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Full Length Article

The Beishan underground research laboratory for geological disposal of high-level radioactive waste in China: Planning, site selection, site characterization and in situ tests

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ABSTRACT

With the rapid development of nuclear power in China, the disposal of high-level radioactive waste (HLW) has become an important issue for nuclear safety and environmental protection. Deep geological disposal is internationally accepted as a feasible and safe way to dispose of HLW, and underground research laboratories (URLs) play an important and multi-faceted role in the development of HLW repositories. This paper introduces the overall planning and the latest progress for China's URL. On the basis of the proposed strategy to build an area-specific URL in combination with a comprehensive evaluation of the site selection results obtained during the last 33 years, the Xinchang site in the Beishan area, located in Gansu Province of northwestern China, has been selected as the final site for China's first URL built in granite. In the process of characterizing the Xinchang URL site, a series of investigations, including borehole drilling, geological mapping, geophysical surveying, hydraulic testing and in situ stress measurements, has been conducted. The investigation results indicate that the geological, hydrogeological, engineering geological and geochemical conditions of the Xinchang site are very suitable for URL construction. Meanwhile, to validate and develop construction technologies for the Beishan URL, the Beishan exploration tunnel (BET), which is a 50-m-deep facility in the Jiujing sub-area, has been constructed and several in situ tests, such as drill-and-blast tests, characterization of the excavation damaged zone (EDZ), and long-term deformation monitoring of surrounding rocks, have been performed in the BET. The methodologies and technologies established in the BET will serve for URL construction. According to the achievements of the characterization of the URL site, a preliminary design of the URL with a maximum depth of 560 m is proposed and necessary in situ tests in the URL are planned.

1. Introduction

Safe disposal of high-level radioactive waste (HLW) is a challenging task for the sustainable development of nuclear energy and environmental protection. Geological disposal is considered to be a feasible and safe option for the long-term management of HLW worldwide, and many countries have considered building deep geological repositories (DGRs) in which to dispose of spent fuel or vitrified HLW. In order to investigate the suitability of geological rock formations such as crystalline, clay and salt rocks for hosting DGRs, to develop and test disposal concepts and technologies, to gain knowledge about thermo-hydro-mechanical-chemical-biological-radiological (THMCBR) processes in geological and engineered barriers, and finally to assess and demonstrate the long-term performance and safety of DGRs, a number of underground research laboratories (URLs) have been constructed around the world (Kickmaier and McKinley, 1997; Nuclear Energy Agency (NEA), 2001; Zhang et al., 2006; Wang, 2007).

URLs can generally be divided into generic URLs and site-specific URLs. Generic URLs are facilities developed for research and testing purposes at a site that will not be used for waste disposal, while site-specific URLs are facilities developed as a potential site for waste disposal and a precursor to the development of a repository at the site (Nuclear Energy Agency (NEA), 2001; Ahn and Apted, 2010). Over the past few decades, generic URLs have been developed within pre-existing underground excavations, such as mines and tunnels, e.g. the Grimsel test site and Mont Terri road tunnel in

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Switzerland and the Tournemire facility in France. There are also purpose-built generic URLs in specific rock types, such as the Äspö Hard Rock Laboratory in granite in Sweden and the Whiteshell URL in granite in Canada. The site-specific URL may be constructed either adjacent to or within the proposed repository location. Site-specific URLs include the ONKALO URL in granite in Finland, the Meuse/Haute Marne URL in claystone in France (Delay et al., 2010), the Gorleben URL in salt in Germany, and the ESF in volcanic tuff in the United States (Nuclear Energy Agency (NEA), 2001).

In 2014, the concept of the area-specific URL was firstly proposed by Wang (2014). An area-specific URL is a facility at a site within an area under consideration for a HLW repository, or located near a future repository site, and may be a precursor to the development of a repository at the site. The area-specific URL acts as both generic URL and site-specific URL to some extent. It aims to investigate host rock suitability, conduct general research and development (R&D), guide the layout of disposal tunnels and the design of the repository, and demonstrate technological operations. When a general area has been identified as the first top priority area for a repository, but a specific site has not been selected, an area-specific URL can be built as long as the site has similar geological, hydrogeological, engineering geological conditions and environments to those of a future in-depth repository site. The area-specific URL has a potentially important role, i.e. if the site characterization and experiments conducted in the URL demonstrate that the site is suitable for a repository, the process of selecting and confirming the site will be accelerated (Wang, 2014). Meanwhile, all experience and investigation results obtained from such a URL can be transferred directly to the future DGR in the selected area.

The development of URLs is one of the most important stages in national geological disposal programs. With the rapid development of nuclear energy in China, challenges with respect to the safe disposal of HLW are increasing. To meet these challenges, China plans to build a URL for the geological disposal of HLW around 2020. This paper introduces the overall planning, site selection, site characterization and in situ test plan for China's first URL.

2. Overall planning for China's URL development

The Chinese government has decided that the installed capacity of nuclear power plants (NPPs) will reach 58 GW by 2020, with an additional 30 GW under construction (The State Council of China, 2012). The spent fuel generated from those NPPs will reach 83,000 tons by 2050. The Chinese policy for HLW disposal is that the spent fuel from light-water reactors should be first reprocessed, then vitrified, and finally geologically disposed. The preliminary repository concept proposed is a shaft-tunnel model located in saturated zones of granite (Wang, 2010; Chen et al., 2012; Liu et al., 2014; Zhao et al., 2014a). The Chinese strategy for HLW disposal can be characterized by three typical stages: (1) laboratory studies and site selection for the HLW repository (2006–2020), (2) underground in situ testing (2021–2040), and (3) repository construction (2041–2050). One of the major milestones is to complete the URL construction by 2020 (China Atomic Energy Authority (CAEA), 2006).

The 13th Five-year Plan for the National Economy and Social Development of China (2016–2020) determined that "*the construction of China's URL should start before 2020*", while the completion of the URL construction will be around 2024. The successful construction of the URL relies on the overall planning including a definition of the strategy, a technical road map, functions of the URL, a plan for in situ tests, and technical preparations.

2.1. URL strategy

As introduced above, URL types include generic URLs, site-specific URLs and area-specific URLs. It is presently not necessary for China to build a generic URL. If we plan to build a site-specific URL, the site for the future repository has to be selected. However, it is difficult to have a repository site right now because of the long approval process. The most suitable option is thus to build an area-specific URL (Wang, 2014). With this basic understanding, the major considerations of the URL strategy are as follows:

(1) To build an area-specific URL in a representative granite formation within the area that has been identified as having the greatest potential for a geological repository in China.
(2) The URL will be a large-scale facility with full functionality.
(3) The URL will be about 500 m deep, similar to the depth of the future repository.
(4) The URL should be expandable.
(5) The URL will serve for technology development and demonstration, site characterization, and public acceptance.
(6) The URL will be open to domestic and international cooperation in the R&D of HLW repositories in granite.

2.2. Technical road map

On the basis of a nationwide comparison and intensive consultation, the China Atomic Energy Authority (CAEA) and the Ministry of Environment Protection (MoEP) decided in July 2011 that the Beishan area in Gansu Province can be regarded as the first priority area for China's HLW repository. This important decision has provided a sound basis for URL site selection. The technical road map for the construction of the "Beishan URL" is divided into four stages:

(1) Site selection and characterization for the URL;
(2) A feasibility study for the URL;
(3) Preliminary design and detailed design for the URL; and
(4) Construction of the URL.

In stage 1, site selection and characterization for the URL was mainly conducted in the Beishan area during 2016–2017. Candidate sites from Xinjiang and Inner Mongolia regions were also considered for a comprehensive comparison.

During the feasibility study stage, the site will be confirmed, preliminary approval from the local government of Gansu Province and the MoEP will be obtained, data needed for design will be acquired, and other specific reports, such as an environment impact assessment report and a safety assessment report, will be prepared. Design criteria for the URL will also be determined.

2.3. Functions of the Beishan URL

The following functions are planned for the Beishan URL:

(1) To characterize the deep environment of the representative Xinchang granite site, including geological, hydrogeological, geochemical and geomechanical conditions;
(2) To develop and demonstrate disposal concepts by conducting full-scale experiments;
(3) To develop technologies and equipment for excavation and construction of the repository, emplacement of HLW canisters, backfilling and sealing of boreholes, tunnels and shafts, and to evaluate the cost of repository construction;