TWENTY YEARS OF UNDERGROUND RESEARCH AT CANADA'S URL

N. A. Chandler
Atomic Energy of Canada Limited, Whiteshell Laboratories
Pinawa, Manitoba, Canada R0E 1L0

ABSTRACT

Construction of Atomic Energy of Canada Limited's (AECL's) Underground Research Laboratory (URL) began in 1982. The URL was designed to address the needs of the Canadian nuclear fuel waste management program. Over the years, a comprehensive program of geologic characterization and underground hydrogeologic, geotechnical and geomechanical projects have been performed, many of which are ongoing. The scientific work at the URL has evolved through a number of different phases to meet the changing needs of Canada's waste management program. The various phases of the URL have included siting, site evaluation, construction and operation. Collaboration with international organizations is encouraged at the URL, with the facility being a centre of excellence in an International Atomic Energy Agency (IAEA) network of underground facilities.

One of AECL's major achievements of the past 20 year program has been the preparation and public defense of a ten-volume Environmental Impact Statement (EIS) for a conceptual deep geologic repository. Completion of this dissertation on the characterization, construction and performance modelling of a conceptual repository in the granite rock of the Canadian Shield was largely based on work conducted at the URL. Work conducted over the seven years since public defense of the EIS has been directed towards developing those engineering and performance assessment tools that would be required for implementation of a deep geologic repository. The URL continues to be a very active facility with ongoing experiments and demonstrations performed for a variety of Canadian and international radioactive waste management organizations.

INTRODUCTION

The Underground Research Laboratory (URL) near Lac du Bonnet, Manitoba, Canada is now in its 21st year of operation. Shaft collar site selection and the start of surface facility construction occurred in 1982. The URL is situated in a granite batholith towards the western edge of the Precambrian Canadian Shield (Fig. 1.). Atomic Energy of Canada Limited (AECL) constructed the facility to provide a representative geological setting for conducting research and development activities in support of the Canadian nuclear fuel waste management program. The objective for the URL, as established in 1982 (1) was to establish a plan of activities that included both site evaluation and underground experimentation:

- the site evaluation program was to involve characterization of the rock mass, groundwater flow systems and groundwater chemistry of the geologic environment;
- the underground program was to involve studies of the geologic barrier and the engineered components of the repository sealing system.

The results from the first twenty years of the URL program have done much to achieve these objectives. Work directed at improving technical capabilities related to site evaluation, modelling the performance of a geologic barrier, and the engineering of repository sealing systems, continues today.

In Canada, over 25 years has been spent advancing the technologies for disposal of nuclear fuel waste from Canadian reactors. Between 1978 and 1996, AECL took a lead role in developing the disposal technology. Since 1997, Ontario Power Generation Inc. (OPG), the principal producer of nuclear fuel waste in Canada, has assumed the responsibility under its Deep Geologic Repository Technology Program. The comprehensive and multidisciplinary URL research and development program has contributed to defining a robust conceptual design for an underground repository. Results from research at the URL were used in the assessment of the feasibility and safety of deep geological disposal as documented in an Environmental Impact Statement (2). The Federal Environmental Assessment Panel that conducted a public review of the disposal concept (3) acknowledged that, from a technical perspective, the safety of Canada's concept for nuclear fuel waste disposal was adequately demonstrated.

Upon completion of the public hearings for review of the EIS in 1997, AECL and OPG moved forward together into the next phase, which has been the development of technologies required for design and construction of a deep geologic repository. While a public process for reviewing the various options available for long-term management of Canada's spent fuel is ongoing, OPG and AECL continue to work to address identified technological gaps in our capabilities, should a decision be made for Canada to move towards eventual construction of a deep geologic repository.

Currently, there are fifteen experiments or experimental programs ongoing at the URL, some of which have international participation from Japan, France, Korea and the USA. Many of the experiments are conducted in parallel with numerical modelling programs, to help develop these as tools for either engineering design, performance assessment or both. The program of study at the URL is formulated along three broad topic areas:

- studies into site characterization, or long-term geologic monitoring methodologies
- studies of solute transport through fractured and unfractured crystalline rock, and
- studies in support of the engineering design of repository sealing systems.

AECL has a 31-year surface and a 34-year underground mineral lease for the URL site from the province of Manitoba, currently expiring in 2011 and 2014 respectively. These leases have been extended once in the past, and AECL can apply for future extensions if warranted. The URL is well accepted by residents in eastern Manitoba, and its staff regularly participates in community events in the neighbouring towns of Lac du Bonnet and Pinawa. The URL is an important factor in the commerce of this region with most of the approximately 50 people working at the site living near-by. Part of the success in community relations can be attributed to a lease condition stipulating that the site shall not be used for storage or disposal of spent fuel. The URL has been used only for generic non-site specific studies into spent nuclear fuel disposal in crystalline rock. The site has proven to be ideal for this purpose with varied and interesting geology representing a wide variety of potential deep geologic conditions. Once a decision is made to initiate the site selection process in Canada, the URL will provide invaluable expertise and technology to support siting investigations.

SPENT NUCLEAR FUEL MANAGEMENT IN CANADA

In Canada, the Federal Government has legislative authority for the development and control of nuclear energy, which it regulates through the Canadian Nuclear Safety Commission (CNSC). The Federal Government is responsible for the development of policy for radioactive waste disposal. The CNSC ensures that the use of nuclear energy does not pose undue risk to health, safety, security and the environment. They license nuclear facilities, which will include nuclear waste disposal sites and facilities. The waste producers and owners are responsible for the management of their wastes, and they include utilities with nuclear power stations, AECL, and uranium mining/processing/fabrication companies.

Nuclear reactors in Canada have a capacity to generate approximately 17% of the country's electricity. Of the 22 Canadian CANDU® power-generating reactors, not all of which are currently in service, 20 are in the province of Ontario, one is in Quebec and one is in New Brunswick. In addition to these, AECL, the developer of CANDU® technology, has responsibilities for spent fuel from its research reactors. However, OPG, being the principal owner of spent nuclear fuel, has taken the lead in managing the program for interim storage and long-term management. In 1998, OPG had accumulated 1.2 million used fuel bundles (23,000 MgU) and projected at the end of life of the current reactors that there would be 3.2 million used fuel bundles in Ontario (4) and 3.6 million bundles in all of Canada. The used fuel bundles are currently stored initially in water-filled bays located at each nuclear generating station. Once a fuel bundle has spent 6 to 10 years in a bay its rate of heat generation has decreased sufficiently that it can be stored in dry storage facilities at the reactor sites.

In 1978, the governments of Canada and Ontario announced the Canadian Nuclear Fuel Waste Management Program of research with the intention of verifying "that permanent disposal in a deep underground repository in intrusive igneous rock is a safe, secure and desirable method of disposing of radioactive waste" (5). AECL was given the role of developing the technology for immobilization and disposal, and OPG's predecessor, Ontario Hydro, was given the responsibility for storage and transportation. In 1981, the two governments issued a second joint statement in which they announced the process by which acceptance of the disposal concept would be undertaken and that "no disposal site selection will be undertaken until after the concept has been approved"(6).

In 1988, a formal review of the disposal concept was initiated in accordance with the Federal Environmental Assessment and Review Process, and AECL was charged with preparing the Environmental Impact Statement (EIS) on the concept for disposal of Canada's nuclear fuel waste, which, together with its nine supporting primary reference documents, was issued to an Environmental Assessment Panel in 1994 (2). For review of the disposal concept, neither a site, nor a site-specific design could be assessed, since disposal site selection had not been undertaken. Instead, assessment case studies of hypothetical systems were performed (7) based on information derived from extensive laboratory and field research.

The eight-member Environmental Assessment Panel was asked to comment on the safety and acceptability of the disposal concept and to make recommendations to the Federal Government to assist them in reaching decisions on the acceptability of the concept. It was also asked to examine the criteria used to determine safety and acceptability and to recommend future steps that should be taken in the long-term management of nuclear fuel wastes (3). The Panel came to four major conclusions at the end of a three-year period of deliberation that involved review of the documents, receipt of 536 written submissions from both the general public and learned societies, and 13 weeks of public hearings held in 16 communities in five provinces of Canada involving 531 registered speakers. The Panel conclusions in 1998 were that: there must be broad public support to ensure acceptability of any concept for managing nuclear fuel wastes; that safety is only one part of acceptability and must be viewed from both technical and social perspectives; that from a technical perspective safety of the concept was, on balance, adequately demonstrated but from a social perspective it was not; and that the concept as described in the EIS was not demonstrated to have broad public support, and therefore, in its current form did not have the required level of acceptability. The panel report included recommendations for establishing a process to address several important issues and recommended that Canada not move towards siting a repository until these issues were addressed and alternate options studied.

The Government of Canada accepted the recommendations of the Panel. The Nuclear Fuel Waste Act was passed by the Federal Government and came into force in November 2002. The act required the nuclear energy corporations to form a waste management organization, which they did (called the Nuclear Waste Management Organization or NWMO). The act also required the establishment of a segregated fund for nuclear fuel waste management in Canada, with funding coming from all the nuclear utilities and AECL. By the end of 2005, the NWMO must complete a study of options for the long-term management of nuclear fuel waste and recommend a preferred option. The options to be studied must include deep geologic disposal, long-term storage at reactor sites, and long-term centralized storage above or below ground. The government will exercise oversight throughout the decision-making process via the Nuclear Fuel Waste Bureau, established within the Ministry of Natural Resources Canada.

The work conducted at the URL has played an important role throughout this process, and continues to have a role today and into the foreseeable future. Construction of the URL and characterization of the site, followed by an initial phase of large-scale in situ testing contributed immensely to the preparation of the EIS, and was helpful in allowing the Environmental Assessment Panel to conclude that the safety of the disposal concept had been adequately demonstrated. Public tours of the URL were an integral element of the process of public review of the EIS. Today, the nuclear utilities and the NWMO have been charged with providing a detailed description of the deep geologic disposal option for comparison with long-term storage options. Work at the URL provides information that will help to demonstrate the technologies that would be used in the engineering and safety assessment of a repository. Upon submission of this study in three years, the government of Canada will set policy for the future. If Canada is to move towards the deep geologic disposal option, the URL will continue to play an important role in the implementation of the project.

GEOLOGICAL SETTING OF THE URL

A site or preferred siting region for nuclear fuel waste disposal has not been identified in Canada. The disposal concept specified in the EIS stated only that the site would be located somewhere in intrusive igneous rock in the Canadian Precambrian Shield at a depth of between 500 and 1000 m. The Canadian Shield has a wide distribution, and occupies millions of square kilometres, roughly half of the areal extent of Canada (Fig. 1). The URL is located within the Canadian Shield in the Lac du Bonnet granite batholith (Fig. 1). The batholith is one of a number of similar post-tectonic and post-metamorphic batholiths within the Bird River and Winnipeg River sub-provinces of the Canadian Shield (8). The batholith has an areal extent of 1400 km^2 on surface and extends in depth to between 6 and 25 km. The granite at the URL is approximately 2,600,000,000 years old.

The URL has much to offer as a generic site for conducting studies into nuclear fuel waste disposal. The site has interesting and varied geology and is crosscut by two low-dipping thrust faults, or fracture zones (Fig. 1), with a deeper third thrust fault that appears to die out before passing below the URL excavations. The blocks between the thrust faults define different structural domains that can be distinguished by the presence of intrusions and segregations and by the pattern and frequency of subvertical fracturing, as well as by differing in situ stress regimes.

People who visit the URL often leave with the impression that the site is a large sparsely fractured block of predominately intact granite. This impression is supported by observing only one water-bearing fracture as they walk around the main test levels at depths of 240 m and 420 m below surface. Visitors do not generally have an opportunity to observe the fracture zones and associated splays and the 200 m of subvertical fracturing nearer to the surface. Experiments conducted at the URL make use of five testing regions as identified in Fig. 1. These include:

1. 5 km^2 of exposed granite outcrop on the surface of the URL lease;
2. zones of highly fractured rock in three fracture zones or thrust faults;

3. moderately fractured rock with an inter-connected fracture network;
4. low-to-moderately stressed sparsely fractured rock; and
5. highly-stressed sparsely fractured rock in a region of high pore water salinity.

The following are examples of studies performed in each of the five regions:

- near surface: A hydrogeologic network of over 130 shallow and deep boreholes was established to monitor the variations in hydraulic head caused by construction of the URL. A large proportion of these boreholes continue to be monitored today. Included within this network is the hydrologic monitoring of a site dedicated to understanding local-scale run-off and infiltration in a granite outcrop.

- highly fractured rock: Extensive characterization was performed to determine the hydraulic and solute transport properties of the fracture zones that cross the URL site, and to test our ability to predict the transport of solutes through the geosphere using available numerical tools. The work included studies of the mechanical-hydraulic coupling that was apparent in the measured responses.

- moderately fractured rock: A comprehensive study of solute transport through rock having between one and five fractures per linear metre is being performed at the URL. When the URL shaft was constructed in 1984, there was also a study of the effect of excavation on the hydraulic and mechanical response in the moderately fractured rock near the surface. These programs involved numerical modelling components (9).

- low stressed, sparsely fractured rock: The excavations on the 240 m Level of the URL are stable with little excavation related damage. Experiments at this level study the performance of engineered sealing materials in the absence of rock damage. Studies have also been directed at improving excavation methods such as controlled blasting. The existence of a single water-bearing fracture at this level allowed the study of the hydro-mechanical response of the fracture to excavation and the study of radionuclide transport in an isolated block taken from the fracture.

- high stressed, sparsely fractured rock: The rock at the 420 m Level of the URL is stressed to the point of fracturing in the roof and floor of excavations. In some cases the fracturing can result in small, but continuous, regions of highly damaged rock. Experiments at this level study rock response to excavation, including designing excavations to minimize damage. Experiments are conducted at this level to study technologies for constructing seals in excavations with zones of damaged rock. The high pore water salinity at this level also provides an environment for testing the effect of salinity on engineered barrier components. Diffusion tests are also conducted within the sparsely fractured rock.

PHASES OF THE URL

The siting of the URL, the initial evaluation phase, facility construction and lessons learned in developing the operating phase experiments have been described previously (10, 11) and will be discussed here only briefly.

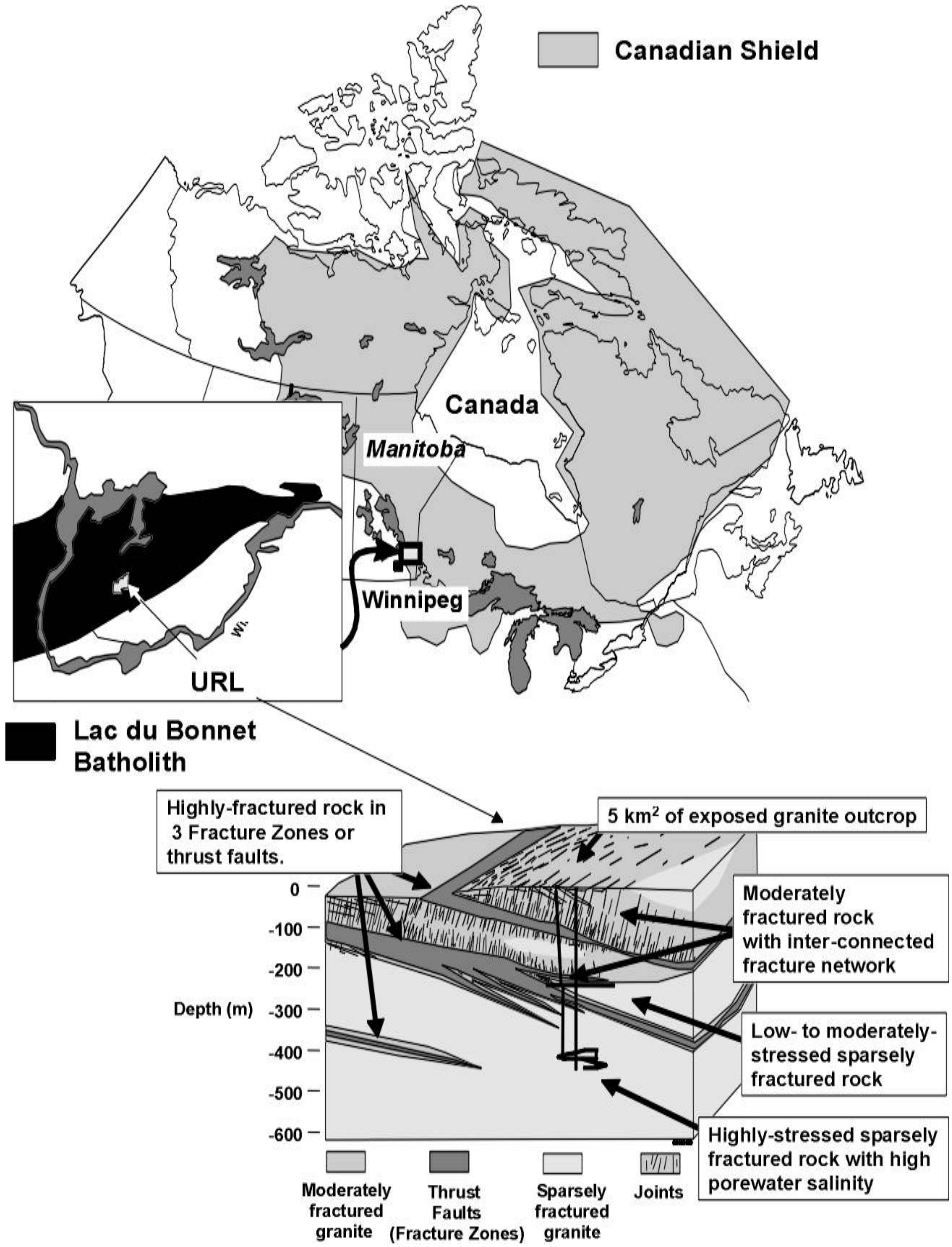

Fig. 1. The location of the URL within the Canadian Shield (above) and the Geologic Setting of the URL (below).

Siting Phase

The URL siting phase started in 1978. A regional reconnaissance was performed to identify a suitable location for an underground research facility on the Lac du Bonnet batholith. A small set of screening criteria was established for selecting a site. The site had to be larger than 1 km^2, be predominantly outcrop, and be undisturbed by previous excavations. The site had to be within, but not close to, well defined hydrologic boundaries. The site had to be accessible, near power, near AECL's Whiteshell Laboratories and available for lease. Eight potential sites were identified, with the current site chosen as the one best meeting the criteria (12).

Site Evaluation Phase

The site evaluation phase was carried out between 1980 and 1983. The objective was to develop an approach to characterization that would provide the necessary information for designing and constructing a repository in granite. The site evaluation phase also was directed at providing site-specific information for the design, construction and safe operation of the URL facility, and the design of experiments and interpretation of results. The evaluation phase involved surface mapping, airborne and ground geophysical surveys, surface water and meteorological data collection, and the drilling of shallow boreholes for piezometric measurements. Drilling of seven deep, cored boreholes and a number of shallower boreholes intended for use in a hydrogeologic monitoring system, followed these initial surveys (13). The detailed characterization revealed three low-dipping fracture zones that controlled the large-scale patterns of groundwater movement and groundwater chemistry within the rock mass (Fig. 1). The location of the shaft was specified in a region of moderate fracture zone permeability to allow access to proposed areas of future underground experiments. Based on the experience gained at the URL, an approach to underground characterization for a deep geologic repository has been developed (14). The objective of such a program would be to obtain information for optimizing the design of excavations and engineered barriers and to provide a baseline against which to monitor the performance of a repository during its operation and following its closure.

Construction Phase

Shaft collar excavation and construction of the surface facilities took place during 1982 and 1983. Excavation of the URL shaft to a depth of 255 m began on 1984 May 12 and continued for the remainder of the year. The URL excavations are illustrated in Fig. 2. The loop of horizontal excavations on the 240 Level (240 m below surface) and the raise-bored ventilation shaft were completed by 1987. The main shaft was extended to a depth of 443 m in 1988, followed by the excavation of the 420 Level and the ventilation shaft over the following three years. The URL construction phase (15) adhered to the observational method, following a design process similar to that followed on many large geotechnical construction projects. Design specifications were based on evolving characterization information. The primary objective was always to provide a safe and efficient underground research facility. The design-as-you-go (or observational) method was aimed at minimizing construction and operating costs, providing underground access to a variety of hydrogeologic and geomechanical environments, and accommodating development and evaluation of characterization techniques during construction. During all phases of URL development, research activities generally had priority over construction activities, although the objectives of both were not always divergent. The guiding principle was to maximize the benefit to the research program in order to best achieve the objectives set out for the URL.

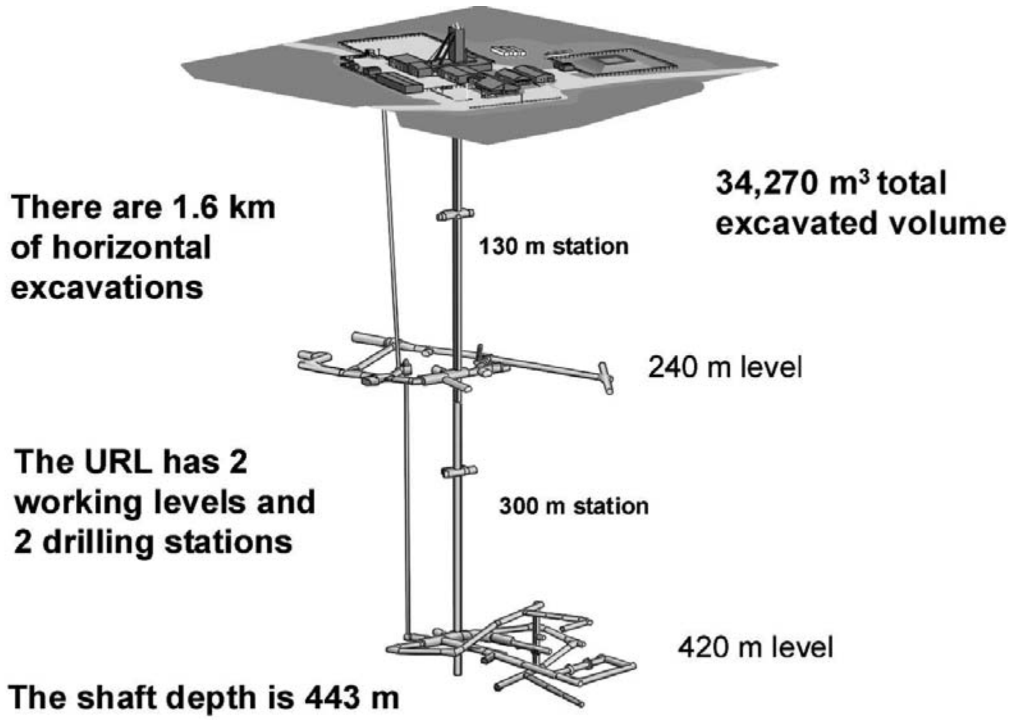

Fig. 2. Underground Research Laboratory Excavations.

Operating Phase

The program of URL operating phase experiments was developed in 1989 and underwent peer review by a panel of leading Canadian scientists (16). The peer review panel and the AECL experiment managers together defined experimental priorities and objectives, which were subsequently reviewed and approved by the URL Experiment Committee. The planned URL program included seven major operating phase experiments, and two experimental programs:

- Solute Transport in Highly Fractured Rock Experiment
- Solute Transport in Moderately Fractured Rock Experiment
- Grouting Experiment
- Buffer/Container Experiment
- Shaft Sealing Experiment
- Mine-by Experiment
- Multi-Component Experiment
- In situ Stress Program
- URL Characterization Program

The operating phase experimental program was initiated in 1990, six years after the beginning of URL shaft construction. As of 2002, seven of the nine operating phase experimental programs have been performed. The exceptions are the Grouting Experiment (although experimental grouting activities have been performed) and the Multi-Component Experiment, while the Shaft Sealing Experiment was redesigned to become the Tunnel Sealing Experiment. Over the years, the experimental program has expanded beyond the limitations of these nine experiments. Thirty-three URL experiments, or experimental programs, are either on going or completed. These are listed under four broad experimental categories in Table 1. Current experiments at the URL are noted by (*) in Table I.

The important conclusions from the completed portions of the experimental program are numerous, and discussed in detail in several reports that summarize experiment construction, operation, observations and conclusions (14,17,18,19,20,21,22,23,24,25,26).

Table I. URL Program of Experiments

Solute Transport	Dedicated microbial borehole and microbial studies*
in Highly Fractured Rock (HFR)	Concrete-rock interface study (CRIS)*
in Moderately Fractured Rock (MFR)*	**Excavation Damage/Excavation Stability**
Quarried Block Radionuclide Migration Experiment (QBRME)*	In situ stress measurement program and stress characterization in deep boreholes and fractured rock*
In Situ Diffusion Experiment*	Room 209 Excavation Response Test
EDZ Solute Transport Test	ANDRA Engineered Blast Feasibility Study
Recharge Infiltration Experiment (RIEX)*	Mine-by Excavation Response Test
URL Hydrogeological Monitoring*	Room 209 Connected Permeability Test
JAERI Rockmass Experiment	Heated Failure Tests (HFT)
Materials and Sealing Studies	Blast Damage Assessment Study (BDA)*
Buffer/Container Experiment (BCE)	Mine-by Connected Permeability Test
Isothermal Buffer-Rock-Concrete Plug Interaction Test (ITT)	Excavation Stability Study (ESS)
Fracture Zone Grouting Experiment	Thermal-Hydraulic Experiment (THE)
High Pressure Grouting Simulator	Thermal-Mechanical Stability Study (TMSS)
Large Concrete Blocks	**Multi-disciplinary**
Light Backfill Placement Trials*	URL Characterization Program
Seal and interface evaluation / effect of salinity (SEAS)*	Tunnel Sealing Experiment (TSX)*
Buffer-coupon long-term test (BCLT)*	Composite Seal Experiment (CSE)*
* Ongoing experiments in 2002.	Engineering Design of Repository Sealing Systems (ENDRES)*

URL OPERATING PHASE EVOLUTION AND CURRENT EXPERIMENTAL PROGRAM

The URL experimental program performed before 1997 had somewhat different objectives than the program performed subsequently. Public hearings for AECL's EIS were held in 1996 and AECL was given an opportunity to present field evidence from in situ experiments. Many experiments from the initial suite of large-scale experiments were completed by 1996, and the results of these experiments were very useful in addressing some of the concerns held by the Environment Assessment Panel after their initial review of the EIS documentation. Subsequently, OPG, as the principal waste owner, assumed responsibility for experimental programs that supported the plan for management of Canada's spent fuel.

This included experiments at the URL. Also during this time, organizations from Japan, France and the USA were collaborating on major experiments at the URL such as the Tunnel Sealing Experiment and the Quarried Block Radionuclide Migration Experiment (QBRME).

While experiments preformed prior to 1997 had the primary focus of demonstrating the safety and feasibility of AECL's concept for deep geologic disposal, as outlined in the EIS, the work after 1997 was directed towards addressing identified gaps in technologies required to construct and license a deep geologic repository. Much of the work performed at the URL is conducted as part of OPG's Deep Geologic Repository Technology Program, which is addressing issues in geologic characterization, safety assessment and repository engineering.

An example of the new direction in study is the Engineering Design of Repository Sealing Systems (ENDRES) project currently underway (27). The ENDRES project is designed to identify and address gaps in sealing technology. The overall objective is to define and develop an integrated set of engineering tools to optimize the design of repository sealing systems. These engineering tools are broadly categorized into three groups: numerical models; instrumentation; and physical tests for characterizing the performance of sealing components or sealing systems. This project attempts to link together the results of a number of in situ experiments, many of which are listed below. Specific gaps in the technologies required for engineering design of a repository have been identified. A number of projects (e.g. Composite Seal Experiment and the Blast Damage Assessment study) will be performed over a six-year period to address many of these gaps. Other ongoing experiments being performed at the URL are addressing identified technological gaps in safety assessment analyses (e.g. the Buffer-Coupon Long term Test, the In situ Diffusion Experiment).

The following is a brief description of the status of current URL experimental projects. The listed projects are being carried out in collaboration with OPG and a variety of other international partners.

Tunnel Sealing Experiment (TSX)

The TSX is now in its second phase. In the first phase, two full-scale tunnel seals, one comprised entirely of pre-compacted clay blocks and the other of high-performance concrete, were constructed and pressurized with water to 4 MPa (21). In the current phase of the TSX, the bulkheads are being heated first to 50ºC, and then to 80°C to examine the potential effects of a warming repository on seal performance. The current phase of the TSX is expected to run for 3 years before the experiment is disassembled with the seals inspected to more clearly identify factors that affect their performance.

Solute Transport in Moderately Fractured Rock Experiment (MFR)

The goal of the MFR experiment is to determine the applicability of equivalent porous medium-based models on flow and transport through rock with a fracture frequency of 1 to 5 per metre. Hydraulic tests and migration experiments are performed in approximately a 100,000-m^3 volume of moderately fractured rock using conservative, chemically reactive, and colloidal tracers.

In Situ Diffusion Experiment

Low permeability, sparsely fractured rock surrounding a deep geologic repository is an effective barrier to radionuclide mass transport. An understanding of diffusion processes within intact crystalline rock is required to reduce parameter uncertainty in mass transport calculations. The experiment consists of a program of in situ tests, supported by laboratory studies, to examine diffusion in sparsely fractured rock with the aim of establishing a database of effective diffusion coefficients. Injected tracers are allowed to diffuse into the rock from boreholes for about 12 to

14 months before overcoring to retrieve rock samples. The results of the in situ experiments are compared with laboratory diffusion studies.

Buffer-Coupon Long-term Test (BCLT)
The interactions between potential components of a used fuel disposal container (carbon steel, copper and uranium) and compacted bentonite or sand-bentonite buffer material under natural groundwater conditions are being studied. A series of 5-m deep boreholes have been drilled into a region of intact rock. A series of buffer-encapsulated coupons of the various materials have been installed in the lowermost metre of each borehole. Each assembly contains coupons of carbon steel in contact with copper, copper by itself, unirradiated uranium in an insoluble ceramic form, and a tracer within small discs of compacted sand-bentonite or pure bentonite. These installations will be recovered by overcoring of the surrounding rock, one borehole at a time, at various times over the next 3 to 20 years. On recovery, each of the coupons will be removed, examined for corrosion and biofilms and the surrounding buffer will be analysed to determine the distribution of corrosion products, microorganisms and the tracer concentration profile.

URL Hydrogeological Monitoring Program
The URL Hydrogeologic Monitoring Program records and maintains the hydrogeologic, hydrologic and hydrogeochemical data collected from the URL monitoring network on surface and underground. These include data from approximately 50 surface borehole and 360 underground packer-isolated intervals, as well as a meteorological station, and two rain gauges. The collected data are used to maintain the hydrogeologic database to observe long-term trends within the Lac du Bonnet batholith and to define background hydrogeologic, hydrologic and hydrogeochemical conditions for URL experiments.

Blast Damage Assessment study (BDA)
The energy imparted to the rock either by drill-and-blast excavation or by redistribution of the in situ stress field results in damage (fracturing or microcracking) in the rock adjacent to excavations. Understanding the development of damage near underground excavations is important to repository engineering design as rock damage can act as a preferred pathway for transport of water-borne contaminants along the perimeter of a tunnel. Previous damage studies have focused on the damage that occurs as a consequence of stress redistribution in a high stress environment. The BDA examines the damage around an 18–m-long tunnel in low-stressed rock, where blast-induced damage predominates. The objectives of the BDA are to provide quantitative data on the extent of blast-induced fracturing around tunnels in different stress environments; to assess the hydraulic connection of the damaged rock across successive blast-rounds; and to provide information on the growth of microbes from explosive's by-products.

Seal Evaluation and Assessment Studies (SEAS)
This work involves two series of laboratory tests performed at the URL surface facilities. A first series of laboratory tests examines the influence of permeant salinities up to 350 g/L (NaCl) on bentonite-based backfill materials of various compositions and densities. Hydraulic conductivity and swelling pressure are used as a measure of the ability of the backfill to function within a waste repository. A second series of tests examines the influence of interfaces between dissimilar sealing materials, or the surrounding rock, on mass transport under both saline and fresh water conditions.

Light Backfill Placement Trials
Pneumatic placement of backfill is proposed for sealing the upper portions of the rooms and tunnels in a repository. The material, termed light backfill, is likely to be composed

of sodium-bentonite clay and crushed granite. These Light Backfill Placement Trials include a series of placement tests, each performed in two parts: the standard pneumatic placement method and an in situ compaction assisted pneumatic placement method. Different sand-bentonite mixtures are being tested, with the objective to determine which compositions and textures of pneumatically placed materials can produce light backfills with sufficient density to produce positive swelling pressure upon saturation with either fresh or saline water.

Composite Seal Experiment (CSE)

The use of seals having both concrete and swelling clay components was proposed in the EIS reference documents (2). The CSE will provide information, at an intermediate scale, on compacted sand-bentonite material placed adjacent to high performance concrete within a single seal. AECL's Low-Heat High-Performance Concrete (LHHPC) (28) is used in the CSE as it has little or no free lime to react with other components of the sealing system. A planned series of tests in 1.24 m diameter boreholes will study the performance of seals with and without keys (excavated annular notches designed to cut-off excavation damage) in low stress-lower salinity and high stress-higher salinity environments. The first test has been constructed and pressurized to 2 MPa, while a second test is under construction. The experiments are also being used to test the longer-term performance of different instrumentation in representative, and possibly harsh, environments.

Dedicated Microbial Borehole/Microbial Studies

Biofilms were grown underground on granite coupons in pressure vessels hydraulically connected to three borehole zones for more than three years, under as close to borehole conditions as possible (i.e., pressure, redox conditions, temperature). These biofilms were subsequently sampled and analyzed to characterize their microbial content. Radionuclide sorption studies on these biofilms are also being conducted to estimate the effects that naturally occurring biofilms have on radionuclide migration in the geosphere. The biofilms grown on the granite coupons are not entirely natural as they were grown on coupons outside of the borehole, and it is desirable to microbially characterize undisturbed material from the fracture zone, and to compare these results with the coupon-grown biofilms. A dedicated borehole was drilled at the URL using steam-cleaned drilling equipment and UV treated drilling water from a URL fracture zone. This dedicated microbial borehole is a unique underground microbial characterization facility. Additional work at the URL includes microbial characterization of sealing materials for any of the in situ tests.

Recharge Infiltration Experiment (RIEX)

A study is being carried out on a rock outcrop in the URL lease area to evaluate the relationship between surface hydrological processes, groundwater recharge and paleohydrologic conditions. Initial groundwater monitoring in shallow boreholes (50-m depth) indicated strong vertical gradients exist in this upland recharge area as surface waters infiltrated and recharged the groundwater flow system. Data from long-term groundwater monitoring of wells in the area have also shown that recharge of the groundwater flow system can be concentrated in localized upland outcrop areas. A multi-level groundwater monitoring system has been more recently installed, and surface and subsurface samples are analyzed for ionic concentrations and environmental isotopes (^{2}H, ^{3}H, ^{18}O, ^{14}C). The infilling minerals from fractured rock samples are undergoing isotopic analyses to provide additional information on the paleoclimatic record of this study area.

Quarried Block Radionuclide Migration Experiments (QBRME)
The QBRME involves the physical and hydraulic characterization of a single, natural fracture in a 1-m^3 block of rock quarried from a hydraulically active subvertical fracture zone at the 240 Level of the URL. A facility has been constructed underground so that the transport solution can be taken directly from the fracture zone from which the block was removed, thus maintaining the in-situ geochemical and redox conditions of the fracture. The facility has been licensed by the CNSC to allow radionuclide migration experiments in the large blocks. Physical and hydraulic characterization data are used to develop a flow and transport model that will then be compared to the results obtained in migration experiments in the fracture using chemically reactive and conservative radioisotope tracers.

IAEA CENTRE OF EXCELLENCE

The Canadian URL is one of the IAEA centres of excellence for training in and demonstration of radioactive waste disposal technologies in underground research facilities. Other underground facilities in the network include the Waste Isolation Pilot Plant and Yucca Mountain in the USA, the HADES facility in Mol Belgium, and the Grimsel Test Site and Mont Terri Facility in Switzerland. The objectives of the IAEA network are to supplement national efforts and promote public confidence in radioactive waste disposal schemes, to contribute to resolution of key technical issues, and to encourage transfer and preservation of knowledge and technologies. The countries that intend to participate in network activities are those that have operating nuclear reactors but do not have ready access to underground research facilities. Participation will benefit all involved through sharing of technology and innovation, and through sharing of costs by collaboration. The Government of Canada has committed to help the success of this IAEA initiative by offering the use of both the URL facility and staff.

The IAEA annual meeting of both facility owners and interested participants was held in Winnipeg and at the URL in September 2002. Representatives from 20 countries on four different continents were in attendance. The outcome of the meeting set broad objectives for the network over the next ten year period and established training sessions, coordinated research projects and fellowships that will be held over the next year, with two of these training sessions planned to be hosted at the URL. URL staff understand that many of the countries who will ultimately participate in the network are not yet prepared for underground experimentation. However, AECL is prepared to make a long-term commitment to help the network realize its goals.

CONCLUSION

The URL is entering its 21st year of operation, with the surface facility construction beginning in 1982. Work conducted at the URL has contributed greatly to the Canadian nuclear fuel waste management program. Today, after performing large-scale in situ tests in the crystalline rock of the Canadian Shield for more than a dozen years, staff at AECL and the URL have a wealth of experience in solute transport, rock mass characterization, excavation design and engineered barriers within a wide variety of scientific and engineering disciplines. The work has been performed in support of not only the Canadian program but also of waste management programs for countries that do not have a dedicated underground research facility of their own. The key messages from this paper are not just that a great deal of important scientific work has been performed at the URL to date, but that the experimental program at the URL is still going strong, and will continue to have an important role to play in Canada, and internationally, well into the future.

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