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On area-specific underground research laboratory for geological disposal of high-level radioactive waste in China



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ABSTRACT

Underground research laboratories (URLs), including “generic URLs” and “site-specific URLs”, are underground facilities in which characterisation, testing, technology development, and/or demonstration activities are carried out in support of the development of geological repositories for high-level radioactive waste (HLW) disposal. In addition to the generic URL and site-specific URL, a concept of “area-specific URL”, or the third type of URL, is proposed in this paper. It is referred to as the facility that is built at a site within an area that is considered as a potential area for HLW repository or built at a place near the future repository site, and may be regarded as a precursor to the development of a repository at the site. It acts as a “generic URL”, but also acts as a “site-specific URL” to some extent. Considering the current situation in China, the most suitable option is to build an “area-specific URL” in Beishan area, the first priority region for China’s high-level waste repository. With this strategy, the goal to build China’s URL by 2020 may be achieved, but the time left is limited.

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1. Introduction

With the rapid development of nuclear power in China, the disposal of high-level radioactive waste (HLW) will soon become an import issue of nuclear safety and environment protection. It means how to safely dispose of the HLW resultant from the reprocessing of spent fuel of nuclear power plants and the HLW produced in defence industry in the past.

HLW is a specific waste generated in nuclear industry, with tremendous potential harms to the human environments, because it contains Np, Pu, Am, Tc and other radioactive elements which are highly radioactive, toxic, heat-generating and with long half-life. Therefore, safe disposal of HLW becomes an important issue for the sustainable development, the environment protection and the happiness of our future generations.

In 2012, the Chinese government updated its mid-long term plan for nuclear power plant (NPP) development (The State Council of China, 2012), that is, the installed capacity of NPP should reach

58 GW by the year of 2020, while other 30 GW under construction, and the electricity produced by NPPs will account for 4% of the installed capacities in total. In such case, the spent fuel generated from those 58 NPPs will reach 82,630 tons by 2050. The HLW generated from the reprocessing of the spent fuel from those power plants must be disposed of in a safe manner. Meanwhile, certain amount of high-level liquid waste has been generated from the defence industry, and has been in interim storage facilities for several ten years. Those liquid wastes need to be vitrified and safely disposed of as early as possible.

Geological disposal is currently considered as the technically feasible and safe manner for long-term management of HLW, and many nuclear countries have considered to build geological repositories to dispose of the spent fuel or vitrified HLW. The engineered system of the repository is designed to complement the natural geological barrier and to provide primary physico-chemical containment of the waste. The overall disposal system is designed to be passively safe in the long term and thus to impose a minimal burden on future generations.

However, lack of actual implementation experience for geological repository and the need to ensure the permanent safety of the repositories have resulted in construction of many underground research laboratories (URLs) in many national radioactive waste disposal programmes (NEA, 2001; Wang, 2007). In the URLs, the characterisation, testing, technology development, and demonstration activities are carried out (NEA, 2001; Zhang et al., 2006). Those URLs are essential to provide scientific and technical information and practical experience that are needed for the design and construction of disposal facilities and, most importantly, for safety assessment.

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A URL plays a very important role in the development of geological repositories. Generally, URLs include “generic URLs” and “site-specific URLs”. Facilities developed for research and testing purposes at a site that will not be used for waste disposal are called “generic URLs”, while those as a potential site for waste disposal and a precursor to the development of a repository at the site are called “site-specific URLs”.

This paper first introduces the latest progress of URLs in major waste management programmes, and then proposes the strategy for China’s URLs. Furthermore, a preliminary plan to build China’s URL, an “area-specific URL” in the Beishan area, Northwest China, which is the first priority area for China’s HLW repository, is discussed.

2. Progress of underground research laboratories development in the world

A URL may be a purpose-built facility in which large research programmes may be undertaken, or a quite simple facility, for example, attached to existing underground facilities such as high-way tunnels, hydropower tunnels. The host rocks of URLs include granite, salt, clay, shale and tuff. The URLs may be constructed at depths of a few hundred to one thousand metres underground or at shallower depths.

URLs provide a platform for understanding the hydrologic, thermal, mechanical, chemical and biological characteristics and the coupled processes that will control the performance of natural and engineered barriers of a geological repository. In addition, URLs allow the development of technology needed for construction, operation and closure of a repository, as well as the demonstration of that technology and overall repository concept. URLs may also be used to verify the long-term performance of engineered barriers and monitoring systems (Rothfuchs et al., 2010). Most importantly, a URL provides access to the deep geological environment under realistic repository conditions.

Once constructed, a URL can act as a focus for a dedicated research and demonstration programme related to repository development. URLs also provide unique chance for international co-operation projects.

2.1. The types of URLs

There are generally 2 types of URLs: generic URL and site-specific URL.

2.1.1. Generic URL

Generic URL is a facility built for research and testing purposes at a site that will not be used for waste disposal but provide information that may support disposal elsewhere. Generic URLs may be developed to obtain general experience of underground construction techniques, model testing, verification of measurement techniques, and characterisation of host rocks for future repositories. These types of URLs have been developed within pre-existing underground excavations such as mines and tunnels, for example, the Grimsel Test Site and the Mont Terri road tunnel in Switzerland, the Tournemire facility in France. There is also a purpose-built generic URL in a specific rock type, such as the Äspö Hard Rock Laboratory in granite in Sweden, the Whiteshell URL in granite in Canada.

2.1.2. Site-specific URL

Site-specific URL is a facility built at a site that is considered as a potential site for waste disposal and may be a precursor to the development of a repository at the site. It is developed to gain information and experience on the repository site. The site-specific URL may be constructed either adjacent to, or within the

proposed repository location. This type of URL may be partially or completely subsumed within the repository. Site-specific URLs may be aimed at confirming the suitability of the host rocks, guiding the layout of disposal tunnels and design of the repository, and demonstrating the technological operations. Also, a lot of general researches and developments may be carried out in it. Such 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, the ESF in volcanic tuff in USA (NEA, 2001).

2.2. The major function of URLs

URLs are an important stage of national geological disposal programmes as they provide unique and critical technical experience, knowledge and confidence in geological disposal. The general functions of URLs include:

- (1) To help facility siting and disposal-system design: siting a repository in a rock mass with favourable isolation properties, developing durable, long-lived waste containers compatible with the geological environment, and developing robust engineered barriers.
- (2) To support repository design by underlying scientific and engineering research: through R&D to provide the information necessary for design, verify the characteristics, and assess the performance of the disposal system.
- (3) To evaluate and demonstrate the safety: to develop tools to evaluate and demonstrate the performance and safety of the repository under different possible future scenarios.

More specifically, the functions of URLs include:

2.2.1. Characterisation

- (1) To conduct in-situ investigations in order to understand geostress, geological, hydrogeologic, geochemical, structural, and mechanical properties of the host rocks, to understand the deep underground environment and its response to imposed changes.
- (2) To obtain samples and data required for safety assessments and other R&D activities such as radionuclide migration experiments, rock property tests and repository design.
- (3) To develop specific devices and equipment for site characterisation and verify their applicability and reliability.
- (4) To determine the reliability of surface-based methods of site characterisation.

2.2.2. Tests

- (1) Tests of the reliability of different site characterisation methods.
- (2) Tests of engineered materials such as containers and buffer materials.
- (3) Tests of excavation methods for future repository construction.
- (4) Tests of in-situ radionuclide migration.
- (5) Tests of the conceptual and numerical models that are used to assess the performance of the repository system and/or its component parts.

2.2.3. Technology development

Technology development includes the development of equipment, techniques, and expertise for characterisation, testing, repository construction, waste emplacement, construction of engineered barriers, and repository closure.

2.2.4. Demonstration

Basically, it is the demonstration of (a) the feasibility of the repository design and (b) the behaviour and performance of various components of repository at full- or reduced-scale and under real and/or simulated repository conditions, for example, demonstrations of sealing and waste emplacement and retrieval techniques.

2.2.5. Training of personnel

The URLs may be used as a training centre for personnel for future disposal working and repository operation.

2.2.6. Confidence building

A URL may also act as an exhibition centre for the public, government officers, scientists and international visitors. The confidence of the public may be enhanced after their visit to the URLs by understanding the concepts and functions of engineered and natural barriers of the repositories.

In a word, a variety of activities may be carried out in URLs, ranging from basic research to development of a pilot waste-disposal facility, which give URL important functions for the development of geological repositories.

Some examples of experiments performed at URLs are given in Table 1.

2.3. The current trends of URLs in the world

It has been more than 40 years since the first URL in the world was put into operation in the Asse Salt Mine in Germany in 1965. The achievement from the URLs has greatly promoted the development of disposal techniques and the implementation of disposal programmes. Especially, the site-specific URLs have played an important role in confirming repository site and gaining licences from regulatory authorities (Kickmaier and McKinley, 1997; NEA, 1999).

With the operation of current URLs and the huge number of experiments conducted, many useful data have been collected and practical disposal technologies have been developed, thus confidence in geological disposal has been gradually built, at least in the community of waste management. The current URLs have shown the following trends:

- (1) The current URLs are focussing on various long-term experiments under simulated repository conditions, full-scale demonstration and verification experiments of disposal system, prototype repository tests and confidence building tests.
- (2) More and more concentration is focused on the refinement of site characterisation methods, collection of key data for performance assessment and safety analysis.
- (3) More emphasis is imposed on gaining of actual operation experiences for future repository.
- (4) More emphasis is on international cooperation, cost sharing and results sharing.
- (5) The important role of URL in gaining the public support and confidence in geological disposal has been recognized at a very high level.
- (6) Concerning those experiments aims at collection of general data, and their importance is decreasing.

3. A new concept: area-specific URL

Based on the descriptions mentioned above, it can be clearly seen that the existing URLs in the world are classified into 2 types: generic URLs and site-specific URLs. They are either related or not related to the future repository sites.

Table 1

Technical information obtained from URLs (NEA, 2001).

Objectives	Examples
Development of methods and equipment for underground characterisation and testing of the reliability of different methods	<ol style="list-style-type: none"> (1) Ventilation experiment, cross-hole hydraulic and seismic tests, borehole radar, and validation drift experiments at Stripa; (2) Extensometer development at URL, Canada; (3) Development of equipment and procedures for brine permeability tests in halite at WIPP; (4) Brine migration test at Asse.
Further development and testing of excavation techniques	<ol style="list-style-type: none"> (1) Demonstration of technical feasibility of drilling galleries in plastic clays at HADES; (2) Comparison of tunnel boring machine to drill and blast excavation techniques at Äspö and Grimsel; (3) Demonstration of deep borehole drilling technique at Asse; (4) Studies of the performance of disposal technologies at Olkiluoto.
Quantification of impacts of excavation on host rocks	<ol style="list-style-type: none"> (1) Excavation-damaged zone experiments at Äspö, Grimsel and WIPP; (2) Disturbed zone studies around blasted tunnel and drilled disposal holes in Olkiluoto Research Tunnel; (3) The coupled thermo-hydro-mechanical experiment in the Whiteshell URL.
Application of site-exploration strategies to adapt underground systems as more information is acquired	<ol style="list-style-type: none"> (1) Fracture mapping and hydraulic measurements to select locations for full-scale deposition holes in Olkiluoto Research Tunnel; (2) Application of geophysical methods at Grimsel, Tournemire and Stripa.
Determine reliability of surface based methods of site characterisation	<ol style="list-style-type: none"> (1) Comparison of permeability-test results from deep boreholes with in-situ permeability tests at WIPP; (2) Comparison of pre-excavation predictions to properties found in tunnel at Äspö.
Testing and development of conceptual and numerical models of processes potentially relevant to radionuclide transport through rock	<ol style="list-style-type: none"> (1) Radionuclide Retardation Project at Grimsel; (2) Unsaturated zone transport tests at Yucca Mountain; (3) Solute transport and diffusion experiments at URL, Canada; (4) Gas-threshold-pressure tests at WIPP; (5) Tracer retention programme at Äspö.
Simulation of effects caused by emplacement of radioactive waste (heat, nuclide release, mechanical impact)	<ol style="list-style-type: none"> (1) Study of the effect of heat and radiation on clay at HADES; (2) Thermal simulation of drift emplacement at Asse; (3) Heater tests at Stripa, Yucca Mountain, WIPP, and Grimsel; (4) Thermal-structural interactions tests at WIPP; (5) Thermo-hydro-mechanical tests at URL, Canada.
Demonstration of engineered barrier systems (feasibility)	<ol style="list-style-type: none"> (1) Borehole sealing and buffer mass tests at Stripa; (2) Full-scale engineered barriers experiments at Grimsel; (3) Development of borehole seals for HLW canisters at Asse; (4) Buffer and container testing at URL, Canada; (5) Small-scale seal performance tests at WIPP; (6) Repository sealing experiments at HADES.

(continued on next page)

Table 1 (continued)

Objectives	Examples
Experiments related to long-term processes, post-operational phases, corrosion, geomechanical stability, etc.	(1) Concept demonstration for disposal in clay at HADES; (2) Coupled thermo-hydro-mechanical processes test at Kamaishi; (3) Materials interface interactions tests at WIPP; (4) Backfill and material behaviour at Asse; (5) Thermo-hydro-mechanical tests at URL, Canada.

For a country without a URL for geological disposal studies, it has 3 options to follow:

- (1) To construct a generic URL in a suitable place.
- (2) To select a repository site first, followed by construction of a site-specific URL.
- (3) To conduct experiments in URLs that are operated in other countries.

However, in China, these three options are not suitable for the geological disposal programme for HLW.

- (1) If a generic URL is constructed, it may not be costly. However, considering that it is generally constructed within pre-existing underground excavations, the restrictions in the design of in-situ research plan and the layout of research facilities make it inconvenient for scientists to work and for the public to visit. Moreover, the experiments in such URL may only be copies of those experiments conducted in other URLs, while the data obtained will only act as references for repository design and safety assessment. Although a URL is built, a site-specific URL must be built in the future repository site, suggesting that such a URL is not an appropriate option for China.
- (2) Constructing a site-specific URL has many advantages as described above. This type of URL will not only be used to confirm a site, but also all the data from the URL and the experiment conducted in the URL will be used for design and safety assessment. Furthermore, demonstration of disposal can be conducted within it, possibly evolved into a real geological repository. However, the construction of such URL will significantly depend on whether the repository site has been approved or licenced. If the site is not approved, this type of URL cannot be built. Considering the situation in China at present, it will not be soon for China to determine a final site for geological repository. Without a site, a site-specific URL cannot be constructed soon, thus the establishment of China's URL will be delayed consequently.
- (3) Using abroad URLs to conduct experiments is also an option for China. It has the advantages to conduct related experiments necessary for us in the well-equipped URLs and we have chances to share and exchange experiences with international experts. Also, the Chinese scientists can be well trained through practical underground experiments. However, taking part in the experiment in other URLs will be very costly, and merely limited experiments rather than systematical experiments can be conducted. In addition, the data used for China's repository design will be limited, thus it would not be a good choice for China right now, although China will consider joining some of experiments in other URLs. Therefore, a concept of "area-specific URL", or the 3rd type of URL, is proposed in order to satisfy

China's current need for R&D for geological disposal, further contributing to promotion of China's repository programme.

An "area-specific URL" is referred to as the facility built at a site within an area that is considered as a potential area for HLW repository, or built at a place near the future repository site, and may be a precursor to the development of a repository at the site. It acts as a "generic URL" and as a "site-specific URL" to some extent. It can be aimed at confirming the suitability of the host rocks, conducting general research and development, guiding the layout of disposal tunnels and design of the repository, and demonstrating the technological operations.

The establishment of an area-specific URL depends on whether a repository site is determined, but not fully depends on whether the site is selected. It means, in the case that the repository area has been roughly confirmed, even though the repository site is not finally determined, the site for the area-specific URL can be selected there. As long as the site has similar geological, hydrogeological, engineering geological conditions and environments in terms of future in-depth repository site, the area-specific URL site can be determined. As this type of URL is a kind of specific research facility which does not have a very close relation with future repository, the URL site of this type may be approved quickly.

The area-specific URL has a potential important role, i.e. if the site characterisation and experiments conducted in the URL have proven that the site is suitable for a repository, the process to select and confirm a site will be accelerated accordingly.

4. The feasibility to build China's area-specific URL

As discussed above, the optimum option for China is to build an "area-specific URL". This paragraph describes the possibility to build an "area-specific URL".

4.1. Progress in site selection in China

Site selection for China's HLW repository began in 1985, an important step in the China's HLW disposal programme. The whole siting process was divided into four stages: nationwide screening, regional screening, area screening and site confirmation. During the siting process, the following factors were considered: socio-economic factors and natural factors, including political support, population, economic potential, plant/animal resources, mineral resources, land use, local public acceptance, geological/hydrogeological conditions and engineering geological conditions. Since 1985, the following activities have been conducted for site selection (Wang et al., 2004, 2006; Wang, 2010).

- (1) Nationwide screening (1985–1986): According to the preliminary siting criteria, five regions have been selected as the potential regions: southwestern China, eastern China, Inner Mongolia, southern China and northwestern China.
- (2) Regional screening (1986–1989): Based on the results from the first-stage screening, further investigation was conducted and 21 candidate areas were selected. In northwestern China, the Beishan area in Gansu Province is considered as the most important area.
- (3) Area screening (1990–present): Since 1990, most efforts have been made on the Beishan area. Studies include regional crust stability, tectonic evolution, lithological studies, hydrogeological studies and preliminary geophysical survey. However, site selection for a HLW repository started in Xinjiang Uygur Autonomous Region in 2012.

4.2. The feasibility to build China's area-specific URL

In early 1990s, China initiated the feasibility study to build a generic URL. Site selection for the URL was conducted in Beijing area, and 2 sites (e.g. Yangfang and Sihuyu) were selected for investigation. However, the consideration to build a generic URL in Beijing was suspended in 1995, and no more considerations to build a generic URL were mentioned since then.

Considering many generic and site-specific URLs developed in other countries and experiences obtained, China should, from the strategic point of view, build a site-specific URL in order to gain experiences and provide data for repository design and safety assessment. However, although China has determined that the Beishan area is the first priority area for HLW repository, the exact location of the site has not been fixed and licenced. Thus it is not suitable for China to build a site-specific URL at present.

Considering it would be easier for China to determine a potential region or the first priority region for HLW repository, it will be possible for China to build an “area-specific URL” in the “first priority region”, i.e. building an URL in Beishan area, the first priority region for China's HLW repository. In July 2011, the China Atomic Energy Authority, together with the Ministry of Environment Protection, approved that the Beishan area is “the first priority area” for China's HLW repository. The approval has laid a solid basis on building an “area-specific URL” in Beishan area.

4.3. The characteristics of the Beishan area

The Beishan area, located in northwestern China's Gansu Province, has been selected as the most suitable area for China's HLW repository because of its favourable socio-economical and natural conditions. The Beishan area is characterised by extremely sparse inhabitants, no useful farm land, poor mineral resources, poor animal and plant resources, poor economical potential, but with convenient transportation conditions.

Within the area, 8 granite intrusions have been chosen as candidate subareas for HLW repository. Among them, 3 subareas (Jiujiang, Xinchang–Xiangyangshan and Yemaquan) have been selected as the most potential subareas.

During 1999–2013, surface geological, hydrogeological and geophysical surveys and borehole drilling were conducted in Jiujiang, Yemaquan and Xinchang–Xiangyangshan granitic subareas. 11 deep boreholes and 8 shallow boreholes (BS01–BS19) have been drilled and a series of borehole tests, such as pumping tests, injection tests, borehole televiewer and borehole radar survey, water-sampling and geo-stress measurement were conducted. Results show that the granite massifs have enough volume in terms of good integrity and favourable engineering conditions.

4.3.1. Geology of Beishan area

The topography of the area is characterised by flatter Gobi and small hills with elevations ranging between 1000 m and 2000 m above sea level. The height variation is usually several tens of metres. The crust in the area is of block structure, with the crust thickness of 47 km–50 km. The seismic intensity of the area is lower than Grade VI and no earthquakes with $M_s > 4.75$ were recorded in history. Since the Tertiary's period, it is a slowly uplifting area without obvious differential movement. Those geological characteristics show that the crust in Beishan area is stable, and has a great potential for the construction of a HLW repository. Surface geological mapping, surface geophysical survey and borehole investigation have shown the good integrity of the granitic rock mass in Jiujiang, Xinchang–Xiangyangshan and Yemaquan subareas. The Jiujiang subarea has an area of 380 km², bore drilling of BS01 and BS03 shows a good integrity of granite.

Deep boreholes of BS06, BS17, BS18 and BS19 were drilled in Xinchang subarea (with an area of 110 km²). The drilling results also show that the rock mass is of extremely high quality, and the RQD (rock quality designation) values of rock cores from those 4 boreholes are higher than 98, except for several fractured zones. In Beishan area, the dominant rocks are porphyritic monzonitic granite and tonalite. The deep intact rock of Beishan area is of high density, low porosity, high strength, low strain and high brittleness.

4.3.2. Hydrogeology of Beishan region

The Beishan area is an arid Gobi desert area, with an average annual precipitation of 70 mm, while annual evaporation of 3000 mm. More important, there is no yearlong stream and other surface water bodies in the area. Therefore, the Beishan area is also poor in groundwater resources. Pumping tests have shown that the outflow rates are less than 50 m³/d in most of the surface wells. The present water table in the potential site area is 28–46 m below ground surface. Chemical analysis shows that the groundwater in Beishan area is of Cl–SO₄–Na type, with pH value of 7–9, while the total dissolved solid (TDS) is larger than 2 g/L. In-situ water sample from borehole BS03 at depth of 440 m shows the TDS value is 4.15 mg/L, pH value is 7.58, while the dominant ions are Na⁺, Cl[–] and SO₄^{2–}.

4.3.3. Permeability of rock mass

Permeability study shows that the hydraulic conductivity of rock mass in boreholes BS06, BS17, BS18, BS19 at Xinchang subarea ranges between 6.6×10^{-10} m/s and 3.9×10^{-14} m/s, suggesting that most of the borehole sections have extremely low permeability, except in the sections of 139.97–150.30 m, 170.22–180.55 m and 210.22–220.55 m in depth. Considering the moderate in-situ stress and extremely low permeability, the host rocks could be an excellent place for the construction of disposal facility and for the permanent isolation of radionuclides.

4.3.4. In-situ stress

In-situ stresses have been measured in Beishan area in 9 deep boreholes by using hydraulic fracturing method. The results show scatter in the stress profile with depth, but the trend that the stress increases with the depth is apparent. For those boreholes, the minimum horizontal stress ranges between 4.54 MPa and 12.77 MPa, while the maximum horizontal stress ranges between 6.94 MPa and 19.59 MPa, belonging to middle stress range.

4.3.5. Suitability of the Beishan area

The obtained data show that the Beishan area has positive socio-natural conditions for the construction of a HLW repository. Further performance assessment study has also shown the suitability of the area (Zhou et al., 2013a). The assessment model was developed based on the FEP (features-event-process) analysis and scenario development for the “normal scenario” (Zhou et al., 2013b), i.e. the expected evolution of such a repository. The repository concept is a KBS-3 multi-barrier variant having shaft-tunnel access, with vitrified HLW glass encapsulated in a carbon-steel overpack surrounded by a bentonite buffer located in saturated zones within granite. The natural barrier consists of nearly intact near-field granite within fractured far-field granite. The biosphere is a desert environment with no agriculture and limited grazing activities due to poor water resources. The assessment period for radionuclide releases extends from the end of a 1000-year containment period to up to 10⁶ years. Three variants for the “normal scenario” are also assessed, including no sorption by corrosion-products, a new highly transmissive fractured zone forming within the intact repository host rocks, and impacts arising from heterogeneous flow paths in the host rocks. The results show that, for the reference case (with

nearly intact host rock) no release of radionuclides to the biosphere is observed. For the extremely conservative variant scenarios, calculations indicate limited radionuclides reaching the biosphere over a million year period with insignificant annual dose, and the maximum annual dose from a single waste package is only 1.45×10^{-4} Sv per year.

There are about 26 URLs across the world, built in different host rock types including granite (the Äspö URL, the ONKALO facility, the Mizunami URL, etc.), claystone (the Meuse/Haute-Marne URL), stiff clay (the HADES facility), rock salt (the Gorleben facility, the WIPP facility), tuff (the Yucca Mountain's ESF), etc. Compared with those URL sites, Beishan site has a great potential for the construction of a HLW repository. Also, the Beishan area can be regarded as the first priority area for China's first URL, while an "area-specific URL" can be built in a location within this area.

If the concept to build an "area-specific URL" is approved by the government, the exact location of the URL site may be determined within 3–5 years. Next, a feasibility report can be compiled based on detailed site investigation, design, environment impact assessment and safety assessment. With the approval of the government authorities and regulatory organizations, detailed engineering design and construction can be started. The construction may need 3–5 years. If all thing goes well, the goal to build China's first URL for geological disposal of HLW by 2020 (CAEA, 2006) will be reached.

5. Conclusions

- (1) URLs, including "generic URLs" and "site-specific URLs", are underground facilities in which characterisation, testing, technology development, and/or demonstration activities are carried out in support of the development of geological repositories. Facilities developed for research and testing purposes at a site that will not be used for waste disposal are called "generic URLs", while facilities, developed at a site that is considered as a potential site for waste disposal and may be a precursor to the development of a repository at the site, are called "site-specific URLs". The existing URLs have played very important roles in the development of geological repositories in their host countries.
- (2) Besides the generic URL and site-specific URL, a concept of "area-specific URL", or the 3rd type of URL, is proposed. It is referred to as the facility that is built at a site within an area that is considered as a potential area for HLW repository or built at a place near the future repository site, and may be a precursor to the development of a repository at the site. It acts as a "generic URL" and also as a "site-specific URL" to some extent. It can be used to confirm the suitability of the host rocks, to conduct general research and development, to guide the layout of disposal tunnels and design of the repository, and to demonstrate the technological operations.
- (3) Considering that it would be easier for China to determine a potential region or the first priority region for HLW repository, it will be suitable for China to build an "area-specific URL" in the "first priority region".
- (4) Systematic characterisation and performance assessment have shown that the Beishan area has favourable socio-natural conditions for building a HLW repository. Accordingly, the area was considered as the "first priority region" for a HLW

repository by the government in 2011. Thus, it has a great potential to build an area-specific URL in the Beishan area.

- (5) China has set up a goal to build a URL by 2020. With the strategy to build an "area-specific URL" in Beishan area, the goal by 2020 may come true, but the time left is limited.

Conflict of interest

I wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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