for 7–10 years
- checking and controlling the compositional changes of the solution underground
- the construction of a membrane technology unit and its operation.

The restoration of the Turonian aquifer will be performed by a combination of methods including:

- injecting the contaminated water into the hydraulic barrier
- pumping of the most contaminated water in the membrane technology plant; starting in 1996 with a capacity of 2 m^3/min

- discharging the water containing only a low level of contaminants into the river. This method will be used only during the final phase of restoration.

7.2.8. Stage I of desalination plant

The system of evaporators, crystallisers and recrystallisers will treat 6.5 m^3/min of acid solutions producing 5.5 m^3/min of clean water to be discharged into the nearby river and 1.0 m^3/min of concentrated solutions. The operation started in July 1996. This technology will produce two main products:

- crystallized ammonia alum. Up to the year 2008 the expected annual production will amount to about 250 000 t/year and later it will decline;
- the filtrate from the crystallization of ammonia alum. The expected production will be about 250 000 m^3/year. Most of the components of the original solution and practically all the contained radionuclides will be concentrated in a rest liquor.

7.2.9. Stage II of desalination plant

The products of the plant (Stage I) are wastes if they cannot be converted to marketable products by further treatment. It is therefore necessary to obtain products that can be safely disposed of in the environment.

At present DIAMO is engaged in an extensive research programme to solve the problems connected with the desalination of underground water. The first results show viable ways for the treatment of stage I products.

The potential commercial products of this technology are:

- Al_2O_3, about 30 000 t annually, or
- $Al_2(SO_4)_3$, about 100 000 t annually, and
- H_2SO_4 (recovered from pyrolytic gases), 100–150 000 t per year.

The projected starting year of the Stage II desalination plant is 2000.

7.3. MANAGEMENT OF A MINE IN FRANCE (LODEVE, COGEMA)

7.3.1. Description

The COGEMA establishment in Hérault includes mining extraction installations and a uranium ore treatment plant. Its nominal product capacity is 1000 tonnes of metal per year and 400 000 tonnes of ore.

7.3.1.1. Geography

The mining division is located at around 7 km south of Lodève and some 40 km from Montpellier in southern France.

7.3.1.2. Ore deposit

The workable uranium ores are in the eastern region of the Lodève Permian basin. They are mainly located in the carbonate sandstone layers, which are rich in bituminous material and sulphides, from the lower part of the Autunian, in the neighbourhood of the east-northwest oriented Hercynian fault zones.

The sequence of these layers has an average dip of 15 to 20 grades towards the south.

The ore deposits are in the following forms:

- in clusters or stockworks, the largest being at the foot-wall of the Saint-Julien fault; the deposits are practically continuous;
- in thick seams varying from 1 to 8 m;
- in narrow strips related to the faults, giving a pseudo vein-like character.

All deposits are located between 0 and 300 m depth.

7.3.1.3. The mine working

The upper parts of the deposit have been exploited by open pit mining, the deep parts including the cluster sectors, by underground mining. The essential part of the production has been supplied by the underground mining.

7.3.1.4. Infrastructure of the underground mine

There are two main ramps.

Ramp A

This is the principal access, with a slope of 17%, a 20 m^2 cross-section and a length of 1900 m. It is located to the south of the deposits, sheltered from possible ground movements.

Ramp B

This ramp has a slope of 25% with a 10 m^2 cross-section and a length of 1300 m.

The main level of the mine and the ore storage to the plant head are connected by an 800 mm belt conveyor with a nominal capacity of 250 t/h. Level galleries, with 15 m^2 cross-section, were drifted from the main accesses providing the transport infrastructure and additional surveys by boreholes radiating from these galleries.

Finally, several raises provide the mine utilities:

- 2.4 m holes as ventilation shafts and ore or waste rocks bin,
- pilot holes (11") for fuel and concrete delivery, and other technical use.

The underground workings are divided into sections extending 200–300 m east–west and around 100 m north–south.

A 2.40 m diameter shaft provides the primary ventilation of the section. Several vertical structures (2.40 m diameter) dug between an upper section gallery and a lower level roadways serves for exhausting the air from the workings in the upper part and as ore chute in the lower section.

This division of the mine into a main access infrastructure and services, and independent production sections simplifies the ventilation and allows controlling the radiation protection of the personnel and safety in case of fire.

The different working methods developed by the mine are based both on the trackless mechanization of drilling, scaling, bolting, and removal operations and on the existence of manufacturing and delivery installations for the cemented embankments required for working the Mas Lavayre clusters.

The ore clusters are worked by:

- raises, starting from several sub-levels,
- horizontal cuts 4 to 5 m high backfilled with cement,
- each cut is worked by parallel drifts 4 to 5 m wide, and
- the drifts in two successive cuts are never exactly superposed.

The seams with thicknesses between 4 and 8 m are worked:

- either in two cuts by the method used for the ore clusters
- or starting with opening up the roof of the seam and descending.

Seams between 2 and 4 m thick are worked:

- either by parallel drifts for more than 3 m thick seams
- or by backfilled chambers with or without selective extraction of the ore.

7.3.1.5. Ore treatment

The principal stages of the process used at Lodève are indicated in Table IV. The alkaline leaching is more selective than sulphuric acid leaching, which explains why it is not necessary to use an ion exchange processing system.

Although the alkaline route is well established, its application at Lodève is complicated by the joint presence in the ore of sulphides, organic material and molybdenum. The sulphides are converted during leaching into sulphates which prevent the recycling of the sodium carbonate. It is necessary therefore to pay particular attention to the consumption of carbonate in the process. The organic materials, which follow the uranium up to the precipitation with lime, are eliminated when the preconcentrate is roasted.

The liquors from the precipitation stage contain some of the organic material, some molybdenum, a little uranium and sodium sulphide. The molybdenum and uranium are both recovered and in addition a purified and crystallized sodium sulphate is produced which is dispatched directly for sale.

7.3.1.6. Waste management

The tailings, resulting from ore processing, are taken at the filtration output by belt conveyors then discharged in the excavations of the adjacent Mas d'Alary open pit mines. The liquid effluents from the plant and the tailings storage as well as the mine drainage water are subjected to specifically adapted processing.

TABLE IV. ORE TREATMENT PROCESS CHARACTERISTICS

	At the start	Modifications made in 1984
Mechanical preparation	Crushing in two stage	radiometric ore sorting
	Grinding in rod and ball mills in closed circuit (particle size 160 μm)	
Leaching	Alkaline (Na_2CO_3) in two time periods (3 h and 6 h) with oxygen (6 bar, 140°C)	
Solid-liquid separation	Filtration by belt filters after each of the two leaching periods	
Purification	Neutralization at pH5	
	Precipitation of a concentrate by lime addition	precipitation by soda addition
	Roasting and dissolution by H_2SO_4	dissolution by H_2SO_4 and filtration to eliminate Zr
	Treatment of mother liquors by precipitation to eliminate molybdenum (recovered), organic material and uranium	
	Crystallization of Na_2SO_4	
Concentrate production	Precipitation by magnesia	precipitation by hydrogen peroxide
	Dewatering in centrifuges	dewatering in thickener and filtration
	Spray drying	
Product	Magnesium diuranate	uranium peroxide

7.3.2. Production planning

7.3.2.1. Discovery of the deposit

The discovery of the first uranium bearing ores by the Commissariat à l'Energie Atomique (CEA) was in 1953; a prospecting mission was implanted at Lodève in 1957; the deposit was developed little by little in an unfavourable economic situation.

7.3.2.2. Implementation of the working

In 1974, with the energy crisis and the decision to use nuclear energy to produce the major part of the French electricity supply, the valorization study of the Lodève deposits was started and these reserves were estimated to be 18 500 tonnes of uranium contained in the ore.

In mid-1975, the first site installations were constructed (offices, stores, workshop, change room) and in September the digging of the access to the main deposit, that of Mas Lavayre, was started. This involved surveying the deposit more accurately, so as to prove the reserves by boreholes, defining the methods for working and ore extraction, carrying a pilot plant study of the treatment process developed in the laboratory. These objectives were reached at the start of 1978 and the work was then accelerated with the beginning of yellow cake production in early 1981.

While the underground work continued and the surface installations were under construction, COGEMA issued an order for the processing plant in mid-1978 and obtained, at the end of 1978, the authorization for open pit mining of the Mas d'Alary deposit with the objective, outside of ore production, of completing the first pit for the storage of the mill tailings at the start of 1987. In April 1979, the authorities issued the construction license for the ore processing plant and its operation was authorized in September 1980. The first kilogram of uranium, as yellow cake, was produced on 16 April 1981.

7.3.2.3. Production

The plant has operated at full capacity since 1982. But the underground mine did not reach sufficient production until 1983 and the open pit mine provided the required additional ore (see Fig. 1).

7.3.2.4. Exhaustion of reserves

The exhaustion of the main open pit deposits occurred in 1984; the production was then provided by the exploitation of small deposits in a radius of around 10 km from the plant; this represented about 1/5 of the total production and was completely stopped in 1993.

In 1993, the recoverable underground mine reserves were still in the order of 4500 tonnes of uranium, but their characteristics and the very poor economic environment did not allow maintaining the production rate; this was then progressively reduced and all production was definitively stopped in April 1997.

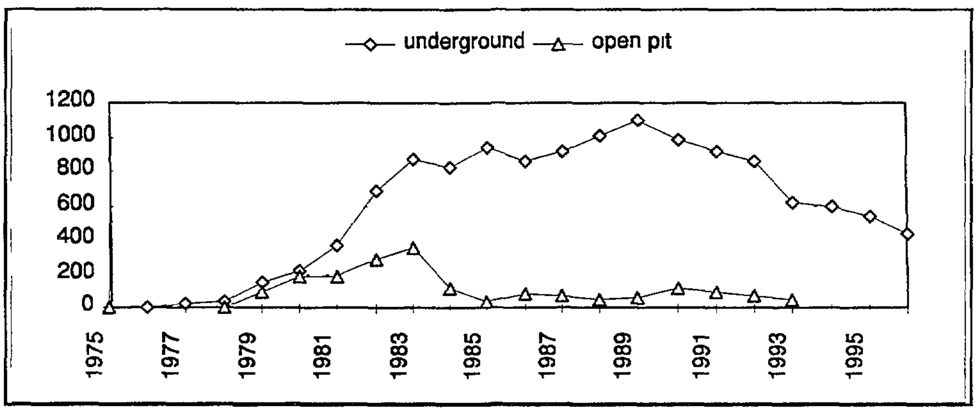


FIG. 1. Uranium extraction

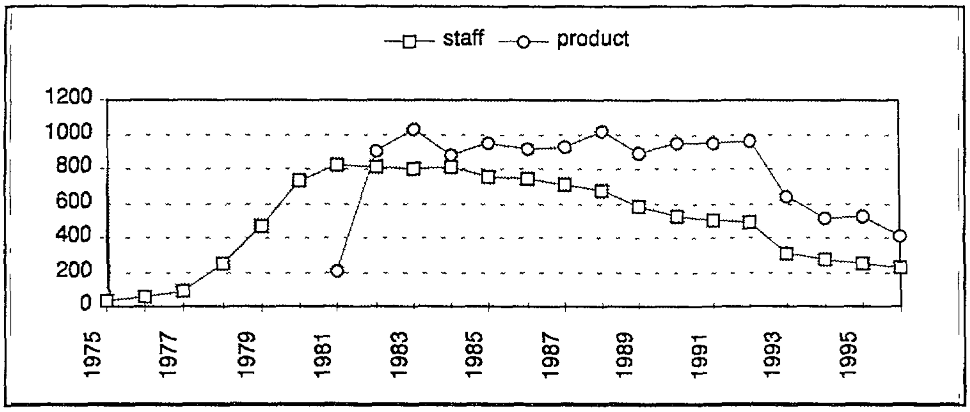


FIG. 2. Production and staff.

7.3.3. Functional structures

The functional structures of the site implemented at the startup of the workings were essentially characterized by:

- the separation between mining operations which are within COGEMA's Mining Division and the processing operations which are the responsibility of a COGEMA subsidiary;
- the integration of maintenance services in each production unit of the mining division, (open pit mine, underground mine, general services, processing plant).

The grouping of the maintenance resources into a single unit, achieved in 1990, provided better use of the personnel and a significant reduction in costs. The mining and processing operations were more integrated in 1993 when it was decided to decrease the production. This new structure has provided more flexibility in employee management. Finding the most suitable functional structure requires both clearly defined objectives and a good analysis of the situation. The following is the example of the evolution of the functional organization of the underground mine.

The structure for the production, under the responsibility of the mine general foreman, was, in 1986, as follows:

- deputy general foreman: one per shift
  - ensure the distribution of personnel and material
  - ensure the co-ordination between production units
- supervisor responsible for a production unit
  - organize and co-ordinate the production of his unit
  - participate in his unit's operations projects, participate in training his personnel
- supervisor: one per shift
  - ensure the follow-up and inspection of the work.

This structure satisfied the necessity, that was felt at the mine startup, of creating independent micro structures that could take on the mine development problems and implement operating methods and personnel training. In 1986, these objectives had been reached. the personnel had mastered the mining techniques and methods and this hierarchical structure was no longer justified (see Fig. 2). The objective was then to motivate the responsibilities of the personnel.

The positions of production unit supervisors were abolished so as to decrease the number of hierarchical levels and concurrently a technical group was formed which has been responsible for determining methods, planning sites and improving techniques.

7.3.4. Organization tools

The following does not pretend to be an exhaustive inventory of the organization tools implemented by the Lodève mining division: it gives only a few examples intended to show that the dynamism of the teams requires a strong involvement that is obtained through planning and co-operation.

7.3.4.1. Safety management

Since 1987, an adaptation of the Dupont de Nemours method has been used in the Hérault Mining Division. The strength of this safety method is based on a communications system connecting three fundamental points:

- Upward communication, the employees are not afraid to talk about their problems or even to propose solutions (*human factor*).
- Commitment of all the hierarchy to be receptive and to take decisions (*hierarchy involvement*).
- Working and management tool "the audit": this makes possible exchanging and distributing information (*management*).

The results obtained for all Lodève sites are similar and encouraging:

mine:
in 5 years, the frequency and seriousness of accidents has been reduced by a factor of 5

plant:
the frequency and seriousness of accidents over the same period has been reduced by a factor of 3.

But the essential of the applied methodologies is to have created a synergy applicable to other subjects where progress can be made such as the organization of mine sites and the selective working of deposits.

7.3.4.2. Planning of site operations

Each working site has an associated standard plan, showing the initiation of the operations and the distribution of the resources of the different sites in the same section of the mine. This standard plan allows anticipating organization problems and judging the results.

7.3.4.3. Communication in the underground mine

Carrying out mining operations requires constant transmission of information between the personnel, concerning organization and safety as well as technical questions. This extends from the repair of equipment up to, management of emergency situations (fire alarms, first aid for the injured).

The traditionally employed communication methods in mines, like telephone, often respond poorly to the site requirements and systematically run up against the problem of the dispersion of the personnel. These considerations led the mine to adopt radio transmission techniques and to equip the personnel with individual radiocommunication units.

The implementation of such a system involves and strongly motivates the personnel. The progress made has affected all the mine operations; safety, organization, maintenance and is clearly shown in terms of simplification of the organization and gains in productivity.

7.3.4.4. Graphical information

In addition to the purely technical contribution of graphical information in terms of visualizing the underground workings, the implementation of a tool common to topographers, miners and geologists has made possible strengthening the team spirit between the different participants in the underground mine.

7.3.5. Preparation for the shutdown

Mining is a rather special industrial operation since the resources, are limited and the operation consists in consuming them. Any mining operation thus has a finite lifetime and the miner must constantly discover new workable reserves and also, shut down the workings when the results are negative. The workable volume of a given deposit depends, in fact, on its extraction cost and the metal sales price. When the prices are high, the low grade parts of the deposit can become economically workable. When the prices are low, only the high grade ores are workable. The preparation of the closing is thus part of the normal mine activities. It covers both environmental and social aspects.

7.3.5.1. Environmental aspects

The creation of the Lodève mine is contemporary with the introduction of an impact study, corresponding to a new awareness of the environment, in the authorization procedures file. In this respect, all the requests for operations authorizations submitted by the mining division have included an environmental impact study defining the conditions of the shutdown of the operations and the restoration of the sites. This has allowed anticipating the problems and implementing the required preventive measures as soon as possible.

Among these preventive measures can be cited:

- Making the personnel aware of protecting the environment as an integral part of safety.
- Carrying out site restoration tests of exhausted open pit mine sections, since the beginning of the 1980s, which have allowed data collection.
- taking into account the requirements of site restoration work in a global context which has made possible optimization and reduction of costs.

The Lodève mine has small open pits at the edge of the main deposits. The restoration of these sites and their subsequent monitoring have given the mine personnel mastery of the techniques which have since been used to restore the larger sites. This progressive approach to the problems has also allowed setting the objectives of the restorations:

- Ensure the safety of the public and the environment, with, in particular, certification of the safety of all the mine structures as well as the perennial safety of the restored sites.
- Applying the optimization principle to make all the residual impacts as low as reasonably possible (in particular the radiological impact).
- Limit the consumption of space and therefore the surface of the land.
- Succeed in the integration in the landscape and the possible development of a certain activities on the restored sites by taking into consideration the wishes of the local organizations after joint meetings with them and the administration.

The end of production at Lodève was scheduled for mid-1997. Recent years have thus seen a major development in the preparation of site restoration in the following fields:

- Studies concerning tailings storage facilities: geotechnical stability of the building up of tailing containers, geomechanical stability (erosion resistance) and geochemical stability of coverings, geochemical change of tailings.
- Studies regarding the underground mine: the main study concerns the site's hydrogeology which should allow forecasting the phenomena resulting from the rising of water levels during mine flooding. This study required drawing a complete inventory of the water inflows into the underground mine and their characterization.
- A pilot test covering about one third of a tailings pond was conducted to measure the radiological efficiency of a 1 m thick layer of non compacted waste rock: radon emission measurements were made directly over the tailings and after covering and compared with measurements made over the waste rock dump.

These pre-shutdown studies benefited from the data provided by the environment monitoring network which was installed at the beginning of the mine production.

7.3.5.2. Social aspects

As it was absolutely necessary to maintain the productivity in spite of the drop in production, this imposed a reduction in the number of employees. This was spread out over several years and accompanied by major social and economic measures with the objectives of helping the COGEMA miners to reconvert inside or outside the group and to facilitate creating or maintaining industrial activities in the region (see Fig. 2).

7.3.6. Communication

In each phase of the life of a mine, both internal and external communication are highly recommended practices. At Lodève, both of these have increased with the approach of the closure to respond to the growing needs to be informed and to understand. In conformity with COGEMA's communication strategy, people living in the vicinity of the mining sites are leading targets for information specifically concerning mining sites environment. The mine personnel are, of course, favoured and informed first. COGEMA provides others, like administrative and political authorities, press and associations with information adapted to their interests.

The aims of these communications are to show and explain what COGEMA does to protect the environment, thus allowing everyone to form his or her own opinion. This is a means of ensuring that discussions and changes will be carried out in a spirit of co-operation.

Communication must therefore be based on transparency. COGEMA ensures communication by the following means:

- sending by mail information to people living in the vicinity of the sites,
- "open house days" and visits to installations,
- sessions of statutory commissions generally comprising representatives of administrations, local political authorities and environmental protection associations.

The results of site monitoring are published regularly: this is a good way of being transparent. The quality of this monitoring is thus essential. Every abnormality is explained and everyone is free to ask questions. This is important for winning the confidence of those concerned. Constancy, consistency and persistence are key factors for success.

7.4. USA: SMITH RANCH URANIUM PROJECT

During the 1980s, in situ leaching of uranium emerged as an economically attractive and environmentally preferred means for extracting uranium ores in the USA. In 1989, Rio Algom Limited acquired the Bill Smith properties in Converse County, Wyoming. In-place uranium reserves now exceed 19 600 tonnes (43 million pounds) U_3O_8. Following review of prior work and substantial additional geological, licensing, and engineering studies, Rio Algom is constructing a commercial ISL mine, the Smith Ranch Project, with a planned annual capacity of 907 tonnes (2 million pounds) U_3O_8. The following sections are intended to describe the Smith Ranch Project and the newly identified Reynolds Ranch Project which lies immediately to the north. In addition, a description of the in situ uranium process is provided along with a discussion of the associated environment consequences.

Rio Algom Limited (RAL) acquired the Bill Smith properties, Converse County, Wyoming Corporation in January, 1989. Ownership and control of the property were assigned to RAL's subsidiary, Rio Algom Mining Corporation (RAMC) at that same time.

Originally planned as an underground uranium mining project, the potential of the property as an in situ leaching (ISL) project was recognized and extensive pre-development efforts had occurred prior to acquisition. Following review of this work, RAMC implemented a comprehensive development program focused on commercial licensing, engineering and geological studies as well as innovative uranium marketing strategies. The fruits of this program are the construction of the Smith Ranch Project and the initiation of a pre-development for another new project, Reynolds Ranch. The following sections describe the Smith Ranch Project and Reynolds Ranch, provide an introduction to in situ leaching (ISL) of uranium, and point to the environmental advantages and soundness of the technology as practiced by RAMC.

7.4.1. Regional geological setting

7.4.1.1. Physiography

The Smith Ranch Project area is located in the southern portion of the Powder River Basin (Fig. 3) near Douglas and Glenrock, Wyoming. The Powder River Basin is a structural basin open to the north, bounded on the south by the Laramie Range and Hartville uplift, on the east by the Black Hills, and on the west by the Big Horn Mountains and the Casper Arch. The Basin includes an area of approximately 3100 hectares (12 000 square miles) (Fig. 4).

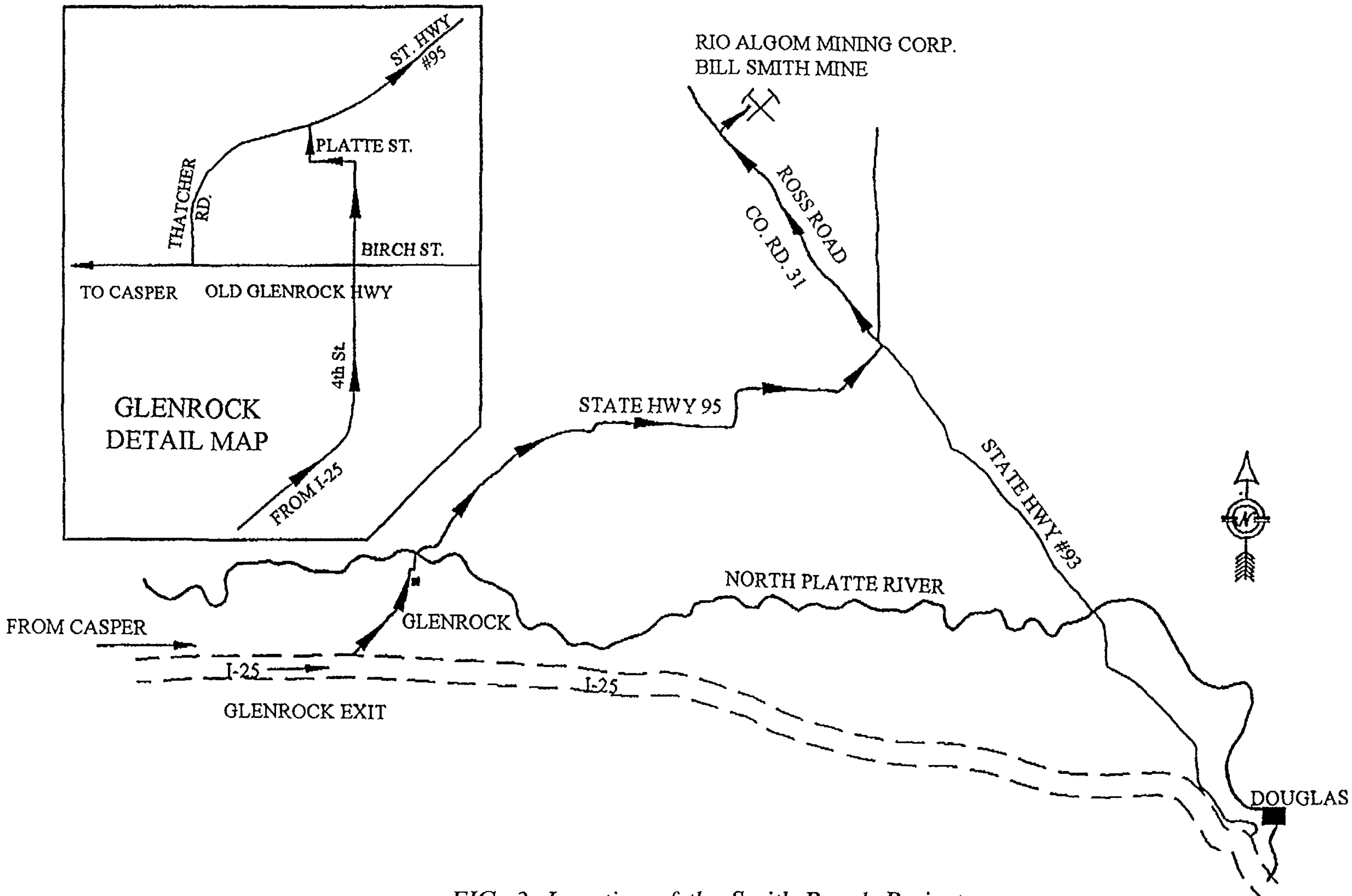


FIG. 3. Location of the Smith Ranch Project.

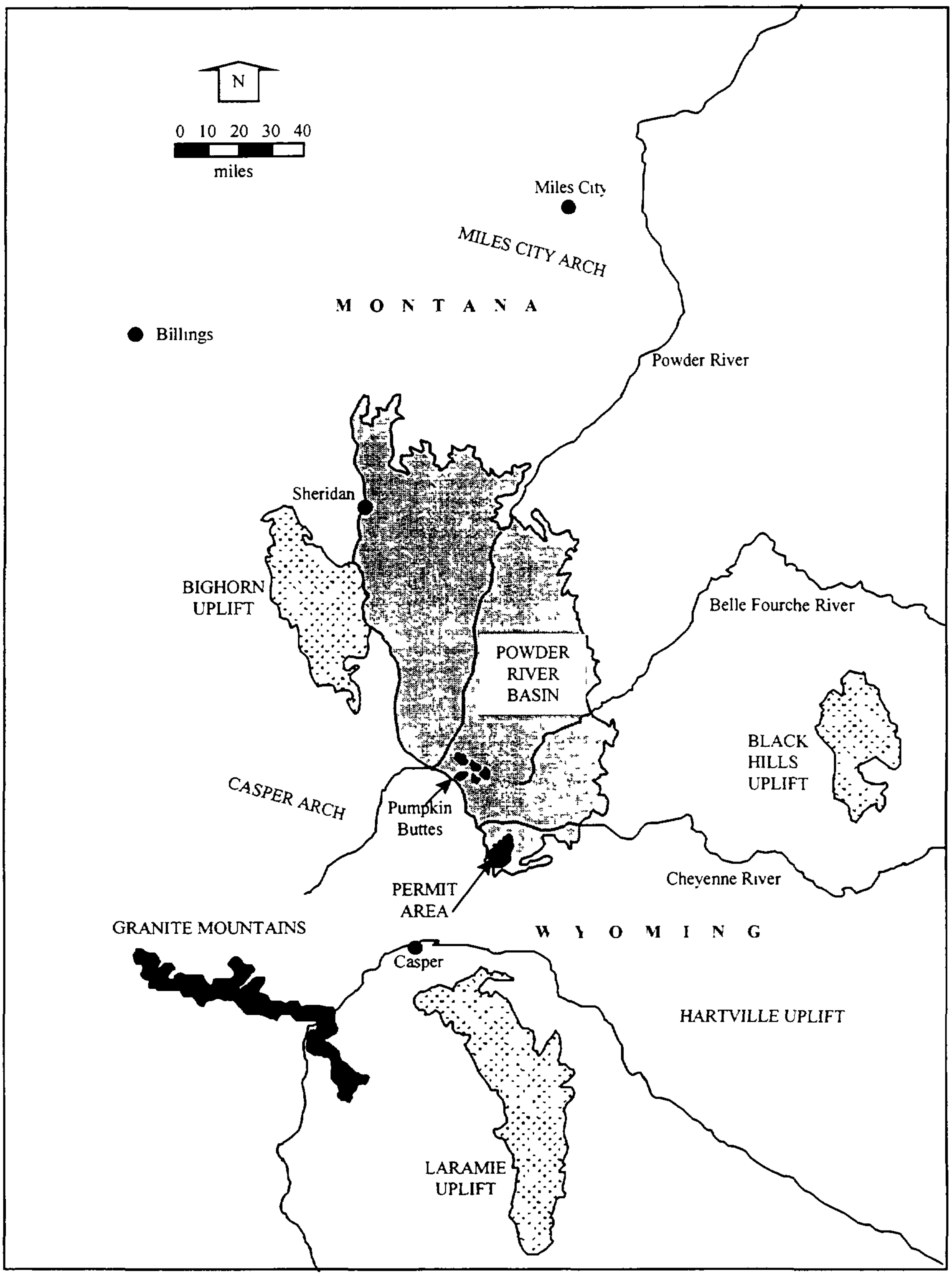


FIG. 4. Physiography in the Powder River Basin.

7.4.1.2. Topography

The present day topography of the Powder River Basin is the result of uplift in Pleistocene time when rejuvenated streams began down-cutting and excavating thick sequences of Oligocene, Miocene and Pliocene age sediments. The topography of the permit area is characterized by gently rolling upland areas, broad stream valleys, steep sided draws and rounded ridge crests.

7.4.1.3. Geological history and stratigraphy

All of the important uranium deposits in the Powder River Basin are in Tertiary strata, that is, Paleocene Fort Union formation and Eocene Wasatch formation (Fig. 5). At the end of Cretaceous time structural uplifts had developed and continental deposition began during Paleocene time. Most of the basal Paleocene Fort Union formation rocks were derived from erosion of Cretaceous shales and sandstones and hence are mostly fine-grained clastic. By late Paleocene time erosion had cut into the crystalline core of ancestral Laramie Mountains and intermittent loads of arkosic sediments poured into the southern end of the present Powder River Basin.

In late Paleocene to early Eocene time the Powder River Basin underwent further subsidence with corresponding uplift of the surrounding mountain blocks. Deposition during this period was primarily by large, sluggish streams with associated coal swamps. In early Eocene time large amounts of coarse clastic eroded from the highlands forming large fans and braided stream deposits. Deposition of the Wasatch formation in the Powder River Basin was to a degree cyclic with periods of quiescence allowing coal swamps formation followed by periods of uplift and rejuvenation of the coarse clastic cycle. Sedimentary studies show the Granite Mountains to be the main source of clastic material with minor clastic provided from the ancestral Laramie Mountains and Hartville uplift.

Following deposition of the Wasatch formation, minor subsidence of the Powder River Basin resulted in a northerly regional dip of approximately 1½ degrees in the Eocene and earlier rocks. Degradation of the area continued from middle to late Eocene with the development of a mature topography which later was buried by Oligocene deposits. During the Oligocene, Miocene and Pliocene times large deposits of sandstones and tufaceous sediments collected in the Powder River Basin. Vulcanism was incessant during this period with streams choked with volcanic ash.

A major regional uplift took place near the close of Pliocene time and rejuvenated streams began erosion and down-cutting of the existing sediments. This erosion continued and brought about the present topography. Uranium mineralization occurs in both the Paleocene Fort Union formation and Eocene Wasatch formation. Local geology and associated uranium resources are discussed in the following sections.

7.4.1.4. Local geology

Within the permit boundary the host sandstones for uranium mineralization are the arkosic sandstone units of the upper Paleocene Fort Union formation and lower sandstone units of the Eocene Wasatch formation.

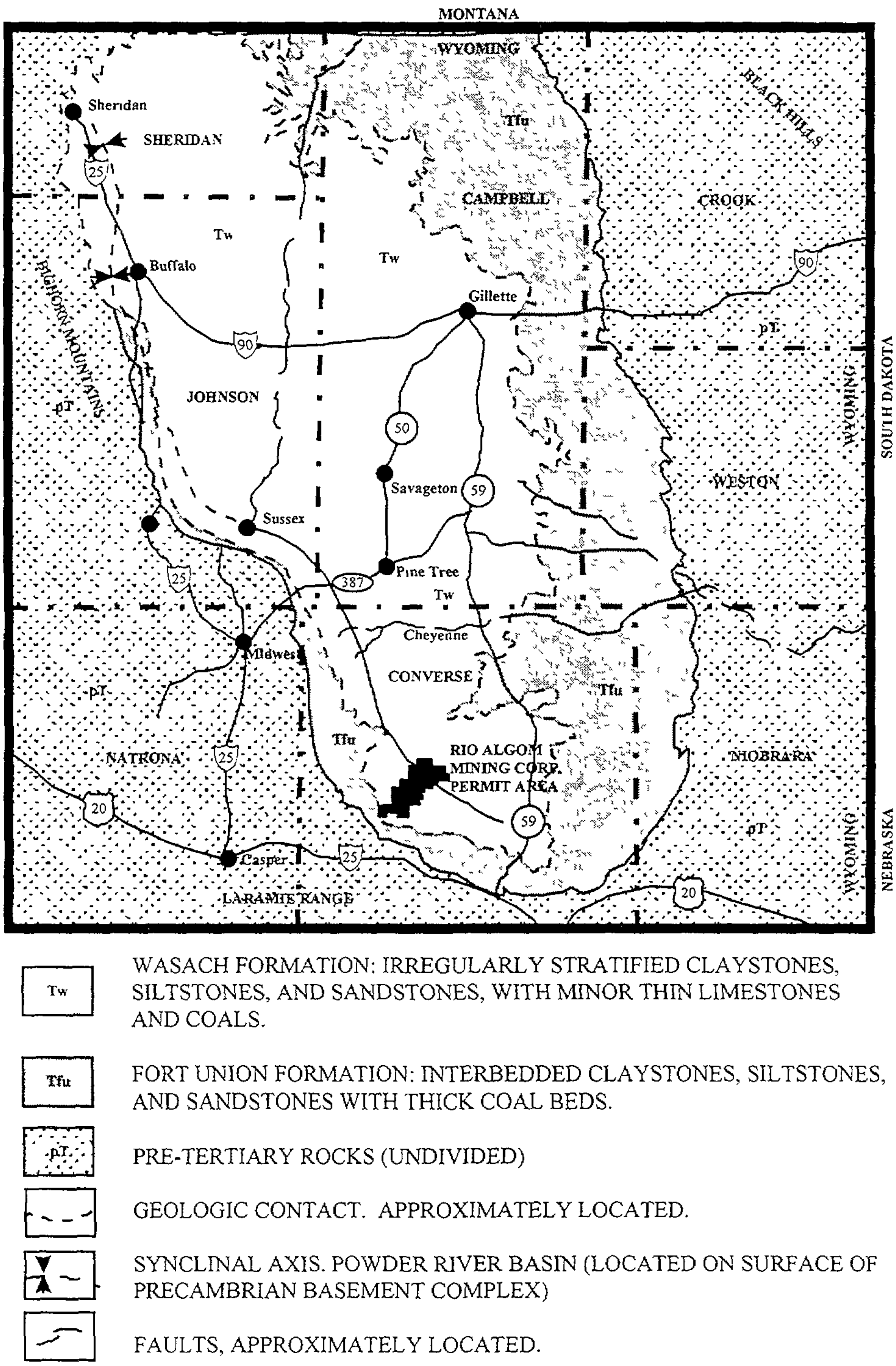


FIG. 5. Generalized geological map of Powder River Basin post-tertiary formations.

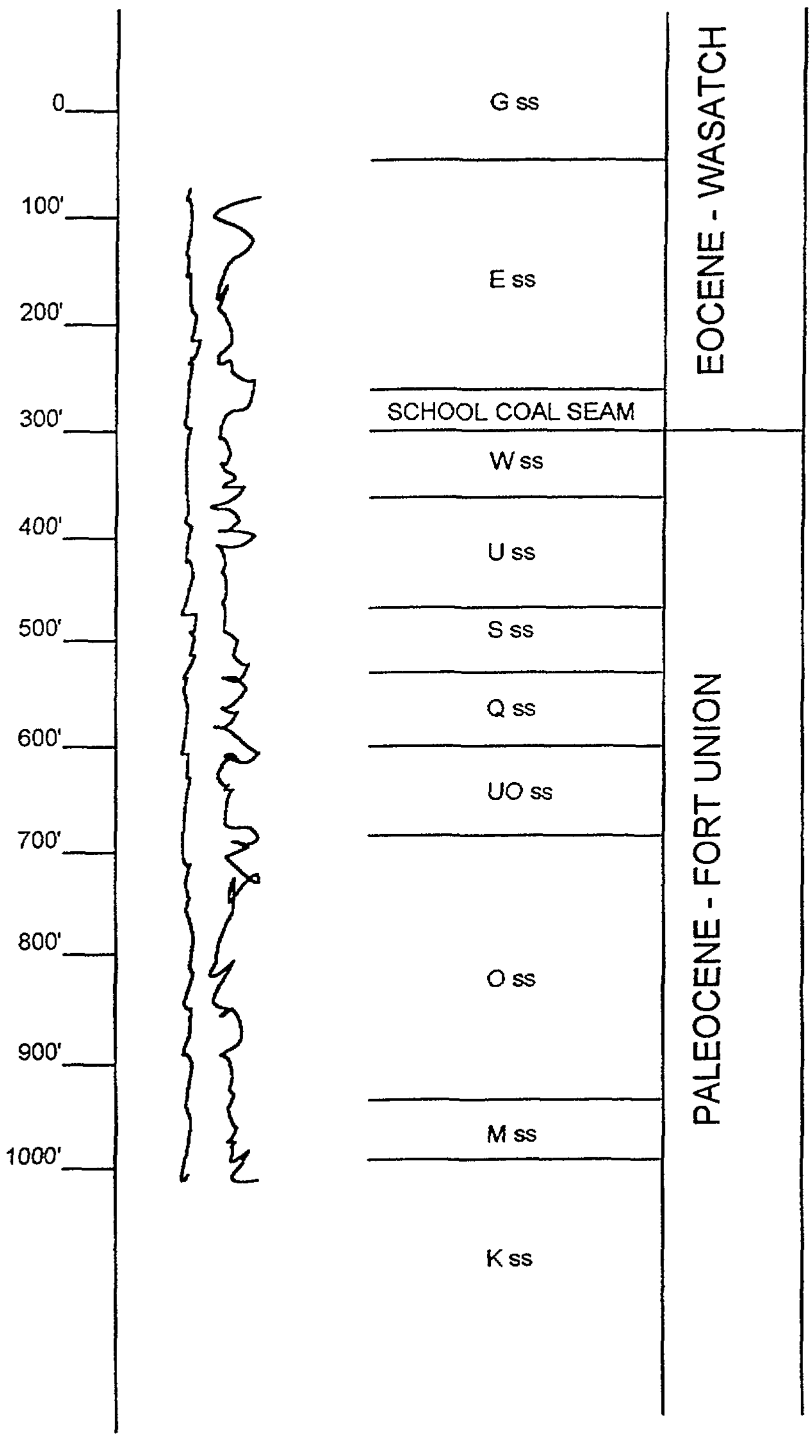


FIG. 6. RAMC sandstone zoning South Powder River Basin.

The Wasatch formation is the youngest bedrock unit throughout the permit area with thickness ranging from 61 to 91 metres (200–300 feet) in the northern and southern portions of the permit area to 152 metres (500 feet) in the central area. The Fort Union formation is over 305 metres (1000 feet) thick. However, only the upper 183 to 213 metres (600 to 700 feet) contains the arkosic sandstone units with associated uranium mineralization.

RAMC has arbitrarily named the major sandstone and shale units within permit area. Sandstone units from youngest to oldest are E, W, U, S, Q, O, M and K. Actual contact between the Fort Union and Wasatch formation is defined as the base of the School Coal seam or the correlatable lignite zone present throughout permit area. In general, the contact would be at top of W sandstone unit when present (Fig. 6).

Resources for the permit area are primarily in the Paleocene Fort Union formation. The O, M, and K sandstone units account for the bulk of resources with Q, S, and U sandstone units locally having significant leachable reserves. Lesser resources are contained within the E sandstone of the Eocene Wasatch formation. Thickness of these sandstone units ranges from 3 to 60 metres (10 to over 200 feet) with the O sandstone the thickest and most persistent. The ore occurs as typical Wyoming roll fronts, generally north facing C shaped features. The sandstone units, depending upon thickness, interbedded shales, and high lime zones, can contain one to twenty mineral fronts with the O sandstone unit being the most complex.

7.4.2. Amenability to ISL mining

The uranium ore bodies at Smith Ranch were extensively tested and evaluated to demonstrate their suitability for alkaline ISL mining. The key aspects of these efforts are:

7.4.2.1. Laboratory studies

Laboratory scale tests by the previous owner demonstrated the amenability of the main ore deposits to a mild alkaline lixiviate. This also was confirmed by two successful field pilot programs. These laboratory and field tests are key factors supporting the project.

7.4.2.2. Wyoming ISL experience

In the State of Wyoming, there are two ongoing commercial ISL operations and 25 pilot plants have operated. In the South Powder River Basin two projects are significant: (a) Kerr-McGee/RAMC's successful pilot plants at Smith Ranch, and (b) Everest Minerals, Inc./Power Resources, Inc.'s continuing commercial operations on an adjacent property, the Highland Project. The favorable results from both of these projects were instrumental in providing a high degree of confidence for the commercial development of Smith Ranch.

7.4.2.3. The Smith Ranch pilot tests

Pilot operations were conducted to obtain plant and wellfield information for economic analysis and to satisfy Wyoming Department of Environmental Quality requirements for licensing. Insofar as possible, pilot operations simulated commercial operations. Two tests were run, one each in the Q sand Unit of Sec. 36 and the O sand Unit of Sec. 26. The Q test operated from October of 1981 through November 1984 with restoration continuing to May 1986. Aquifer stability and restoration of the Q test was accepted by the State in August

1987. The O test began operation in August 1984 and continued through 1990. Results are summarized in Table V.

TABLE V. SMITH RANCH ISL PILOT SUMMARY

	Q-SAND	O-SAND
Leaching Period	Oct. 1981–Nov. 1984	Aug. 1984–Jan. 1991
Restoration Period	Nov. 1984–May 1986	—
Restoration Certified	Aug. 1987	—
Pilot Flow Rate	378 L/m (100 gpm)	568 L/m (150 gpm)
5-Spot Pattern Size	30 m × 30 m (100 ft × 100 ft)	36 m × 36 m (120 ft × 120 ft)
Ore Depth	152 m (500 ft)	229 m (750 ft)
In-Place Reserves	61 235 kg	103 480 kg
Production	35 380 kg	96 615 kg
Recovery	58%	93%
Fluid Processed		
Pore Volume	11 730 m^3	45 800 m^3
Pore Volume — Production	42	45
Pore Volume — Restoration	20	—
Days/Pore Volume	22	56

The Q sand unit is one of the thinnest ore-bearing units in the Smith Ranch area. It sometimes thins to a metre (3 feet) or less and the entire sand interval can be mineralized. Within the test area, it ranges from 3 to 15 metres (10 to 45 feet) in thickness. The O sand unit is, in general, the thickest zone within Smith Ranch. It is formed from the coalescing of several individual sand units. In the test area, it is 75 to 90 metres (250–300 feet) thick with numerous interbedded discontinuous mudstone units. Uranium mineralization in the test area occurs in the lower one-third of the sand unit.

Both wellfields were arranged as five-spot patterns, i.e. four injection wells arranged in a square with the recovery or extraction well in the center. For the Q wellfield, the square was a nominal 30 m × 30 m (100 feet × 100 feet). Actual spacing ranged from 26 to 34 metres (85 feet to 110 feet) (Fig. 7). For the O wellfield the nominal spacing was 36.5 m × 36.5 m (120 feet × 120 feet) (Fig. 8). All wells, including monitor wells were connected to a wellfield "header house" where injection and recovery flow metres, pressure metres, injection and recovery flow controls, oxygen mixers, and sample ports were located. Each monitor well was equipped with a pump for ease of sampling at the header house. The wellfields were five-spots, and the recovery plant was a standard anionic resin ion-exchange system. Since both tests operated simultaneously for some period, two IX systems were installed. A standard bicarbonate lixiviate with dissolved oxygen gas was used.

Injection and recovery pipelines to each well were buried 1.5 metres (4–5 feet) deep. Pregnant lixiviate from each recovery well was co-mingled at the header house and pumped directly to the plant. Injection lixiviate was pumped to the header house and distributed to individual injection wells. Lines between the header house and plant were also buried 1.5 metres (4–5 feet) deep.

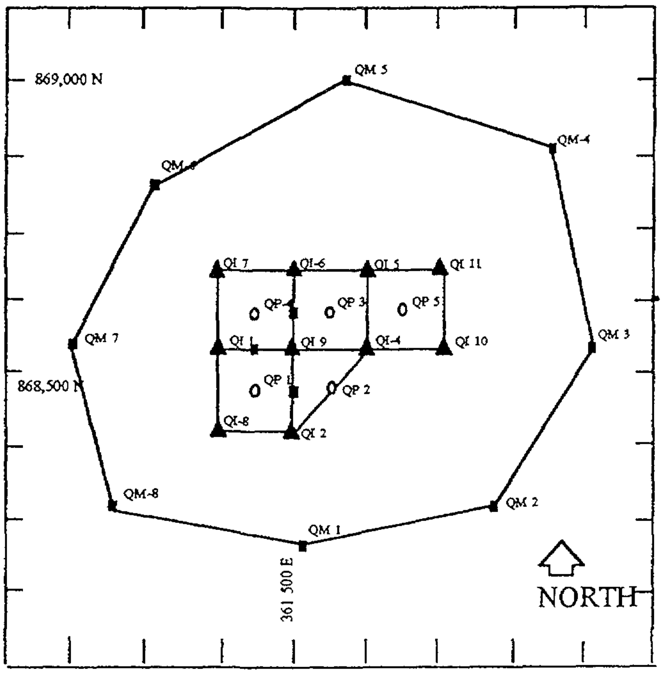
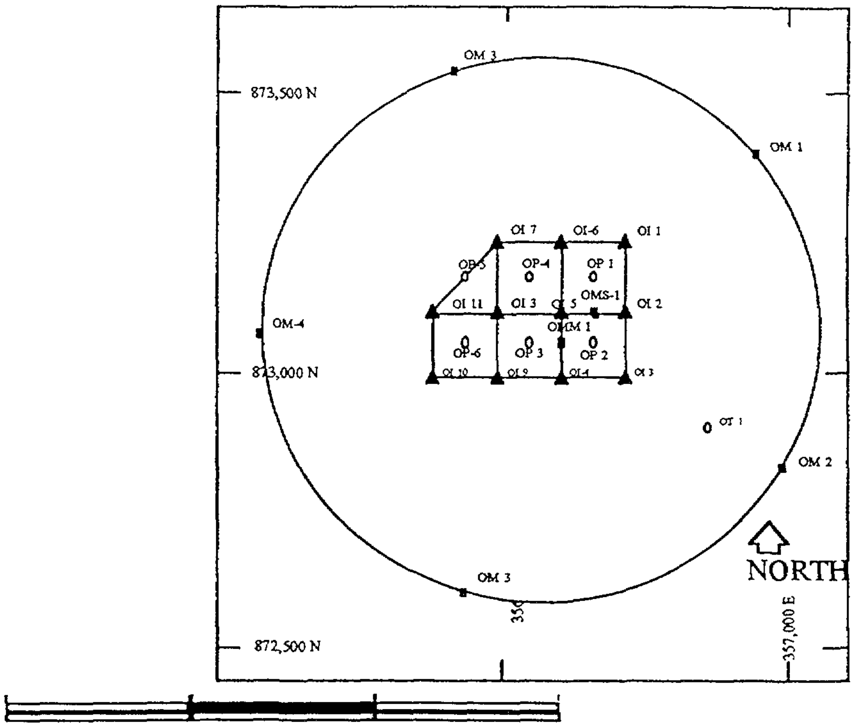


FIG 7 In situ R&D project well pattern "Q" sand deposit section 36-T 36N ,R 74W, Converse County, Wyoming



■ MONITOR WELL ■ LOWER ZONEMONITOR WELL

▲ INJECTION WELL ■ UPPER ZONE MONITOR WELL

○ PRODUCTION WELL 120 FT SPACING BETWEENINJECTION WELLS

FIG 8. "O" sand well pattern section 26-6.36N.,R.74W, Converse County, Wyoming

The general wellfield operating uranium concentrations and flow are shown in Figs 9 and 10. There were no changes in lixiviate conditions that caused any material changes in concentration, although it may appear so from the graphs.

The increase in uranium concentration in the O sand test in late 1986 could be due to an increase in bicarbonate or to a decrease in dilution as the bleed stream was reduced. The mid-1983 increase in the Q test concentration is probably due to a change in the wellfield configuration to pump QI-10, one of the thickest ore holes in the pattern. Note also that peroxide addition in the O test in late 1985 had no affect on uranium concentration, suggesting that the system was not oxygen deficient.

The average uranium concentration for the Q test, from inception until its average dropped to 20 mg/L (a generally accepted cutoff point to begin restoration), was very close to 90 mg/L.

The O wellfield averaged about 70 mg/L over its life. The Q sand recovery wells produced at 0.95 to 1.25 L/s (15–20 gpm) while the O sand recovery wells produced between 1.25 and 1.89 L/s (20–30 gpm). The difference was due to differing license conditions for each test. Aquifer drawdown was not a problem. Balanced injection was maintained within 0.65 L/s (10 gpm).

Lixiviate chemistry was a standard bicarbonate and carbon dioxide leach with oxygen. Early in the Q sand test sequence, hydrogen peroxide was used as a down-hole oxygen source. Later, gaseous oxygen was used, decreasing costs accordingly. All ISL domestic operations now use gaseous oxygen as the oxidant.

7.4.2.4. Geological evaluation of field pilot tests

As the final phase of the pilot program, several cores were obtained from the two wellfields during 1990. Analysis of the cores provided direct information regarding the physical and geochemical state of the ore bodies following prolonged leaching operations.

Two cores were cut within the Q sand pilot and five within the O sand site. Samples were analysed for residual uranium and subjected to petrographic study. More than ninety percent (90%) of the uranium mineral was removed from the clean sands within the Q sand pilot. The only significant residual minerals were intimately associated with impermeable clays, shales, and organic debris. Residual ore grades (in place tails) of less than 0.005% were common. Results from the O sand pilot confirmed this high efficiency leaching. Residual mineral was primarily associated with the impermeable zones. This illustrates the key fact that only reserves accessible to the lixiviate can be mined in an ISL operation. Reserves which are associated with shales and impermeable cemented zones are not minable in situ reserves.

7.4.3. Geological uranium resources

As of December 31, 1996, the in situ resource for the Smith Ranch project area totalled 19 600 tonnes (43.3 million pounds) as U_3O_8 with an average grade of 0.10% U_3O_8. In addition, another 2720 tonnes (6 million pounds) of reserves exist within shallow deposits at or slightly below the water table. A portion of these reserves is likely to be amenable to ISL mining. Future efforts will identify the precise size of this leachable portion. A conservative recovery factor of seventy five percent (75%) yields a recoverable ISL minable uranium reserve of 14 700 tonnes (32.5 million pounds) as U_3O_8.

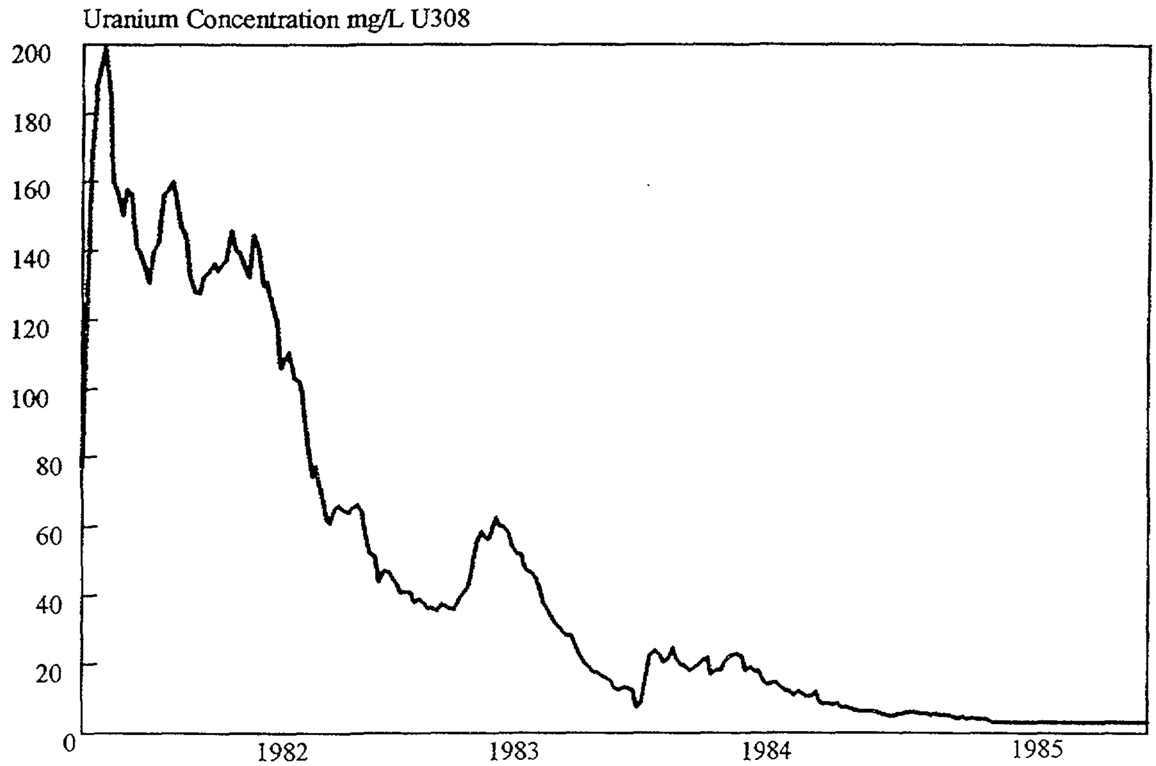


FIG. 9. Q-sand pilot production.

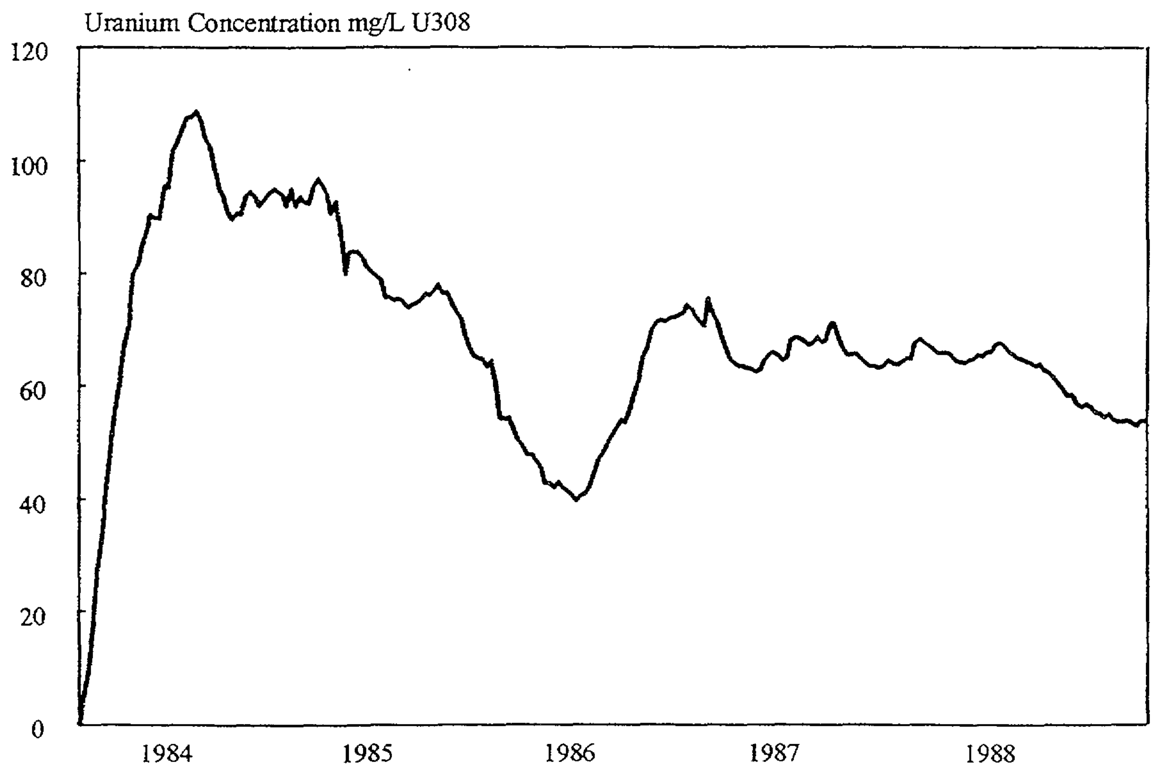


FIG. 10. O-sand pilot production.

Recoverable reserves totalled 10 385 tonnes (22.9 million pounds) at the time of acquisition. The increase now reported results primarily from discovery of additional reserves through subsequent drilling programs by RAMC. The full potential of the property remains untested. Several areas of known mineralization will be subjected to additional drilling in the future. We anticipate that the in situ resources will continue to increase as a result of such drilling. An ultimate potential of 27 200 tonnes (60 million pound) may be realized.

The Company controls additional reserves totaling 2310 tonnes (5.1 million pounds) at other locations within Wyoming.

7.4.4. Licensing/permits

Primary regulatory control for the project is provided by the US Nuclear Regulatory Commission (NRC), US Mine Safety and Health Administration (MSHA), and the Wyoming Department of Environmental Quality (WDEQ). Applicable regulations which fall under the jurisdiction of other federal and state agencies are administered by the primary agencies. A summary of required licenses and the present status of each is shown in Table VI.

The project is currently in compliance with all regulatory license/permit requirements.

7.4.5. Smith Ranch project land holdings

Rio Algom Mining Corp. (RAMC) now controls 21 500 hectares (54 000 net mineral acres) in the Smith Ranch Project Area located in the South Powder River Basin of Wyoming (Fig. 11). Of this total, approximately 15 780 hectares (39 000 net mineral acres) were acquired in January of 1989. RAMC has gained control of an additional 5720 hectares (15 000 net mineral acres) through a mineral leasing and claims staking program. RAMC controls a similar amount of surface rights in the Smith Ranch Project area.

7.4.6. Commercial operating plan for Smith Ranch

The Smith Ranch Project will utilize ISL (in situ leaching) technology to extract uranium from permeable, uranium bearing sandstones located at depths ranging from 137 to 305 metres (450 to 1000 feet). Once extracted, the uranium will be recovered by ion exchange. Periodically, the ion exchange resin will become saturated with uranium. Uranium will be removed from the resin by contact with a salt water solution. The ion exchange resin, stripped of uranium, will be returned to recover additional uranium. The eluted uranium will be precipitated, washed to remove impurities, dried, and packaged for shipment.

7.4.6.1. Uranium ISL mining process description

The mechanics of uranium ISL mining are relatively straight forward. A leaching solution (lixiviate), formed by adding gaseous carbon dioxide and oxygen to native ground water is injected into a uranium ore bearing sandstone through a series of injection wells. As the lixiviate moves through the aquifer contacting the ore, the oxygen reacts and oxidizes the uranium to the +6 valence state. The oxidized uranium then complexes with the carbon dioxide and water to form a soluble uranyl dicarbonate ion $[UO_2(CO_3)_2]^{-2}$. The uranium solution (pregnant lixiviate) flows to a recovery well where it is pumped to the surface by submersible pumps and transported through a piping system to a surface recovery plant. At the recovery plant, the uranium is removed from the fluid by ion exchange. The barren fluid is refortified with carbon dioxide and oxygen and reinjected to extract additional uranium.

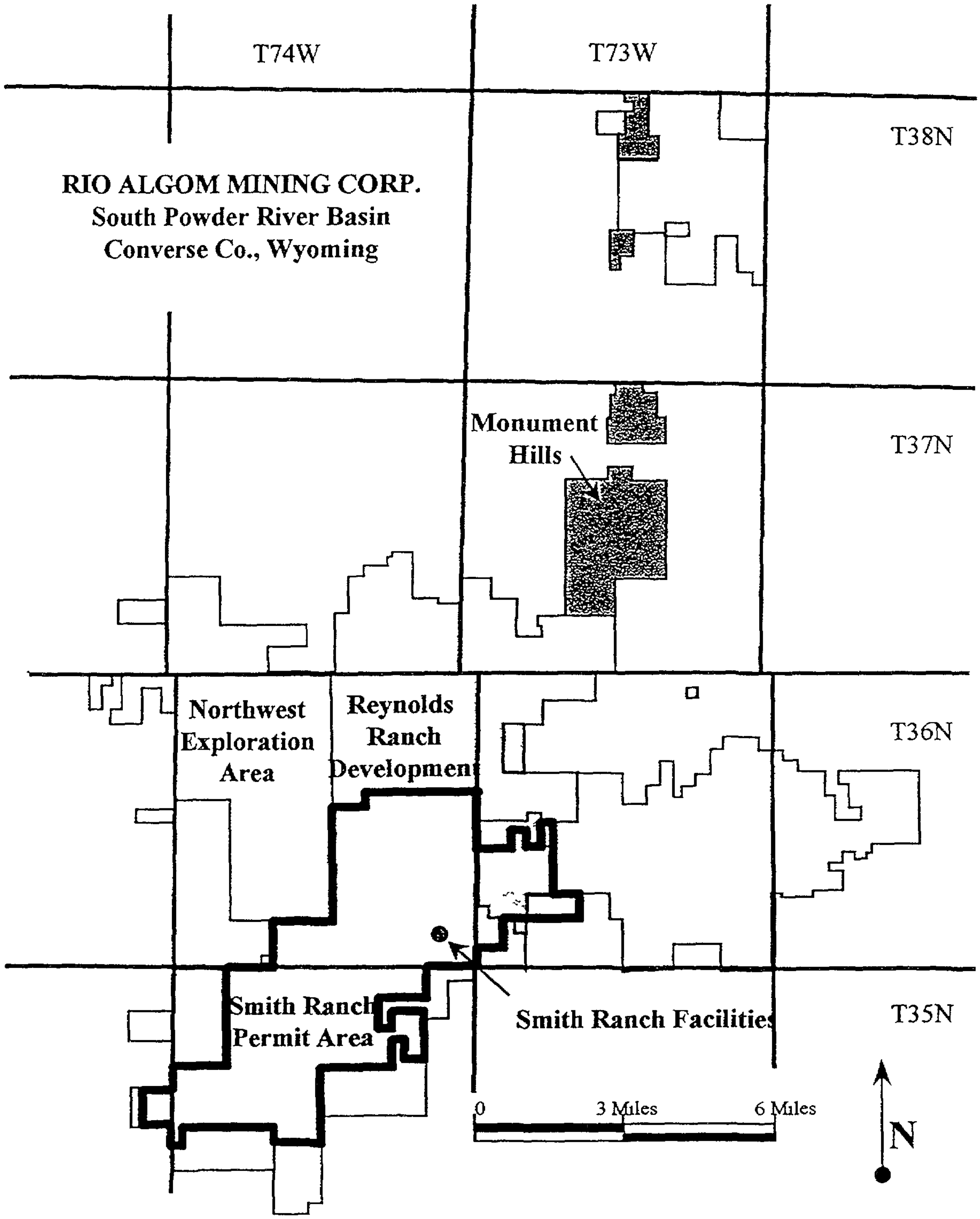


FIG 11 South Powder River Basin, Converse County, Wyoming

TABLE VI. COMMERCIAL LICENSING STATUS (DRAFT)

UNITED STATES NUCLEAR REGULATORY COMMISSION (US-NRC)		
Radioactive Materials Handling Licence	Possess naturally occurring uranium under Federal Law and Rule	Issued in 1992
Permit for Liquids Disposal by Deep Injection	Construct and operate injection well	Application submitted in 1995
Permit for Liquids Disposal by Land Application	Construct and operate Irrigation systems	Application in preparation, will submit in 1995
UNITED STATES MINE SAFETY AND HEALTH ADMINISTRATION (US-MSHA)		
Mine Safety Identification Number	Operate mine under Federal Safety rules and regulations	Advance notification of startup and approved employee training plan required
UNITED STATES BUREAU OF LAND MANAGEMENT (US-BLM)		
Permit to Operate	Operate on Federal lands	Issued in 1992
WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY (W-DEQ)-LAND QUALITY DIVISION		
Permit to Mine	In situ mine uranium	Issued in 1991
Permit for Exploration	Conduct drilling activities for uranium	Granted
W-DEQ-WATER QUALITY DIVISION		
Permit for Liquids Disposal by Deep Injection	Construct and operate injection well	Issued in 1995
Permit for Liquids Disposal by Land Application	Construct and operate Irrigation systems	Application in preparation, will submit in 1995
Permit for Evaporation/Waste Water Ponds	Construct and operate evaporation ponds	General permit granted Final design subject to WDEQ approval
Aquifer Exemption form Public Drinking Water Use Rules	Use ore bearing aquifer for ISL uranium mining	Granted
Permit for Septic System	Construct septic system	Granted
W-DEQ AIR QUALITY DIVISION		
Air Quality Permit for Non-Radionuclide Releases	Emit regulated quantities of airborne emissions	Issued in 1991
W-DEQ-SOLID WASTE DIVISION		
Permit for Non-Hazardous Landfill	Operate an on-site landfill	Granted
WYOMING STATE ENGINEER		
Permit to Construct Wells	Construction of all monitor and operating wells	Monitor well permits for initial wellfields have been issued
Permit to Construct Ponds	Construct waste water ponds	Action independent of W-DEQ authority Reviews final designs for adequate embankment stability
WYOMING COMMISSION OF LANDS		
Special Use Permit	Use surface of Section 36, which is a State Land Section	Submitted November 1991, Returned to RAMC in January 1992

The ISL mining process selectively removes uranium from the orebody. No tailings are generated by the process, thus eliminating a major concern associated with conventional uranium mining. When installing an ISL wellfield, only limited surface disturbance occurs. Much of this will be reseeded and reclaimed during the operating life of the wellfield. The final product of the recovery plant will be vacuum dried yellow cake (uranium oxide) which minimizes the potential for airborne uranium particulates.

After each mining phase of the project, reclamation in that area will be undertaken. After completion of ground water restoration which will be approved by the Wyoming Department of Environmental Quality (DEQ) and the Nuclear Regulatory Commission (NRC), all cased wells will be permanently plugged and capped. The casing will be cut off below plow depth and the site revegetated. Similarly, all other surface disturbances will be reclaimed and state approved grass seed mixtures will be used to re-establish vegetation.

At the end of the project life, all affected lands and ground water will be suitable for their pre-mining uses.

7.4.6.2. Wellfield mining unit concept

The wellfield areas are divided into mining units for scheduling development and for establishing baseline data, monitoring requirements, and restoration criteria. Each mining unit consists of a reserve block in the range of 8 to 24 hectares (20-60 acres). Approximately fifteen such units will be developed. Two to three mining units may be in production at any one time with additional units in various states of development and restoration. A mining unit will be dedicated to only one production zone and typically will have a flow rate in the 189 L/s (3000 gpm) range. Aquifer restoration of a mining unit will begin as soon as practicable after mining in the unit is complete. If a mined out unit is adjacent to a unit being mined, restoration of a portion of the unit may be deferred to minimize interference with the operating unit. The size and location of the mining units will be defined based on final delineation of the ore deposits, performance of the area, and development requirements.

7.4.6.3. Wellfield design concepts

The wellfield pattern is the five-spot pattern. However, it will be modified to fit the shape of the orebody. The cell dimensions will vary depending on the formation and the characteristics of the orebody. The injection wells will be spaced from 23 to 46 metres (75 to 150 feet) apart. All wells will be constructed to serve as either injection or recovery wells. This allows flow directions to easily be changed to optimize uranium recovery and groundwater restoration.

In each mine unit, more lixiviate will be produced than injected. This creates a localized hydrological cone of depression or pressure sink. This pressure gradient provides containment of the lixiviate by causing natural ground water movement from the surrounding area toward the mine unit. It is expected that the over production or bleed rates will be a nominal 0.5% of the production rate for the Q sand mining unit and a nominal 1.5% for the O sand mining unit.

Production zone monitor wells are located approximately 150 metres (500 feet) beyond the mining unit perimeter with a maximum spacing of 150 metres (500 feet) between wells. Monitor wells will also be completed in the aquifers directly overlying and underlying the production zone. Such monitor wells are uniformly distributed across the mining unit area with one overlying and one underlying monitor well for each 1.6 hectares (four acres) of wellfield.

Each injection and recovery well will connect to the respective injection or recovery manifold in a header building. The manifolds will route the leaching solutions to pipelines which carry the solutions to and from the ion exchange facility. Flow metres, control valves, and pressure gauges will be installed in the individual well lines to monitor and control the individual well flow rates. Wellfield piping will be high density polyethylene pipe, PVC and steel. The individual well lines and the trunk lines to the recovery plant will be buried to prevent freezing. The use of field header buildings and buried lines is a proven method of protecting pipelines. The Smith Ranch pilot programs employed this method and operated continuously through the winters without freeze-ups or other significant weather related problems. A typical wellfield is illustrated in Fig. 12.

Well Completion:

Monitor, production, and injection wells will be drilled to the top of the target completion interval with a truck mounted rotary drilling unit using native mud and a small amount of commercial viscosity control additive. The well will be cased and cemented to isolate the completion interval from all overlying aquifers. The cement will be placed by pumping it down the casing and forcing it out the bottom of the casing and back up the casing-drill hole annulus.

The well casing will be Schedule 40 PVC which is available in 6 metre (20 foot) joints. Typical casing will have a 127 mm (5 inch) nominal diameter with a minimum wall thickness of 6.55 mm (0.258 inches) and a pressure rating of 1480 kPa (200 psig).

Three casing centralizers located approximately 9, 27, and 46 metres (30, 90 and 150 feet) above the casing shoe are placed on the casing to ensure it is centered in the drill hole and that an effective cement seal results.

The cement volume for each well is 110% of the calculated volume required to fill the annulus and return cement to the surface. The excess is to ensure that cement returns to the surface. Occasionally the drilling may result in a larger annulus volume than anticipated and cement may not return to the surface. In this situation the upper portion of the annulus will be cemented from the surface.

After the cement has cured, the plug is drilled out and the well completed. The well is then air lifted to remove any remaining drilling mud and cuttings. A small submersible pump is used for final cleanup and sampling. If sand production or hole stability problems are expected, Johnson wire wrapped screen or a similar device may be installed across the completion interval. Typical well completions are illustrated in Fig. 13.

Well Casing Integrity:

After a well is completed and before it is operational a mechanical integrity test (MIT) of the well casing will be conducted. In the MIT, the bottom of the casing adjacent to or below the confining layer is sealed with a downhole packer, or other suitable device. The top of the casing is then sealed and a pressure gauge is installed inside the casing. The pressure in the sealed casing is increased to a minimum of 20% above the maximum anticipated operating pressure 791 kPa (100 psig) and the well is closed, and all fittings are checked for leaks. After the pressure is stabilized, pressure readings are recorded at two minute intervals for ten minutes.

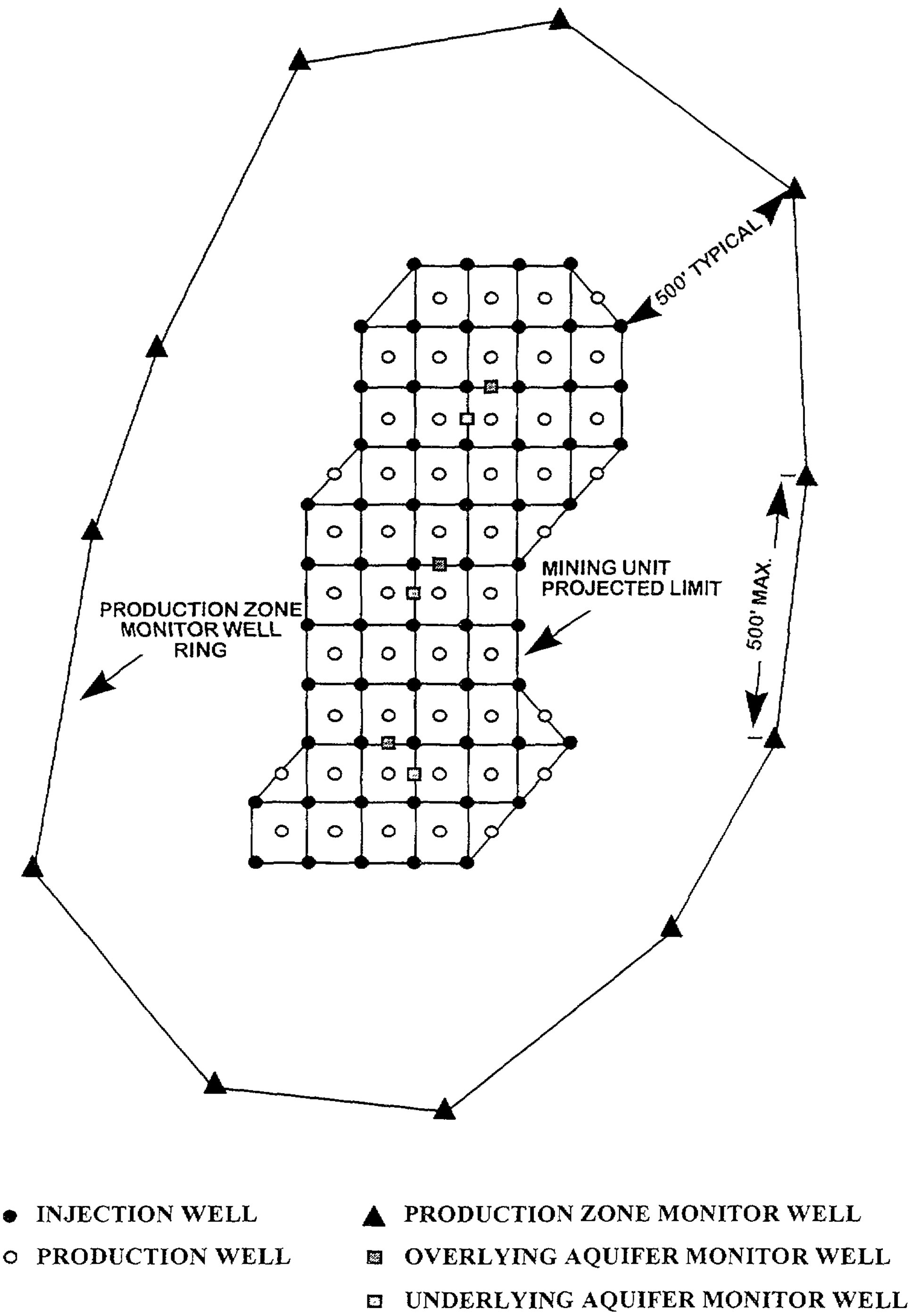


FIG. 12. Typical wellfield development pattern: Smith Ranch Project.

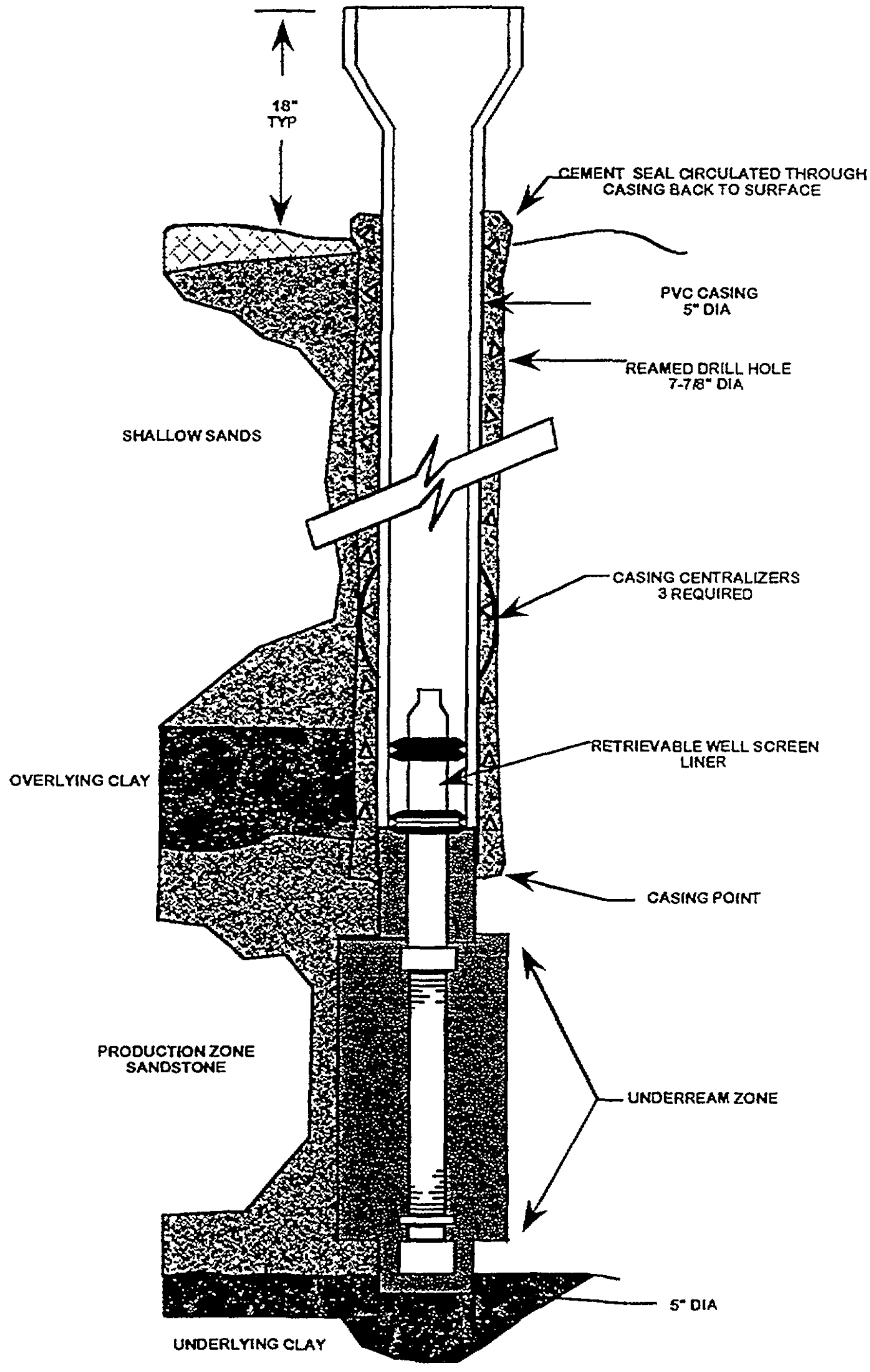


FIG. 13. Well completion method.

If a well casing does not meet the MIT, the casing will be repaired and retested. If a repaired well passes the MIT, it will be employed in its intended service. Also, if a well defect occurs at depth, the well may be plugged back and recompleted for use in a shallower zone provided it passes a subsequent MIT. If an acceptable MIT cannot be obtained after repairs, the well will be plugged. A new well casing integrity test will be conducted after any well repair using a downhole drill bit or under reaming tool.

Monitor wells will be drilled and constructed in the same manner as production and injection wells and all three types of wells must pass MIT.

7.4.6.4. Processing plant design concepts

The processing plant for the proposed project consists of two Ion Exchange Recovery Plants and a Central Processing Plant. The initial Ion Exchange Recovery Plant (IX Facility #1) will be located next to the Central Processing Plant while the second Ion Exchange Recovery Plant will be a satellite unit (IX Facility #2). Schematics which illustrate the major process flow paths in the Ion Exchange Recovery Plant and the Central Processing Plant are presented in Fig. 14.

Uranium recovery using ion exchange resin involves the following processing circuits:

- Resin loading
- Bleed treatment
- Resin elution
- Precipitation
- Product filtering, drying, and packaging.

The IX Facilities are equipped with resin loading and bleed treatment circuits. Each facility can process 189 L/s (3000 gpm) of lixiviate. Ion exchange resin will be transferred by pipeline between IX Facility #1 and the Central Processing Plant. Truck trailers will be used for IX Facility #2. The Central Processing Plant will elute resin from both IX Facilities. The precipitation, product filtering, drying, and packaging circuits will process up to 2.54 tonnes (5 600 pounds) U_3O_8 per day or 907 tonnes (2.0 million pounds) per year.

Resin Loading:

The resin loading circuit in each IX Facility consists of six pressurized vessels, each containing 14.2 m^3 (500 cubic foot) of anionic ion exchange resin. These vessels are configured as three parallel trains for two-stage downflow loading. Booster pumps are located upstream and downstream of the trains.

As the pregnant lixiviate enters the IX Facility, the upstream booster pumps pressurize the fluid to 791 kPa (100 psig). The dissolved uranium in the pregnant lixiviate is chemically adsorbed onto ion exchange resin. Any sand or silt entrained in the pregnant lixiviate will be trapped by the resin bed like a traditional sand filter. The barren lixiviate exiting the second stage will normally contain less than 2 mg/L of uranium. This fluid will be pressurized to 791 kPa (100 psig) by booster pumps and returned to the wellfield for reinjection.

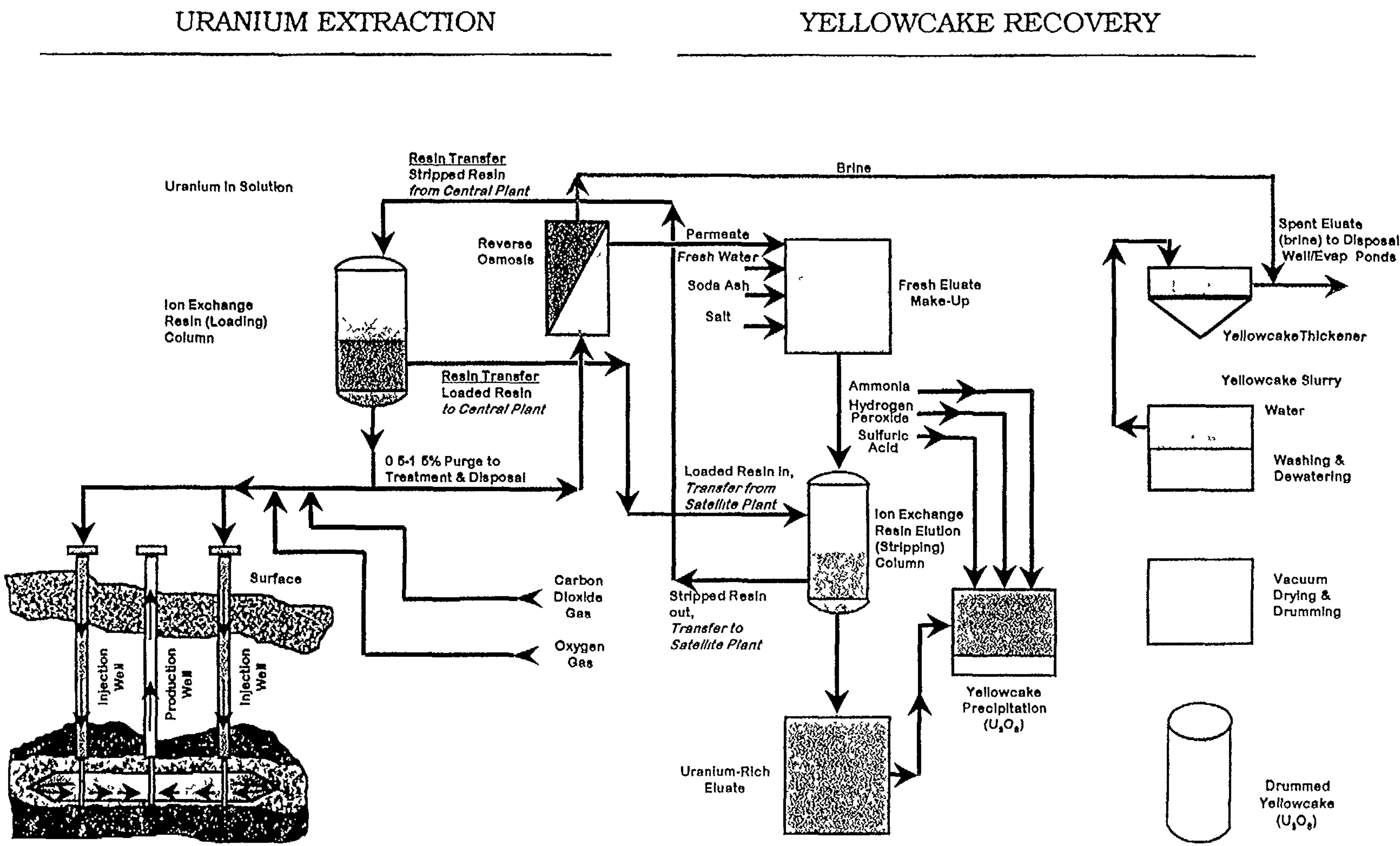


FIG. 14. Flow process schematic.

The lixiviate is composed of native ground water, carbon dioxide and oxygen. Carbon dioxide is added in the IX Facility, both upstream and downstream of the resin vessels. Oxygen is added to the barren lixiviate at the wellfield header houses prior to the injection manifold. The lixiviate concentration of carbon dioxide will be maintained at approximately 2000 mg/L while the oxygen concentration will approximate 500 mg/L.

Bleed Treatment:

To control the movement of lixiviate within the ore zone, a fraction of the barren lixiviate is continuously removed. More fluid is produced than injected. This bleed or blow-down creates a hydrologic cone of depression within the ore zone causing natural ground water from the surrounding area to flow toward the ore zone. This negative pressure gradient holds or contains the lixiviate within the desired ore bearing region and prevents the unwanted excursion of lixiviate away from the ore. This also minimizes the dilution of lixiviate by uncontrolled fluid movement. Based on hydrologic studies, the bleed rates will approximate 0.5% of the production rate for the Q sand mining unit and 1.5% for the O sand mining unit.

The bleed fluid is treated to remove radium mobilized by the ISL mining process as well as residual uranium normally contained in the barren leach solution. Uranium removal is accomplished by additional ion exchange treatment in a single train of two-stage downflow vessels. Radium removal is effected with conventional barium/radium sulfate co-precipitation. A filter press removes the barium/radium sulfate precipitant.

Elution Circuit:

When resin in a first stage IX vessel is loaded with uranium, the vessel is isolated from the normal process flow. The resin is transferred in 14.2 m^3 (500 cubic feet) lots to the Central Processing Plant (CPP). In IX Facility #1, the transfer is hydraulic utilizing dedicated transfer piping. For Satellite IX Facility #2, a bulk tank trailer will be used. At the CPP, the resin passes over vibrating screens with wash water to remove entrained sand particles and other fine trash. It is gravity fed into pressurized downflow elution vessels for uranium recovery and resin regeneration.

In the elution vessel, the resin is contacted with an eluate containing about 90 grams per liter sodium chloride and 20 grams per liter sodium carbonate (soda ash) which regenerates the resin. The eluted resin is rinsed with fresh water and returned to an IX vessel for reuse.

Using a three stage elution circuit, 170 m^3 (45 000 gallons) of eluate contact 14.2 m^3 (500 cubic feet) of resin to create 57 m^3 (15 000 gallons) of rich eluate which contains 10 to 20 grams per liter U_3O_8. The fresh eluate, 57 m^3 (15 000 gallons) per elution, is prepared by mixing quantities of saturated sodium chloride (salt) solution, saturated sodium carbonate (soda ash) solution, and water. The salt solution is generated in salt saturators (brine generators). Saturated soda ash solution is prepared by passing warm water, <314 K (>105°F), through a bed of soda ash.

Precipitation Circuit:

In the elution circuit, the uranyl dicarbonate ions are removed from the loaded resin and converted to uranyl tricarbonate by a small volume of strong sodium chloride/soda ash solution. The resulting rich eluate contains sufficient uranium for economic precipitation.

Sulfuric acid is added to the rich eluate to break the uranyl carbonate complex which liberates carbon dioxide and frees uranyl ions. The acidic, uranium rich fluid is pumped to agitated tanks where hydrogen peroxide is added (0.2 kg H_2O_2/kg U_3O_8) in a continuous circuit to form an insoluble uranyl peroxide compound. Ammonia is then added to raise the pH to near neutral for digestion. The uranium precipitate (slurry) gravity flows to a 11.6 metre (38 foot) diameter thickener. The uranium depleted supernate solution overflows the thickener to surge tanks for disposal via a deep injection well.

Product Filtering, Drying and Packaging:

After precipitation, the settled yellow cake is washed, filtered, dried, and packaged in a controlled area. Washing removes excess chlorides and other soluble contaminants. Filtering and dewatering is done in a filter press. The filter cake is then moved to holding tanks located above the yellow cake dryers.

The yellow cake is dried in one of two low temperature, <394 K (>250°F), vacuum dryers which are totally enclosed during the drying cycle. The off-gases generated during the drying cycle are filtered and scrubbed to remove entrained particulates. The water sealed vacuum pump also provides ventilation while the cake is loaded into drums. Compared to conventional high temperature drying by multihearth systems, this dryer has significantly lower airborne particulate emissions.

By operating at low temperatures, <394 K (>250°F), and under a vacuum, no measurable quantities of insoluble uranium solids are produced, further reducing environmental and occupational risks. This drying technology requires a high purity feed stock because operating temperatures are not sufficient to volatilize contaminates.

The dried yellow cake product will be packaged in 208 litre (55 gallon) steel drums for storage and shipment by truck to another licensed facility for further processing. All yellow cake shipments will be made in compliance with applicable regulations. The vacuum pump system is employed during packaging to minimize airborne particulate emissions.

7.4.6.5. Instrumentation

For control and monitoring purposes, the instrumentation philosophy provides for two separate control systems. Each system is fitted to accommodate the steady state or batch flow nature characteristic of the following process flow streams:

1. Steady State
   - Wellfield/Resin Loading Circuit
   - Precipitation

2. Batch
   - Bleed Treatment
   - Elution
   - Product Filtering, Drying and Packaging

Since the wellfield/resin loading circuit operates at a steady state, small deviations from the normal operating flow rates and pressure profiles ($\pm 10\%$ or greater) indicate major operating upsets. An automatic Emergency Shut Down (ESD) system consisting of pressure and flow rate switches is provided for this circuit. If an automatic shut down occurs, an alarm notifies the operator of the situation. Once the major upset is identified and corrective action taken, only then can the circuit be manually restarted. This type of control system provides the best protection against major spills. Back-up for the automatic ESD system is provided by local displays of the same flow rates and pressures that the ESD system monitors.

The Elution, Product Filtering, Drying, and Packaging Circuits operate in a batch mode. These circuits are controlled by programmable logic controllers (PLC) which automatically open and close the appropriate valves once the processes are manually initiated. The PLC provides closed loop feedback control of the flowrates in the elution and precipitation circuits. All automatic valves have manual control override. Local indication of pressures, levels, flow rates, pH and temperature are provided for complete manual control of these circuits as required.

7.4.7. Environmental consequences

The environmental impact of ISL uranium mining and yellow cake processing are minimal. No tailings are created. Nearly all radioactive daughter products remain underground. Airborne emissions from yellow cake drying are kept at an absolute minimum by a vacuum drying system. Only radon gas is mobilized during the process and is readily controlled by conventional scrubber technology.

Surface disturbances are short term for the installation of wells, pipelines, roads, and processing plants. Removal of this equipment, replacement of stockpiled topsoil, and revegetation return the surface to its original or better condition at completion of the project.

A limited quantity of ground water is consumed in the processing of yellow cake. Additional volumes of ground water are temporarily perturbed by the leaching. However, at the end of the project, all ground water will be suitable for its pre-mining use.

The relatively small work force (about 75 employees) creates no significant environmental stress nor social-economic alterations in the area.

7.4.7.1. Environmental effluent from the process

Gaseous:

The principal gaseous emission representing a potential radiological dose to man is radon-222 gas released to the atmosphere from the circulating lixiviate and to a lesser extent in the elution and precipitation circuits. Some carbon dioxide gas and some acid fumes will also evolve from the plant processes. At the anticipated concentrations and release rates, these gases do not present a health nor regulatory problem.

Other emissions to the air will be limited to exhaust and dust from limited vehicular traffic and small amounts of process chemicals such as ammonia, carbon dioxide, oxygen, hydrogen peroxide, sodium hydroxide, sulfuric and hydrochloric acid. There will be no significant combustion related emissions from the process facility as commercial electrical power is available at the site.

Particulates and Solids:

Particulate emissions from the operation will be primarily dust created by vehicular traffic. However, minimal amounts of yellow cake could be released during drying and packaging. Effluent control equipment will maintain any such yellow cake emissions to as low as practicable and to levels well below allowable standards.

Solid wastes generated by this project will consist of materials such as rags, trash, packing material, worn or replaced parts from equipment and piping, sediments removed from process pumps and vessels, spent ion exchange resin fragments, and the solids remaining in the evaporation ponds after the liquids have evaporated.

The non-radioactive wastes will be disposed in the site's existing solid waste disposal facility as authorized by the Wyoming DEQ.

Radioactive solid waste that has a contamination level requiring controlled disposal will be isolated in drums or other suitable containers and disposed at a NRC licensed tailings facility or at other approved sites. Contaminated solid wastes from the pilot plant operation, *excluding material removed during construction for the second pilot and evaporation pond* solids, have amounted to six 208 liter (55 gallon) drums of material per year.

Liquid:

Liquid effluent from the operation include the production bleed stream, excess fluids from the elution and precipitation process, yellow cake rinse water, plant washdown water, restoration equipment (EDR/RO) waste, restoration bleed, and facility sanitary waste. A deep injection well, 3 050 metre (10 000 feet) subsurface, will be used for disposal to brine type waste streams. Appropriate treatment of all waste streams will precede disposal.

7.4.7.2. Environmental impact

Surface Impacts:

Surface impacts will primarily be from site preparation and construction. Such impacts will be limited to the local soils and vegetation.

The recovery plant will be located within the Bill Smith Mine site where its construction will not result in new surface disturbance. Implementation of the in situ mining project will extend the operating life of the site and livestock grazing will continue to be excluded from the approximately 16.2 hectare (40 acre) Bill Smith Mine site.

Drilling of wells and installation of pipelines will result in temporary disturbance to the soils and vegetation in those areas. However, as demonstrated by the pilot programs, the impact is minimal. Vegetation in these areas is normally reestablished within two years of disturbance.

At startup it is expected that livestock grazing will be excluded from approximately 12 hectare, with the total area increasing to as much as 60 hectares over the life of the project. The area that may be excluded from grazing due to pipelines and the wellfields is expected to average less than 41 hectares over the life of the project.

Surface disturbances associated with the waste water ponds and access roads will be for the life of the project. Topsoil will be removed from these areas and stockpiled before construction. When facilities are no longer needed for the operation, the areas will be recontoured, topsoiled and reseeded. The primary impact of these activities will be the exclusion of livestock and wildlife from the evaporation pond areas for the life of the ponds.

After mining and ground water restoration is finished, all areas will be reclaimed and restored to their pre-mining use. Therefore, there is no long-term surface impact from the operation.

Surface Water Impacts:

No significant or measurable impacts to surface water quality are anticipated as a result of the operation.

Ground Water Impacts:

The most significant water impact will be the withdrawal and beneficial use of about 2466 hectare-metres (20 000 acre feet) of ground water over the life of the project. Most of the water removed will be returned to the environment after treatment by evaporation or disposed by deep well injection into natural brine bearing formations.

Radiological Impacts:

Emissions from radiological materials at in situ mining operations are considerably lower than emissions associated with traditional uranium mining and milling methods. The environmental advantages of the in situ mining method and the processing of the uranium for this project are three-fold.

First, the majority of the radioactive daughter products remain underground and are not removed with the uranium. Second, vacuum drying of the yellow cake eliminates most of the potential radiological air particulate problems typically associated with conventional uranium milling and drying facilities. Third, there are no tailings.

Since in situ mining operations do not involve removal and crushing of the ore there are no large scale radionuclide particulate emissions from the facility. Liquids released from the facility will be treated on site to reduce any contained radiation to levels acceptable for release to unrestricted areas as specified by 10 CFR Part 20, Appendix B, Table II. Therefore radioactive liquids are not an environmental concern.

Under the RAMC operating plan, the radionuclides presumed to be released to the environment are ^{222}Rn, ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb. The ^{222}Rn gas is dissolved in the fluids brought to the surface during mining. A portion of the radon is released from the process water by normal pipeline and tank vents. A minute yellow cake particulate emission may accompany the drier exhaust air even after scrubbing. Packaging of yellow cake is an additional potential source of yellow cake particulates.

Airborne dispersion modeling studies were run to estimate potential radionuclide exposures at and near the project. Total radiation dose commitments including radon-222 are approximately 0.19 milli-Sievert (19 mrem)/year to the most sensitive organ (bronchial epithelium) compared to the average background dose to this organ of 0.03 Sievert (3000 mrem)/year in the USA (NCRP, 1984). Working levels of Rn-222 predicted by the model indicate all receptors will receive far less than the maximum permissible concentration (MPC) for this parameter.

Concentrations of radon daughters such as ^{210}Pb, ^{210}Bi and ^{210}Po also fall well below the MPCs for these elements. Air concentrations of ^{238}U, ^{230}Th, ^{226}Ra and ^{210} Pb produced during drying and packaging yellow cake are, at their maxima, less than 100th of the MPCs for these materials.

Wildlife Impacts:

There are no known endangered species or endangered species habitat within the project area. Therefore, there will be no impact to endangered species from the proposed project.

Other species observed on the permit area are common throughout eastern Wyoming and many other areas of the Rocky Mountain region. Many individuals of the small animal species such as the small burrowing mammals, snakes, lizards, and arthropods that now live in areas of planned disturbance may be destroyed when the vegetation is removed. The total area disturbed during the project life will approximate 200 hectares (500 acres).

Since a relatively small number of reptiles inhabit the disturbed permit area, the impact on these animals will be minor. Vegetation removal will also have a relatively minor effect on insects and other arthropods because of their ability to quickly reestablish populations on reclaimed areas.

Highly mobile species, such as the larger mammals (pronghorn antelope and mule deer) and most birds, will be able to escape the disturbed areas. However, the movement of those animals into adjacent undisturbed habitat may result in increased competition for food, shelter, territory, mates, and other necessities.

For economic value and public interest, the most important wildlife species that utilizes the permit area is the pronghorn antelope. It is estimated that the density of antelope in this region is two to three animals per square kilometre and that they remain in the area throughout the year. Consequently, the loss of 16 hectares (40 acres) of vegetation due to the processing plant and associated facilities may result in a reduction in antelope carrying capacity on the permit area by less than one (1) animal, while mining activities on an average of 16 hectares/year may reduce antelope carry capacity by the same amount. Operation of the additional satellite facilities (an average of 32 hectares/year) could reduce antelope carrying capacity by one (1) animal.

The increased number of people in the permit area could have an additional impact on antelope and other wildlife populations, since some animals are likely to be killed by increased vehicular traffic. These additional wildlife losses are not expected to result in any long term decrease in any wildlife populations, including antelope, since the potential number affected each year is expected to be a very small percentage of the total population.

Other than actual removal of vegetation and potential of accidents resulting from activity in the area, project activities are not expected to significantly affect the antelope population. These animals do not appear to be disturbed by mining and processing activities similar to those proposed for this project. For example, at the Highland ISL Uranium Project adjacent to the Rio Algom permit area, antelope are commonly observed near active mining areas without any noticeable concern. No reduction in the pronghorn population has been observed in the vicinity of that facility since it was originally constructed by Exxon in the early 1970s.

Construction and operation of the proposed project should not have a significant effect on raptors utilizing the permit area due to the small percentage of prey that would potentially be lost as a result of vegetation removal.

Wildlife species will re-invade disturbed areas after they are reclaimed. The time required for re-invasion is a function of the habitat requirements of each species. Herbivores capable of feeding on grasses and weedy plant species (e.g., deer mouse, thirteen-lined ground squirrel, mourning dove, and horned lark) would be the first animals to establish themselves on re-vegetated areas. Those animals also nest on the ground and prefer open habitats. Predaceous arthropods, such as ground beetles and assassin bugs, and insectivorous animals, such as the grasshopper mouse, meadowlark, loggerhead shrike, and horned lizard, would also be expected to be early invaders of revegetated areas. Several other species of animals (such as sage grouse) that are heavily dependent on sagebrush and other shrubs for food, cover, and nesting could take several years to successfully re-invade reclaimed areas because of the time required for shrubs to become re-established.

7.4.7.3. Environmental risks

Tank Failure:

Under normal operating conditions the process fluids are contained in the process vessels and piping circuits within the ion exchange and yellow cake processing plants. Alarms and automatic controls are used to monitor and keep levels within prescribed limits. In the unlikely event of failure of a process vessel or tank within a process building, the fluid would be contained within the building, collected in sumps and pumped to other tanks or a lined evaporation pond. The area would then be washed down with water to eliminate any environmental impact from the failure.

Pipeline Failure:

The rupture of a pipeline between the main process facility and the wellfield could result in a loss of either pregnant or barren solutions to the surface. To minimize the volume of fluid lost, the pipelines will be equipped with high and low pressure shutdown systems and flowmetres. The systems will include alarms so the operator will be alerted immediately if a malfunction occurs. If the volume or concentration of the solutions released in such an accident would constitute an environmental concern, the area will be surveyed and any contaminated soils removed and disposed according to NRC and State regulations. The pipelines will normally be buried approximately 1.5 metres below the surface and constructed with high density polyethylene. The probability of such a failure after the pipelines have been tested and placed in service is considered small.

Fires and Explosions:

The fire and explosion hazard at the site is minimal. Although a strong oxidant (50% hydrogen peroxide) is the yellow cake precipitation reagent, it is stored outside in an approved magnesium-aluminum alloy storage tank with pressure relief valves. The tank will be set on a curbed concrete foundation with sufficient capacity to contain 110% of the tank capacity. The distribution system (piping, pumps, etc.) will solely be constructed from approved materials (magnesium–aluminum alloys, 304 and 316 stainless steel). All equipment will be passivated prior to use.

Heat is supplied to the vacuum dryers through a flammable heat transfer fluid. A natural gas fired heater operating at approximately 422 K supplies energy to the fluid. The heater and heat transfer fluid pumps will be specified and purchased as a package for this specific application. Installation and operation of the system will conform to local and national fire codes. Natural gas used for building heat would be the other source for a potential fire or explosion.

In the central processing plant the uranium will be in solution, adsorbed on ion exchange resin, or yellow cake slurry. An explosion therefore would not appreciably disperse the uranium to the environment. Spilled liquids or slurries would be confined to the building sump or to the runoff control system. Dry product will be stored on a curbed concrete foundation either outside or in a separate building.

Well Casing Failure:

A casing failure in an injection well would have the potential for the most significant environmental impact because the leach fluid is being injected under pressure. It is possible that this type failure could occur and continue for several days before being detected by the monitoring system. If such a failure did occur, the defective well would be either repaired or plugged and abandoned. If contamination of another aquifer was indicated, wells would be drilled and completed in the contaminated aquifer then produced until concentrations of leach solution constituents were reduced to acceptable levels. With proper casing, cementing and testing procedures, the probability of such a failure is very low. No casing failures have occurred in the two pilot programs where a total of 21 injection wells have been operated over several years.

To minimize the environmental impact from a casing failure, monitor wells will be completed in the aquifers above and below the ore zone. The fluid levels and water quality in these adjacent aquifers will routinely be monitored during mining as a check for fluid movement into these aquifers. In addition, casing integrity tests will be performed on all injection wells prior to their use and after any work that involves entering the well with a cutting tool, such as a drill bit or underreamer.

Failure of a recovery well casing would not normally cause an excursion because the production wells operate at pressures lower than the aquifer pressures. However, casing integrity tests will also be performed on both recovery and monitor wells after installation and following any entry of a cutting tool into the well.

Leakage Through Exploration Holes:

Movement of leach solution between aquifers through old exploration holes in the project area is unlikely. The drill holes were abandoned with a full column of bentonitic drilling mud. The clay is an effective seal against fluid interchange between the various aquifer units penetrated by the drilling. Additional well bore sealing is provided by the rapid swelling and bridging of the isolating shales between the sandstone aquifer units.

To ensure there is no communication between aquifers, monitor wells completed in aquifers above and below the ore zone will be routinely checked for changes in aquifer pressure (water level) and water composition. In addition, pre-mining pump tests will be conducted to demonstrate no significant communication between the aquifers exists. Should leakage between aquifers through old drillholes be indicated during the tests, the old holes would be re-entered and plugged. If contamination of another aquifer was indicated wells would be drilled and completed in the contaminated aquifer, sampled, and if needed, produced to reduce the concentration of any leach solution fluids to acceptable levels.

Yellow Cake Transportation Accidents:

An accident involving vehicles transporting the yellow cake could result in an yellow cake spill. In the unlikely event of such an accident, all yellow cake and contaminated soils would be recovered and processed through a mill or disposed in a licensed facility. All disturbed areas would then be reclaimed as required by applicable State and NRC regulations.

The risk of an accident involving an yellow cake spill will be minimized by use of Department of Transportation (DOT) approved containers and exclusive use shipments. To further reduce the environmental impact should an accident occur, a "Transportation Accident Response Guide" for the facility has been prepared and these special instructions will be included with every yellow cake shipment.

Chemical Shipments:

Accidents involving truck shipments of process chemicals to the project site could create a local environmental impact. Any spills would be removed and the area would be cleaned and reclaimed. Chemicals used in in situ mining are common to many industries and present no abnormal risk. These chemicals include dry sodium carbonate, liquid ammonia, liquid carbon dioxide, liquid oxygen, liquid hydrochloric acid, liquid 50% hydrogen peroxide, liquid sulfuric acid, and dry sodium chloride (salt). Since most of the material would be recovered or could be removed, no significant long term environmental impact would result from a shipping accident involving these materials.

Pond Failure:

The waste water ponds will be constructed with leak detection systems and these systems will be monitored daily. If a liner leak was detected, the fluid would be pumped to another pond and the liner repaired as needed. The pond area will be surveyed and reclaimed as part of the final reclamation eliminating any significant long-term impact.

A pond embankment failure would be the most severe type of pond failure. To minimize the risk of an embankment failure the ponds will be inspected daily to ensure there is no significant deterioration of the embankments. Should a failure occur all impacted areas would be surveyed, cleaned up as needed, and reclaimed.

7.4.7.4. Environmental monitoring

Gaseous Monitoring:

Since only liquids are brought to the surface during in situ mining, the only gaseous effluent of significance are the release of radon-222 from the produced solution and limited vapors emitted in the process plant. For control and monitoring of radon-222, a continuous passive radon monitoring station will be established approximately 305 metres (1000 feet) down wind of the recovery plant buildings.

Particulate and Solids Monitoring:

Prior to beginning in situ mining in a mining unit, a gamma survey of the area will be conducted on a north-south, east-west grid system at 61 metre (200 foot) intervals. These readings will be used as background value if a spill, leak or accident involving radioactive release of process or product material occurs.

Particulate monitoring at the site primarily will be operational stack sampling which is conducted to measure yellow cake releases. Sampling frequency will be specified by the NRC. Low volume air particulate sampling will be performed in the yellow cake packaging area.

Non-radioactive solid wastes such as rags and packing material will be disposed in the existing solid waste disposal facility. Inspections will ensure the materials are being properly covered to prevent paper, etc. from being blown out of the disposal pit.

Potentially radioactive solids will be scanned and any found to have a contamination level requiring controlled disposal will be placed in drums or other suitable containers and stored in a designated area. Final disposal of these materials at an NRC licensed facility will be documented.

Liquid Monitoring:

The primary objectives of the liquids monitoring programme are protecting ground water supplies, keeping employee and public exposure to as low as reasonably achievable (the ALARA principle), and preventing or mitigating the impact of any surface contamination resulting in a leak or spill of process solutions.

Preoperational Well Monitoring:

Pre-operational data will be collected on a mining unit basis and will include:

- Baseline water quality data for the mining unit;
- Baseline data for the associated monitor wells;
- Pump tests to determine the hydrologic capabilities of the geological units;
- Pump tests to verify communication between the mining zone and the surrounding monitor wells, as well as isolation of the mine zone from over- and underlying aquifers.

Baseline data for a mining unit are submitted to NRC and DEQ a minimum of 60 days prior to injection of leach solutions in the subject mining area. These data provide the basis for establishing restoration criteria for the mining unit as well as for operational mining.

Monitor wells for a mining unit will be completed in the production zone in a circular pattern around the mining unit and in the overlying and underlying aquifers. The wells will be cleaned, then sampled a minimum of three times and analysed for the same parametres. Additional samples will be collected and analysed for the excursion parametres chloride, conductivity and total alkalinity. Upper Control Limit values (UCLs) for the mining unit are established for each of the excursion parametres. The UCL for a given parametre and type of well is defined by regulations as the mean of baseline plus five standard deviations from the mean as determined after outlier screening.

Operational Well Monitoring:

During operation, the primary purpose of the monitoring program is to detect and correct any condition which could lead to a horizontal or vertical excursion of leach solution or detect such an excursion should one occur. The monitor wells, individual well rates and pressures, and the flow and pressure in the main pipelines are the key components of this programme.

To ensure the leach solutions are contained within the designated area of the aquifer being mined, the production zone, overlying aquifer, and underlying aquifer monitor wells will be sampled twice per month and the samples will be analysed and compared to the excursion parametre UCL values. The fluid level in each monitor well will also be measured and recorded.

If indications of leach solution appear in any of the monitor wells, the production and injection rates will be adjusted as needed to move solutions back toward the wellfield area. If such actions are not effective in controlling an excursion within ninety days, injection of leach solution in the adjacent injection wells will be suspended until a definite decline trend in the concentrations of parametres that exceed the UCL values is established. After this trend is established, injection in the area may be resumed; however, the production and injection rates will be regulated such that the net withdrawal is sufficient to maintain the decline trend.

The pressures and flow for each operating well in the mining unit will be read and recorded each day. These data will be used to maintain the production-injection balance for the mining unit, assure a net bleed is maintained, and confirm that the injection pressure limits are not exceeded.

Pipeline Monitoring:

Pressure and flow indicators on the main pipelines to and from the recovery plant will also be read and recorded daily to assure that conditions are maintained within the safe working limits of the pipeline.

Surface Effluent Monitoring:

Effluent streams subject of monitoring include the bleed stream (combination bleed/restoration during restoration) and the waste liquids routed to the lined ponds or disposal well. The bleed stream volume will be metered and sampled monthly. The sample will be analysed for bicarbonate, chloride, sodium, sulfate, uranium, arsenic, selenium and pH.

Prior to mixing with other waters, the bleed stream will be treated to remove the uranium and to reduce the radium-226 level below the limits in 10 CFR Part 20, Appendix B, Table II for release to unrestricted areas. The bleed stream leaving the radium removal system will be sampled quarterly and analysed for radium-226, thorium-230 and uranium.

Liquid effluents will be metered. The pond solutions will be sampled semi-annually and analysed for bicarbonate, calcium, chloride, sodium, sulfate, TDS, uranium, radium-226, and thorium-230.

The lined treatment pond will be constructed with a leak detection system consisting of a network of perforated pipes in a sand layer beneath the liner with the pipes draining to a collection sump. The pond monitoring program will include either a fluid level sensor in each sump with an alarm displayed at the recovery plant or a daily inspection of each sump by an operator. The ponds will also be inspected daily for visual indications of leaks or embankment deterioration.

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