Canadian Nuclear Society
Waste Management, Decommissioning and Environmental Restoration
for Canada's Nuclear Activities: Current Practices and Future Needs
Ottawa, Ontario, Canada, May 8-11, 2005

Demonstrating the Sealing of a Deep Geologic Repository: The RECAP Project

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ABSTRACT

Atomic Energy of Canada Limited (AECL) has operated an Underground Research Laboratory (URL) for twenty-three years (1982-2005). The URL was designed and constructed to carry out *in situ* geotechnical R&D needed for the Canadian Nuclear Fuel Waste Management program. The facility is now being closed, the final of several phases that have included siting, site evaluation, construction and operation.

The closure phase presents a unique opportunity to develop and demonstrate the methodologies needed for closure and site restoration of a deep geologic repository for used nuclear fuel. A wealth of technical background and characterization data, dating back to before the first excavation work was carried out, are available to support closure activities. A number of closure-related activities are being proposed as part of a REpository Closure And Post-closure (RECAP) project.

The RECAP project is proposed to include demonstrations of shaft and borehole sealing and monitoring as well as fracture sealing (grouting), room closure and monitoring system decommissioning, all activities that would occur when closing an actual repository. In addition to the closure-related activities, the RECAP project could provide a unique opportunity to conduct intrusion-monitoring demonstrations as part of a repository safeguards demonstration.

INTRODUCTION

The Underground Research Laboratory (URL) is situated in a granite batholith near the southwestern edge of the Precambrian Canadian Shield (Figure 1). Atomic Energy of Canada Limited (AECL) constructed the facility to provide a representative geological setting for research and development activities in support of the Canadian Nuclear Fuel Waste Management program[1]. Over 23 years of operation, AECL carried a comprehensive program of geotechnical characterization and underground R&D projects that provided data on the mechanical, thermal, geochemical, hydrogeologic and microbial properties of a granite pluton considered to be typical of the intrusive igneous rock widely distributed throughout the Canadian Shield.[2] Relationships between natural characteristics studied from surface (local and regional flow studies) and underground were assessed. Interactions between various engineered components and natural systems were modeled and evaluated. *In situ* measurement of excavation damage to the rock and investigations of alternative repository-sealing methods were carried out. Environmental surveillance and monitoring has been conducted throughout all phases of the URL. The results have been archived and are available for comparison with data collected during URL closure.

From its initiation in 1982, the work conducted at the URL has played an important role in establishing a nuclear fuel waste management program for Canada. Construction of the URL and characterization of the site, followed by an initial phase of large-scale *in situ* testing provided valuable information for AECL's Environmental Impact Statement (EIS)[3] on the Deep Geologic Repository Disposal Concept. After studying this and other related information, one of the conclusions of the Environmental Assessment Panel was that the safety of the disposal concept had been adequately demonstrated from a technical perspective and should be considered a viable option for the management of Canada's nuclear fuel waste[4].

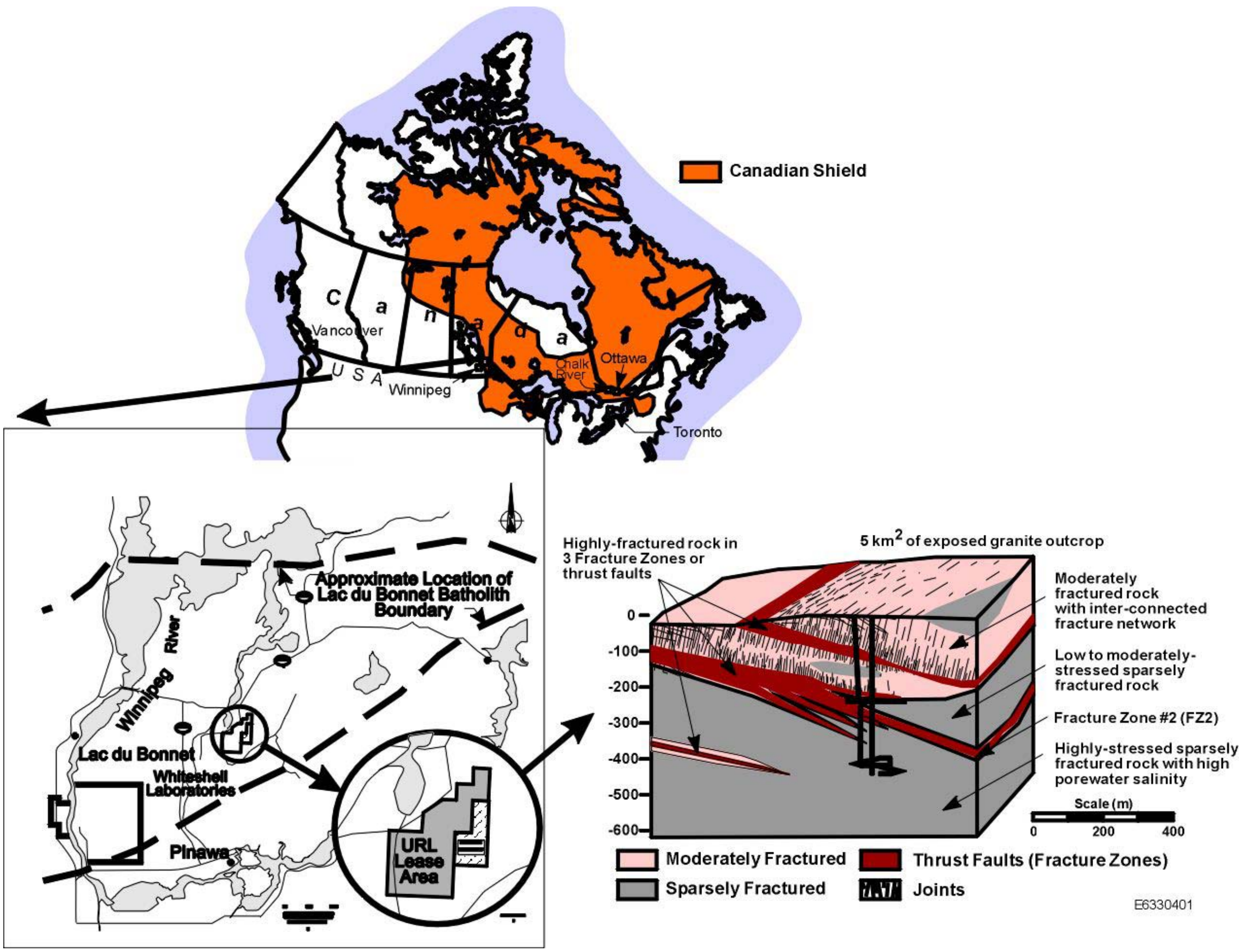


Figure 1: The location of the URL within the Canadian Shield (above) and the geologic setting of the URL.

Although a specific site or preferred siting region for a repository has not been identified in Canada, the URL has much to offer as a generic site for conducting studies into deep geological disposal of nuclear fuel waste. The site has interesting and varied geology and the underground excavations are intersected by two low-dipping thrust faults, or fracture zones (Figure 1). The blocks between the thrust faults define different structural domains that can be distinguished by the presence of compositional layering and xenoliths, the pattern and frequency of subvertical fracturing, differences in groundwater chemistry and wall rock alteration, and differing *in situ* stress regimes. Experiments conducted at the URL have utilized five geologic testing regions as identified in Figure 1:

1. Exposed granite outcrop on the surface of the 5 km^2 lease area;
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.

PHASES OF THE URL

The URL is now entering its final phase, which follows the siting, site evaluation, construction and operational phases. The siting, site evaluation and facility construction phases and the lessons learned in developing the operational phase experiments have been described previously[5,6], and will be discussed only briefly in this paper.

Siting, Evaluation and Construction Phases

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. Site evaluation was carried out between 1980 and 1983. The objective was to develop an approach to characterization that would provide the necessary information for optimizing the designs of excavations and engineered barriers and to provide a baseline against which to monitor performance of a repository in granite during operation and closure. The site evaluation phase was also 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 characterization involved surface mapping, airborne and ground geophysical surveys, surface water and meteorological data collection, the drilling of numerous shallow boreholes and the development of an extensive site-wide hydrogeologic monitoring array of boreholes ranging in depth from 150 m to 1500 m. Drilling of seven deep boreholes and a number of shallower boreholes, intended for use in a hydrogeologic monitoring system, followed these initial surveys[7]. Based on the experience gained at the URL, an approach to underground characterization for a deep geologic repository was developed[8].

The URL construction phase began in 1982 with the excavation of the shaft collar and construction of the surface facilities[9]. Excavation of the URL shaft began on 1984 May 12 and continued for the remainder of the year to a depth of 255 m. The loop of horizontal excavations on the 240-m-deep level and the raise-bored ventilation shaft was completed by 1987 (see Figure 2). The shaft was subsequently extended to a depth of 443 m in 1988, followed by excavation of the 420-m-deep level and the extension of the ventilation raise system over the following three years.

Operational Phase

The operational phase of the URL commenced with the planning of an experimental program in 1989[10]. The initial operating phase experimental program was started in 1990, six years after the beginning of URL shaft construction with seven major experiments and two experimental programs. Over the years, the experimental program expanded to thirty-three experiments and experimental programs[11].

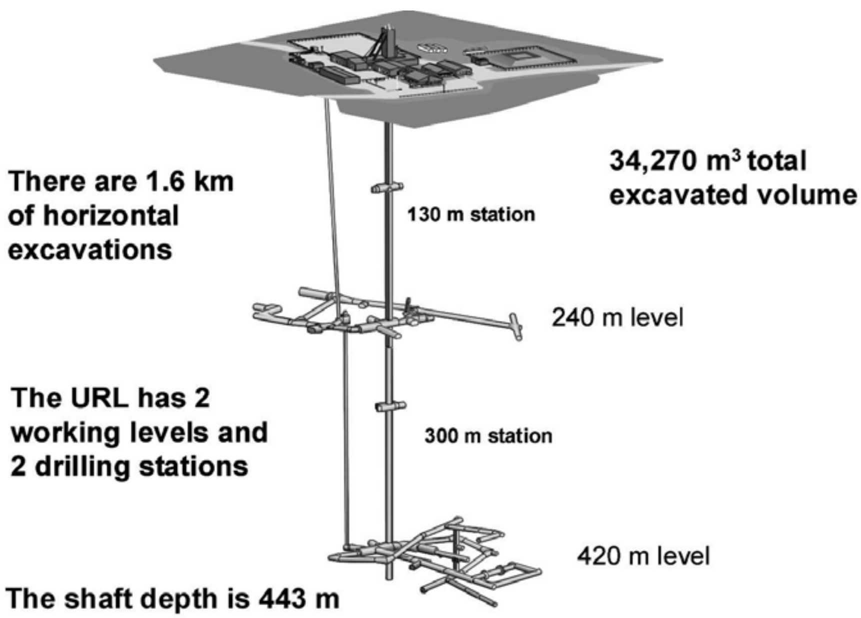


Figure 2: The Underground Research Laboratory excavations.

Closure Phase

The URL has now entered its closure phase. Legislative requirements, scope of work, and costs associated with the decommissioning and closure will be addressed in a decommissioning plan. Options, such as the use of the facilities by other organizations for new projects, can be addressed in the plan. Consideration can be given to accommodating activities such as the multi-disciplinary REpository Closure And Post-closure (RECAP) project which is aimed at addressing important engineering and performance assessment issues related to the final closure of a deep geological repository for radioactive wastes. Experiments can be designed to assess the long-term performance of the shaft and borehole closure sealing systems.

RECAP PROJECT

The closure of the URL presents a unique opportunity for studies directed at addressing important engineering and performance assessment issues related to the final closure of a deep geologic repository for radioactive waste. The permanent closure of the URL will require removal of monitoring equipment, sealing of boreholes and installation of concrete bulkheads on surface at the shaft and vent-raise openings. Permanent decommissioning of boreholes that intersect hydraulically active fractures is necessary in regions where there is a risk of establishing a connection between aquifers. For similar reasons, shaft and vent-raise plugs may be needed below the 240 Level of the URL to isolate Fracture Zone (FZ) 2 from the more saline groundwaters located at depth and the less saline groundwaters within Fracture Zone (FZ) 3 and the vertical fractures closer to surface. The 240 Level contains a number of other hydraulically significant fractures that may need to be isolated as part of a closure plan. Once all the underground activities have been completed, concrete bulkheads need to be installed in the shaft and ventilation raise at ground level to provide safe conditions on surface. Site monitoring will be carried out to ensure that the site meets environmental requirements after decommissioning.

The RECAP project will take advantage of the opportunities presented by the URL closure. The project consists of a number of multi-disciplinary activities that can be carried out in a staged multi-year program of closure and post-closure studies. Several RECAP project activities are associated with work identified as necessary to achieve a safe closure state for the URL, but will involve more extensive monitoring and upgrading to more closely represent the closure of an actual repository. The *in situ* measurements can be used to calibrate post-closure models. Specifically, the RECAP project presents an opportunity to:

1. Demonstrate through construction how shaft, borehole, tunnel and room seals could be emplaced at full-scale in a repository-scale environment.
2. Monitor the post-closure performance of seals, groundwater drawdown recovery and the post-closure host rock geochemical, microbial and hydraulic environment.
3. Test instrumentation systems proposed for long-term post-closure monitoring.
4. Seal a site that has varied geology (connected fracture systems, thrust faults, discrete fractures, and sparsely fractured rock).
5. Test retrievability concepts proposed for a deep geological repository.
6. Complete a full cycle of characterization on a site that was characterized before shaft excavation began, with more than 20 years of construction, operational, and decommissioning characterization information.
7. Investigate systems for repository safeguards, including intrusion detection monitoring.

Up to the present time, international waste management programs have mainly focused on preclosure performance of repository components. Little has been done to demonstrate how a repository would actually be closed and monitored and how characterization or operating phase monitoring instrumentation would be removed. The RECAP project is therefore being presented to interested participants as an opportunity for international cooperation in closure and post-closure studies. Participation may occur in three ways, depending on the specific interests and resources of the participants:

1. Complete participation in the design, construction and monitoring of the URL closure with the possibility for full access to sealing, monitoring and performance modeling information from the siting, site evaluation, construction, operational, decommissioning, and post-closure monitoring phases of the URL.
2. Participation in smaller, specifically defined work packages within the RECAP project (e.g., installing bulkheads, shaft plugs, borehole seals, and monitoring instrumentation).
3. Participation in a demonstration of post-closure monitoring and intrusion detection monitoring related to nuclear safeguards.

RECAP Closure and Sealing Studies

The URL is one of only a very small number of underground research facilities in the world where the host rock mass was geologically and hydrogeologically characterized prior to disturbance by shaft or tunnel excavation. This is representative of an eventual repository characterization approach and provides base-line data for comparison with post-closure monitoring data. Currently, the URL is the only dedicated facility available for a closure project.

In order for waste management organizations to obtain regulatory approval to begin construction on a site, demonstration that a repository can be safely closed, validation of computer codes to predict geosphere response surrounding the repository, and assurance that the closure design will meet regulatory requirements will be necessary. The RECAP project is primarily targeted at addressing these issues. Additionally, countries with organizations having less well-developed repository sealing programs may see the RECAP project as a means of fast-tracking the development of their repository sealing programs. Participating in a full-scale underground closure demonstration is an opportunity to gain experience in the planning, installation and monitoring of sealing components.

Much of the RECAP project will be located at or near the 240 Level, in close proximity to hydrogeologically sensitive regions containing various aquifers. An important aspect of the RECAP project can be focused on how siting and site evaluation information can be used for closure, such as the:

1. Application of characterization information from shaft sinking to design of shaft seals and for use in model predictions for post-closure hydrogeology, and
2. Assessment of the adequacy of existing data, the need for additional data if any, and lessons learned.

The specifications for seal and plug designs have not yet been developed and it is still possible for RECAP project participants to collaborate in the designs.

RECAP Shaft, Room and Tunnel Plugging Demonstrations

As part of a repository process, seals or plugs will be required in boreholes and underground openings to prevent flow from or between the various aquifers. The sealing systems required to isolate conductive regions remote from the URL shaft can be designed and the installation scheduled during the initial stages of URL closure. This will facilitate an enhanced design and provide for extended monitoring. Sealing these fractures can be accomplished with minimal interference from decommissioning activities.

Shaft seals can be installed to avoid intermixing groundwater from FZ2, located just below the 240 Level (Figure 1), with the underlying more saline groundwater. A possible generic design for these seals is provided in Figure 3. The RECAP project participants will be involved in the final design of the seals and monitoring systems.

The room and tunnel seals proposed for the 240 Level are associated with isolation of hydraulically active features that intersect the level or are connected to the level by boreholes. Locations and potential conceptual designs for these seals are shown in Figure 4. As with the shaft sealing activities, the final design and monitoring systems will be defined by RECAP project participants.

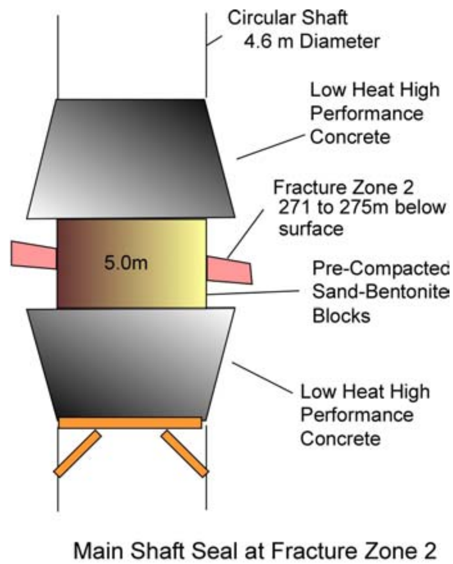


Figure 3: Shaft sealing concept proposed for the RECAP project.

RECAP Borehole Decommissioning and Sealing

The URL contains hundreds of boreholes, some installed from the surface but many drilled as part of the underground monitoring system, some of which are shown in Figure 5. Many of these intersect hydraulically sensitive or active fractures. Decommissioning and sealing of these boreholes will provide a considerable challenge and in many ways mimics what might be expected when a repository site is to be closed and sealed. A particular issue at the URL is how to recover borehole monitoring instrumentation and close boreholes intersecting FZ2 in the high flow regions (up to 600 L/min/borehole)[12]. Ultimately these boreholes will be decommissioned and monitoring will cease.

The timing of borehole decommissioning may depend on the URL closure schedule and RECAP project activities. An array of 20 to 25 surface-based boreholes is proposed to remain after the removal of the monitoring systems from the underground boreholes to monitor the long-term groundwater recovery and allow tracer, alkaline or other migration studies from surface. Most of the proposed boreholes are located within 500 m of the shaft (Figure 6).

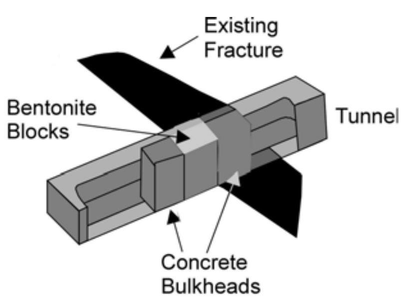
To evaluate the effectiveness of grouting operations, a hydraulically active region, such as FZ2, can be grouted to reduce flow to manageable levels and thereby facilitate monitoring system removal. The effectiveness of the grouting operation can be evaluated with monitoring systems installed in additional boreholes located in close proximity. The monitoring boreholes can then be sealed in a similar fashion. The effectiveness of the borehole seals can also be monitored. Figure 7 shows an example of how a borehole decommissioning, grouting and sealing demonstration can be conducted.

Retrievability Studies

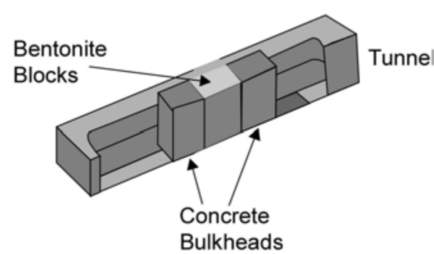
Some international waste management organizations are placing high importance on the reversibility of closure sealing system designs to allow future retrieval of used fuel from a repository if required. That is to say, each step of closure should be removable to allow access to previously closed portions of a repository. The RECAP project could be performed in stages, and experiments could be planned and implemented to address reversibility issues. Some approaches to experimental activities may include, (a) sealing of the lower Levels and FZ2 first, followed by, (b) a period of monitoring and sampling before applying lessons learned to sealing of the upper fracture zone (FZ3) in a second phase. Experiments could also be devised to access shaft and borehole seals several years after construction to evaluate the long-term performance of sealing materials and systems.

Full Circle Characterization

Environmental baseline data were first collected in 1982, before construction of the URL[13]. Environmental data have been collected routinely since that time and the influence of construction and operation activities have been reported in annual environmental monitoring reports[14].



a) Sealing of Intersecting Fractures



b) Tunnel Plugging

c) Options for Sealing of Hydraulically Sensitive Rooms

Figure 4: Room and tunnel plugging concepts proposed for the RECAP project.

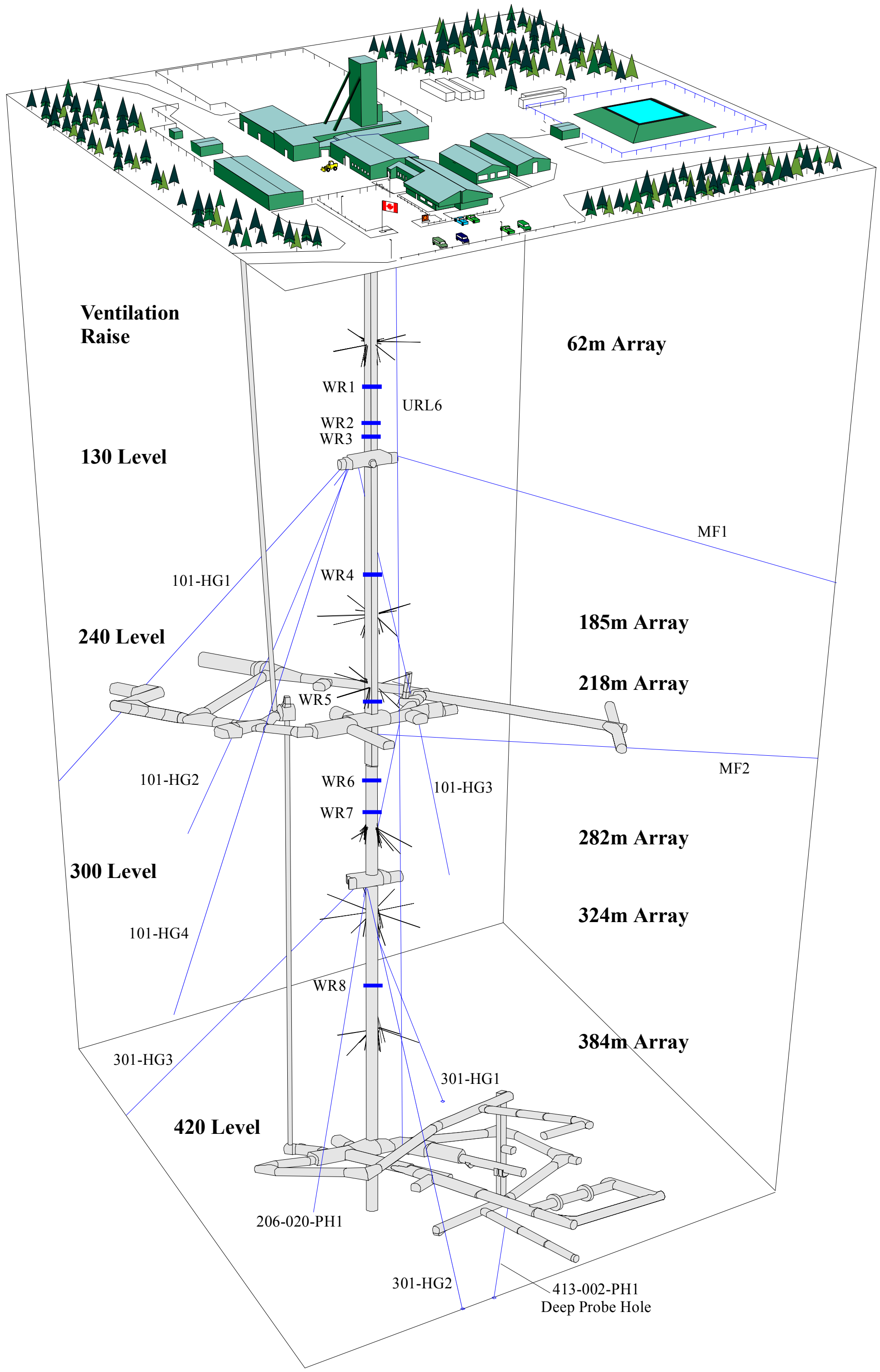


Figure 5: URL view showing some of the subsurface borehole monitoring system.

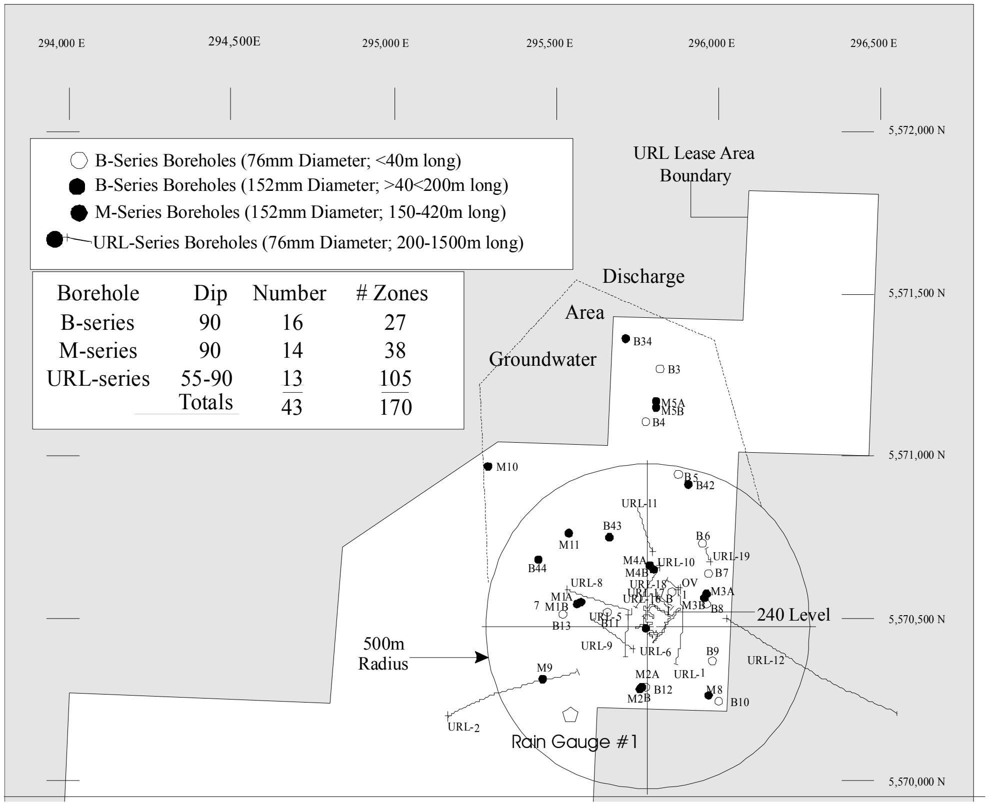


Figure 6: Surface monitoring boreholes proposed for post-closure URL.

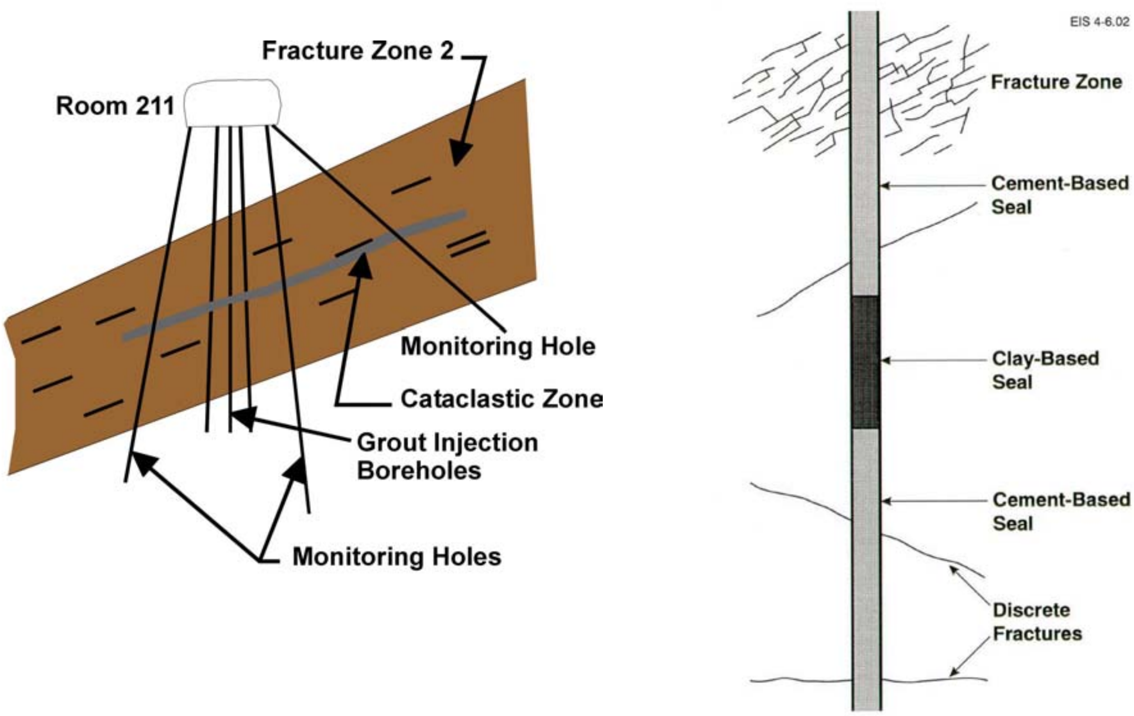


Figure 7: Decommissioning of boreholes intersecting hydraulically active features.

The RECAP project would contribute to a process for full-cycle characterization; that is, the environmental and characterization information collected during shaft sinking and tunnel construction can ultimately be applied to the design of closure seals and to numerical predictions of post-closure response of the geosphere. Developing processes for full-cycle characterization would be of great benefit to organizations constructing new underground laboratories or expecting to begin characterization for a deep geological repository in the near future.

Repository Safeguards

Construction of repository sealing systems and installation of long-term monitoring instrumentation can take into account proposed repository safeguards. The seals and instrumentation can be designed to deter inadvertent or intentional intrusion, and to monitor illicit tunneling and drilling activities or breaching of repository seals. This program can have direct benefit to international regulatory organizations responsible for repository safeguard systems.

CONCLUSION

The URL project, having gone through siting, site evaluation, construction and operational phases, is now entering a closure phase. This provides a unique opportunity to examine important engineering and performance assessment issues relating to the final closure of a deep geologic repository for radioactive waste. An enhanced series of closure activities (RECAP project) are targeted at addressing these issues. The proposed RECAP project is a multi-disciplinary project with planning, construction and long-term environmental monitoring phases that would be carried out in a staged multi-year program of closure and post-closure experiments as well as an extended period of environmental monitoring. Experiments can be designed, if warranted, to facilitate re-entry to examine long-term performance of seals and sealing systems. The RECAP project is of benefit to the international radioactive waste management community. As envisaged, the RECAP project can be implemented and managed by a joint consortium of international organizations.

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