Application of Controlled Blasting During the Construction of the Canadian Underground Research Laboratory

Gregory W. Kuzyk¹, Sangki Kwon²

¹Atomic Energy of Canada Limited, Pinawa, Manitoba, Canada, R0E 1L0
²Korean Atomic Energy Research Institute, Taejon, Korea

ABSTRACT

The Korean Atomic Energy Research Institute is currently planning the construction of an Underground Research Laboratory to carry out research and development related to the disposal of high-level wastes from nuclear reactors used to generate electrical power. This paper discusses the excavation methods used to construct the Canadian Underground Research Laboratory and their application in planning for the construction of a similar underground laboratory and eventually an underground repository for high-level wastes in Korea.

1. INTRODUCTION

Disposal in deep geological formations is currently considered in many countries to be the most rational way to manage high-level wastes (HLW) from nuclear power plants. In Korea, 19 nuclear power plants (15 PWR and 4 CANDU) are operating and produce about 40% of total electrical energy generated. The Korean Atomic Energy Research Institute (KAERI) is carrying out a long-term research and development project for developing technologies needed for the management of the HLW from the reactors.

According to the preliminary concept, the HLW will be encapsulated in corrosion resistant containers and disposed in the underground repository several hundred metres deep in crystalline rock. In order to safely dispose of all the spent fuels (about 36,000 tons), an underground area of approximately 4 km² area is required. The total length of shafts, access tunnels and emplacement rooms will be more than 100 km. Current plans call for most of the underground openings to be excavated by the drill and blast method (Kang 2000). Since the time required for the disposal operations will be several decades, it is necessary to consider the simultaneous construction of emplacement rooms and waste container emplacement operations in separate parts of the repository.

To guarantee the safety of the repository during construction, operation, and after closure, the stability of underground excavations from a geomechanical and hydrogeologic perspective is essential. The construction method used to excavate underground openings should minimize the possibility of damaging the surrounding rock to prevent formation of fractures that could become pathways for radionuclides to escape from the repository. The application of effective blasting techniques can minimize the impact of blasting on the rock mass.

The Canadian Underground Research Laboratory (URL) constructed by Atomic Energy of Canada Limited (AECL) played a major role in the development and validation of various technologies required for deep geologic disposal of HLW. It was constructed to a depth of about 450 m in the Lac du Bonnet Batholith, which contains medium to course-grained gneissic granite rock representative of intrusive igneous rock found throughout the Canadian Shield, see Figure 1. Areas of research, development and demonstration at the URL have included:

• Surface and underground characterization.
• Solute transport studies, groundwater geochemistry and microbiology.
• Analysis of temperature- and time-dependent deformation and failure characteristics of rock.
• Excavation damage assessment and excavation stability, including the development of controlled drilling and blasting.
• Development and performance assessment of clay- and concrete-based sealing material.
Thirty-three major experiments and experimental programs have been carried out at the Canadian URL (Chandler 2003).

At the URL, most of the openings were excavated with the drill and blast method. The method is flexible and cost effective in hard, igneous rock and can ultimately be used to excavate a repository for HLW. To ensure that the seals and bulkheads within a repository perform effectively, it will be beneficial to use controlled blasting methods that minimize damage to the final walls. Therefore, controlled blasting principles were integrated into the blast designs to demonstrate that tunnels can be excavated with minimal damage. This paper reviews the controlled blasting technology developed and demonstrated in crystalline rock at the Canadian URL.

2. GEOLOGIC SETTING OF THE CANADIAN URL

At the URL site, there are several fracture zones around thrust faults located as shown in Figure 1. According to the geological characterization carried out before and during construction, the number of fractures decreases with depth (Everitt et al. 1990). The in situ stress distribution is strongly influenced by the fracture zones. Before the excavation of the URL shaft, in situ stress was determined from 80 hydraulic fracturing tests conducted in 1981. More than 1,000 overcore tests were also performed to check the in situ stress distribution after the excavation of the URL. It was found that the horizontal stress magnitude increases almost linearly down to 270 m and then increases more rapidly below the fracture zone at the 270 m depth. The maximum horizontal stress at deeper locations having fewer fractures is 45-60 MPa, which is 4-5.5 times higher than the vertical stress. High saline pore water with salinity about three times higher than seawater is found in boreholes located at the 420-m-deep level (Gascoyne 2004). With a consideration of the geological, geochemical, and geomechanical characteristics of the URL site, several experiments were developed and performed in five distinctive regions identified in Figure 1.

3. URL CONSTRUCTION

The main underground excavations at the URL include a 443-m-deep shaft, major developments at the 240 and 420 Levels, shaft stations at the 130 and 300 Levels and a 1.8-m-diameter bored ventilation raise. Figure 2 shows isometric view of the URL. Shaft collar excavation and construction of the surface facilities took place between 1982 and 1984. Excavation of the shaft to a depth of 255 m began on 1984 May 12 and continued for the remainder of the year. The loop of horizontal excavations on the 240 Level and a bored ventilation raise to surface were completed by 1987. The shaft was extended to a depth of 443 m in 1988, followed by the excavation of the 420 Level and a ventilation raise to the 240 Level over the next three years.

Considerable time and effort was put into the preparation of relevant design specifications, development of appropriate contract formats and ongoing project management (Peters et al. 1990). Innovative equipment was utilized for construction activities and quality control procedures were implemented to ensure that data were reliable and made available to the research program during every step of construction. Research and construction activities were fully integrated to allow simultaneous collection of geotechnical information during excavation (Kuzyk et al. 1986a).
4. SHAFT SINKING

The shaft, sunk with a drill and blast method in two phases, utilized a benching method of advance in the upper rectangular section and a full-face method in the lower circular section (Kuzyk et al. 1990). During the first phase of sinking, it was found that the benching method did not adapt well to the controlled blasting method. The rectangular section proved to be a poor geometry because it resulted in stress concentrations and unacceptable damage at the corners. To improve on the quality of blasting, the shaft extension was excavated using a circular cross-section and a full-face method of advance. Controlled blasting principles were applied to the full-face blast designs. This change resulted in much less damage to the walls of the shaft and improved stability (Hagan et al. 1989, Kuzyk and Versluis 1989).

The rectangular section of the shaft extends from the surface to the depth of 255 m and has dimensions of 2.8 m x 4.9 m. The circular section, having a diameter of 4.6 m, was excavated from 255 m to 443 m. Figure 3 shows the bench and full-face blasting methods used for shaft sinking at the URL.

In the circular portion, two single-boom jumbos and a Cryderman mucker were set up on a Galloway sinking stage for drilling and removing broken rock. The Galloway stage was designed to integrate both shaft sinking operations and the geotechnical characterization activities (Kuzyk et al. 1986a). One shift per day was dedicated to geotechnical characterization activities while the remaining two shifts were used for shaft sinking operations. Generally, 3.7-m-long full-face blast rounds were advanced.

Figure 4 shows the blast design for the full-face round used to excavate a circular shaft configuration. The blast design was based on blast holes being drilled in four concentric rings. A total of 73 blast holes were drilled, six holes within the cut and 67 blast holes in the four rings. Blast holes
in the inner three rings were charged with high-strength ammonia gelatin dynamite used in production blasting. The perimeter blast holes in the outer ring were charged with a blasting product formulated for perimeter blasting application. Both products are nitroglycerine-based explosives.

Figure 3. Shaft excavation methods used at the Canadian URL.

Blast Geometry and Delay

Delay Allocation for Rings 1 to 4

Allocation in Cut and Helper Holes

Figure 4. Blast design for the excavation of the circular shaft.
5. LEVEL DEVELOPMENT

A drill and blast method was employed to excavate most of the tunnels, test rooms and ramps needed for geotechnical projects on the 240 and 420 Levels. The method is flexible and cost effective in hard, igneous rock and can ultimately be used to excavate a used nuclear fuel repository. To minimize damage to the final walls, controlled blasting principles were incorporated into the blast designs. Quality control and inspection procedures were also deemed to be imperative (Kuzyk et al. 1986b).

In the early stage of construction, the pilot and slash method shown in Figure 5(a) was applied. This method was very effective and produced good results from an excavation damage perspective. However, the tunnel had to be advanced in two steps, first by excavating a pilot heading and then by following with a slash. The typical advance per blast with this method was about 2.4 m. For improved performance, a full-face blasting method as shown in Figure 5(b) was applied in the later stages of construction. This eliminated the need to advance the tunnels in two steps. Although the full-face method was not as effective at reducing blast induced damage, the results were still very acceptable and much better than expected without the application of controlled blasting principles. With the application of the full-face method, the advance per blast increased to 3.5 m. A single boom electric-hydraulic jumbo drill was used to drill the blast holes. Further development of the excavation technology at the URL included a demonstration of long blast round technology that had more than 8 m of advance in a single blast. This work is discussed in Section 7.

6. TUNNEL BLAST DESIGNS

The controlled blasting designs were optimized during the development of the tunnels on the 240 and 420 Levels to produce high quality walls with minimal fracturing and over break. For the most part, tunnels at the URL are relatively small, having dimensions of about 3.5 m wide by 3.6 m high. Tunnel profiles have curved crowns and inverts to reduce stress concentrations around the perimeter and minimize stress related failure.

About 65 blastholes are drilled in each round (Figure 6 shows a typical arrangement). A triangular-shaped cut is advantageous because the blastholes are more widely spaced. Three relief holes are drilled and reamed to a diameter of 89 mm or 100 mm at the center of the face. The cut blastholes are positioned to reduce the effect of sympathetic detonation or dynamic pressure desensitization caused by the earlier firing charges. Blastholes, generally drilled 38-mm diameter, are charged with high-strength ammonia gelatin dynamite or pneumatically loaded ammonium nitrate explosive products. When charged with ammonium nitrate, blastholes are bottom initiated with an additional primer charge of dynamite to ensure a strong detonation front. Typically, 18 cushion and 21 perimeter blastholes are drilled. Low-shock-energy explosives and 11-mm-diameter high-strength detonating cord have been tested and found to be effective in the cushion and perimeter holes respectively, as fragmentation is primarily the result of energy provided by expanding gases. However, for ease of loading and other practical reasons, a product containing a blend ammonium nitrate and formed polystyrene beads has been used in the cushion holes as well. Regular long-period shock tube detonators having period from 0 to 18 are normally used but electronic detonators have also been tested and found to be very beneficial. The detonator delay sequence, charge mass per delay, burden and spacing are determined for specific blast patterns (Kuzyk et al. 1994).

7. LONG BLAST ROUND TECHNOLOGY

During the excavation of the tunnels shown in Figure 7 blast rounds lengths were increased to demonstrate that controlled blasting could be carried out in longer rounds as well. A total of six longer rounds were excavated. Rounds were increased in increments of about 1-metre to a final length
of about 8.7 m (Kuzyk et al. 2003). For the most part, blast designs for the longer rounds were consistent with those used for 3.5-m-long rounds, Figure 6 being typical. There were some exceptions, however. The drill pattern and charge configuration was adjusted to compensate for small changes in ground conditions.

![Diagram of tunnel excavation](image)

(a) 2.4m (Pilot and slash method)

(b) 3.5m (Full face method)

Figure 5. Tunnel excavation at URL.

The controlled blast designs produced a very high quality tunnel wall with minimal bootleg. Only minimal scaling of loose rock was required on the tunnel walls and crown. Ground support or protective screening was not required. Blast No. 216-05, shown in Figure 8, is typical of the performance of long blast round design. This blast broke a total of 8.54 m, which was the average length of the blastholes drilled in the round. There were no bootlegs in the centre of the round, indicating 100% pull. Fragmentation was very good, as can be seen from the photograph in Figure 9. The size of the muck was uniform, seldom exceeding 400 mm in size. The muck pile was level and evenly distributed. For the longer blast rounds, the muck-pile extended as much as 20 m from the face. The long uniformly sized muck-pile is very amenable to removal by continuous mucking systems. With the application of controlled blasting, very high quality tunnel wall with minimal bootleg can be achieved. Only minor scaling of loose rock was required on the tunnel walls and crown. Ground support or protective screening was not required.

8. CONCLUSIONS

The construction of an underground research laboratory for various disposal studies provides an excellent opportunity to demonstrate suitable excavation techniques that can be applied to the construction repository for HLW in Korea. To provide long-term stability during the operation of these facilities, rock damage by blasting must be minimized. When constructing a repository, it will be beneficial to minimize fractures surrounding the emplacement rooms, as they are potential...
pathways for the escape of radionuclides. Adapting controlled drilling and blasting principles can help achieve this objective.

It is also beneficial to demonstrate the robustness (versatility and adaptability) of the controlled drill and blast method, such as that done at the Canadian URL by excavating long blast rounds. It has been demonstrated that the advance could be increased up to 8 m with full face blasting. A very high quality tunnel wall with almost 100% pull can be achieved with long blast rounds. Rock fragmentation is also very satisfactory.

The results of the blasting methods demonstrated at the Canadian URL are dependent on the geological conditions, such as fracturing, *in situ* stresses, and rock properties. These results cannot be guaranteed by applying the same blast designs in the rock mass planned for the Korean underground research laboratory. It is, therefore, highly recommended that appropriate blasting techniques be developed for Korean conditions using the lessons learned at the Canadian URL.

![Figure 7. Schematic showing surveyed length of the long blast rounds.](image1)

![Figure 8. Blast No. 216-05: 8.63 metres in length.](image2)

![Figure 9. Fragmentation in a long blast round.](image3)
9. REFERENCES


