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DEEP GEOLOGICAL DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES IN CHINA

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Abstract：The background，the preliminary technical strategy and the long-term plan for China′s high-level radioactive waste disposal program are presented. China started research on HLW disposal in 1985，with a plan to build a national repository in the middle of the 21st Century. Beishan area，located in Northwest China′s Gansu Province，is selected as the most potential area for China′s HLW repository. During 1999－2004，preliminary site characterization evaluation has been performed，including surface geological，hydrogeological and geophysical investigation，and drilling of 4 boreholes (BS01，BS02，BS03，BS04) and in-situ tests in boreholes. Favorite results have been obtained from the site characterization campaign. Progresses are also made in studies on buffer/backfill materials，radionuclide migration and natural analogue.

Key words：high-level radioactive waste；geological disposal；Beishan site；long-term plan；site characterization
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中国高放废物深地质处置

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摘要：介绍了中国高放废物地质处置计划的背景、初步技术战略和长远规划。中国的高放废物地质处置研究始于 1985 年，计划于 21 世纪中叶建成国家高放废物处置库。位于我国西北甘肃省的北山地区被选为最有远景的处置库预选区。1999～2004 期间，在该区开展了初步的场址特性评价研究，包括地表地质、水文地质和地球物理调查、4 口钻孔(北山 1$^{\#}$，2$^{\#}$，3$^{\#}$及 4$^{\#}$孔)的施工及钻孔现场试验，并获得了大量成果。在缓冲回填材料、放射性核素迁移以及天然类比等方面也取得了进展。

关键词：高放废物；地质处置；北山场址；长远规划；场址评价

1　INTRODUCTION

With the rapid increase of economy in China recently，the shortage of electricity is becoming a major issue problem in some coastal provinces in the past 3 years. These situations made the Chinese government change its policy to nuclear power plant

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At present，there are 5 NPPs in operation on the Chinese mainland：the Qinshan，Qinshan－II and Qinshan－III in East China′s Zhejiang Province，the Daya Bay and Lin′ao in South China′s Guangdong Province. Together with the Tianwan(2 units) under construction，the total electrical capacity produced by the NPPs will be 9.13 GW by 2006，which accounts for 1.6 % of the whole installed electricity capacity in Chinese mainland，while the electricity produced accounts for 2.29%.

In order to safely dispose of the high-level radioactive waste generated from the nuclear power plants and other nuclear facilities，the former Ministry of Nuclear Industry proposed a preliminary long-term program and has been conducting research for the final disposal of high-level radioactive waste since 1985[1]. In August 2005，the China Atomic Energy Authority (CAEA)，which is the government organization in charge of radioactive waste disposal，held the “Workshop on Geological Disposal of High-level Radioactive Waste”，during which a revised long- term program was proposed，with the objective to build China′s high-level radioactive waste repository in about 2050.

In China，the State Environment Protection Administration(SEPA) is the regulatory body. The implementation activities related to radioactive waste disposal are currently managed by China National Nuclear Corporation(CNNC)，while Beijing Research Institute of Uranium Geology(BRIUG) is the leading institute at the present stage.

It is estimated from the Chinese nuclear power plan that the spent fuel accumulated only from light water reactors will be 1 000 t by 2010，while 2 000 t by 2015. Later than 2020，about 1 000 t of spent fuel will be produced each year. There is also another type of spent fuel—the one from CANDU reactors，which are in operation in Qinshan－III nuclear power plant. The annual amount of spent fuel U generated is about 200 t.

The spent fuel from light water reactors in China will be reprocessed first，followed by verification and final disposal. The preliminary concept for China′s repository will be a shaft-tunnel model，located in saturated zones in granite. China has been built a pilot reprocessing plant，which will be put into operation in 2008. The siting for a commercial reprocessing plant will begin soon，while it is planned to be built in about 2020.

2 STRATEGY FOR HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL AND LONG-TERM PLAN

In 1985，CNNC proposed a research and development(R&D) program for the deep geological disposal(DGD) of HLW[1]. The program was divided into four phases：(1) technical preparation phase；(2) geological study phase；(3) in-situ test phase；and (4) repository construction phase. The objective of the program was to build a national geological repository in granite by 2040 that can dispose vitrified waste，transuranic waste and HLW from decommissioning.

In the earlier years，due to the shortage of experiences，there was no exact technical strategy for the development of HLW repository. However，great efforts have been put on fundamental researches，while the importance of generic underground research laboratory(URL) has been recognized. Those URLs were used only for methodological studies，such as the Stripa Mine and the Äspö URL in Sweden，the Asse Salt Mine in Germany，the Grimsel Test Site and Mt. Terri URL in Switzerland，the URL in Canada，the HADES facility in Mol，Belgium，the Tono Mine and the Kamaishi Mine in Japan.

Based on the experiences obtained in other countries，and considering the situation in China，a preliminary 3-step(Site-URL-Repository) development strategy for the HLW disposal in China was proposed[2]：(1) site selection and site characterization；

(2) construction of a site-specific URL at the potential site for HLW repository； and (3) the construction of HLW repository(see Table 1). While fundamental and supporting researches，such as performance assessment，backfill material，radionuclide migration，natural analogues，technology for construction，sealing and closure of a repository are conducted at the same time.

Table 1 Preliminary long-term plan for the implementation of China′s high-level radioactive waste repository

Activities	Phase 1 (2001 – 2020)	Phase 2 (2020 – 2040)	Phase 3 (2040 – 2050)
	Site selection and site confirmation	URL construction and in-situ tests	Repository construction
Site selection and site characterization	Area/site selection，surface investigation，borehole drilling and test，complete site confirmation	Supplementary work for site characterization	Monitoring of the site
Underground research laboratory(URL)	Feasibility study，URL site recommendation，and design of URL	Construction of URL，in-situ tests & demonstration of disposal technology	Part of in-situ tests，monitoring of repository
HLW repository	Conceptual design	Preliminary design and detailed design	Construction completed around 2050
Research and development	Studies on radionuclide migration，engineered barriers，performance assessment methodologies	Studies on in-situ tests，radionuclide migration，engineered barriers，construction technologies	Studies on repository closure，monitoring，etc.

2.1 Step 1

During Step 1，nationwide site screening，regional screening，sub-regional selection，deep geological environment study，site characterization will be conducted；and the objective of this stage is to select a final site and to confirm the site. At present，the Beishan area，located in Northwest China′s Gansu Province，is selected as a potential area for China′s HLW repository. Within the Beishan area，three granite sections(Jiujing，Xiangyangshan—Xinchang，and Yemaquan) are considered as the most favorable sections. In the period of 1999 – 2004，surface geological，hydrogeological，geophysical survey and borehole drilling were conducted in the Jiujing and Yemaquan granite section，while in the next 5 years(2006 – 2010) similar work will be conducted for the other sections.

2.2 Step 2

During Step 2，an URL will be built at the site which has been selected during the Step 1. This URL will be served both as a methodological study and as for site evaluation.

2.2 Step 3

During Step 3，a final repository will be built at the site. It also might be built based on the previous URL.

This 3-step strategy could be a time-saving and money-saving strategy，because large amount of methodological results from foreign URLs are available now，and a generic URL may not be truly necessary for China′s program. However，this 3-step strategy is still under discussion among the scientists and government officials；and it has not been determined as the national strategy.

In 2003，the International Atomic Energy Agency (IAEA) held an international conference on geological repositories in Stockholm. During the conference，Mr. Zhang Huazhu，the chairman of CAEA announced that China is planning to build a national high-level radioactive waste repository in middle of the 21st century[3].

Base on the 3-step strategy and the consideration of CAEA，a preliminary long-term plan for the implementation of China′s high-level radioactive waste repository is proposed in Table 1. It is estimated a site-specific URL at Beishan will be constructed between 2015 and 2020，while a national repository will be constructed around 2050.

3 PROGRESS IN SITE SELECTION AND SITE CHARACTERIZATION

3.1 Site selection

Site selection，started in 1986，has been an important part in China′s HLW disposal program. The whole siting process was divided into 4 stages[4，5]：nationwide screening，regional screening，area screening and site confirmation. During siting process，the following factors have been considered：social-economic factors and natural factors，including political support，population，economical 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：

(1) Nationwide screening(1985－1986)

According to the preliminary siting criteria，five regions have been selected as the potential regions：Southwest China Region，East China Region，Inner Mongolia Region，South China Region and Northwest China Region.

(2) Regional screening(1986－1989)

Based on the results from last stages，further investigation conducted，with a result of selecting 21 candidate areas. In the Northwest China Region，the Beishan area in Gansu Province is considered as the most important area.

(3) Area Screening(1990－present)

Since 1990，most of the efforts have been concentrated on Beishan area，Gansu Province. Studies include regional crust stability，tectonic evolution，lithological and hydrogeological experiments and preliminary geophysical survey. At the same time，possible host rock types for the repository was also investigated，with the conclusion that the granite is the most suitable one for China′s repository.

3.2 Site characterization

Since 1990，the efforts have been concentrated on the Beishan area. Researches include regional geological setting，crust stability，geological characteristics，hydrogeology and methodological studies for site characterization. The IAEA assisted China′s site characterization program through its technical cooperation projects.

Within Beishan area，8 granite sections have been chosen as candidate sections for HLW. Among them，three sections(Jiujing，Xiangyangshan—Xinchang and the Yemaquan) have been chosen as the three most potential sections.

During 1999－2004，site characterization were conducted at the Jiujing Section and Yemaquan Section. Surface geological，hydrogeological，geophysical investgation，drilling of four boreholes(BS01，BS02，BS03，BS04) and a series of borehole tests，such as pumping tests，injection tests，borehole televiewer and borehole radar survey，sample-taking and geostress measurement have been conducted. Favorite finding have been obtained，which provided important data on evaluation of the suitability of the Jiujing Section and Yemaquan Section.

Through the four deep boreholes in the two sections for geological research，hydrogeological experiments and in-situ geostress measurement，rock and groundwater samples and deep geological environment parameters have been obtained. The suitability of the region was evaluated through a series of site characterization methods，the effectiveness of those has been proved. This provided reference to similar work and formulation of standards in the future. Good experiences have been accumulated to evaluate sites in fracture granite media in arid area.

According to China′s program，once it is recognized that the Beishan area is suitable，an underground research laboratory(URL) will be built there；and more detailed site evaluation，in-situ tests，underground experiments will be conducted. The URL will both serve as methodological laboratory and site confirmation tool；and furthermore it might be developed into an actual HLW repository.

3.3 Geology of Beishan area

The Beishan Area，Gansu Province，is the preselected area for China′s high-level radioactive waste repository. The crust in the area is of block structure，with the crust thickness of 47 to 50 km. The seismic intensity of the area is below than Grade VI，and no earthquakes with $M_s > 4.75$ is seen to take place. The topography of the area is characterized by flatter Gobi and small hills with elevations above sea level ranging between 1 000 and 2000 m. The height deviation is usually several tens meters. Since Tertiary it is a slowly uplifting area without obvious differential movement，the geological characteristics of the Beishan area show that the crust in the area is stable；and it has a great potential for the construction of a high-level radioactive waste repository[6].

In the area，8 granite sections have been selected as potential sites for the future URL and HLW repository：

(1) Jiujing；
(2) Xinchang；
(3) Xiangyangshan；
(4) Yemaquan；
(5) Qianhongquan；
(6) Yinmachang—Beishan；
(7) Xianshuijing；
(8) Baiyuantoushan—Heishantou.

3.4 Hydrogeology in Beishan

The Beishan region is poor in groundwater resources. Pumping tests carried out by local geological teams in the 1980s in the area have shown that，for most of the wells，the outflow rates are less than 50 m^3/d. Beishan groundwater can be divided into three categories：(1) an upland rocky fissured unit；(2) a valley and depression pore-fissure unit；and (3) a basin pore-fissure unit. The upland rocky fissured unit is the most prevalent one in this area.

3.4.1 Upland rocky fissured groundwater

This is the most important water type in the Beishan region，occurring in weathered and structural fractures. Groundwater recharge is primarily from precipitation infiltration，with discharge mostly through evaporation and lateral outflows into the fracture water-bearing zones，intermountain areas，and valley depressions. The present water table in the potential site area is 28－46 m below the surface.

3.4.2 Valley and depression pore-fissured groundwater

In the Beishan region，valley and depression topography is generally coincident with the fault zones. This water is commonly more abundant than in other areas. The water table is shallower，with depths of 2－8 m below the surface. The water is mainly recharged by infiltration of rainfall and temporary seasonal floods，and the main discharge includes evaporation and runoff towards the basin and the Hexi Corridor.

3.4.3 Basin pore-fissured groundwater

This groundwater is mainly distributed among the basins in the north and northeast parts of the area and also among the fault basins of the Hexi Corridor. The basins are mainly composed of Jurassic，Tertiary，and Quaternary formations. Groundwater is recharged from the lateral inflows. Well production varies within a wide range(from 10 to 1 000 m^3/d)，depending mainly on the conditions of the basin scale，lithology of the aquifer，and structure. In general，the water table is close to the surface. In some areas，the groundwater becomes artesian.

The well outflow rates and permeability for each groundwater unit are shown in Table 2.

Table 2　Main hydrologic features of each groundwater unit

Groundwater units	Water outflow rates/(L·(s·m)$^{-1}$)	Permeability/m^2
Upland rocky fissure water unit	＜0.011 5	Shallow system：10^{-12}－10^0， deep system：＜10^{-12}
Valley and depression pore-fissure water unit	0.050－0.150	Shallow system：10^{-10}－5×10^{-8}， deep system：＜10^{-10}
Basin pore-fissure water unit	0.011 5－1.150 0	Shallow system：5×10^{-1}－10^{-8}， deep system：5×10^{-10}－5×10^{-8}

4 MAJOR ACHIEVEMENT OF SITE CHARACTERIZATION DURING 2002－2004

4.1 Geological mapping in Jiujing and Yemaquan

In the Jiujing Section，a scale of 1：50 000 surface geological map was completed during 2001，covering an area of 462 km^2. Based on the detailed field investigations and laboratory work，a geological map has been generated.

In Jiujing Section，four granite units are recognized：Jiujing，Bantan，Jiazijing，and Shimenkan. The Jiujing unit is composed of middle-Proterozoic tonalite with an area of 220 km^2. The Bantan unit is composed of porphyritic-monzonitic granite with an area of 53 km^2. The granite in this unit is of good integrity with less deformation and fractures. Thus，it was chosen as the candidate unit for drilling，and borehole BS01 was located in the northern part of this unit.

Yemaquan Section is one of the candidate sections for future HLW repository. It is 150 km north to the Jiayuguan city，Gansu Province. No permanent inhabitants live in the area. The district is an arid Gobi-desert with rocky outcrops. The elevation ranges between 1 400 and 1 600 m. The mean annual temperature is between 4 ℃－7 ℃. The average precipitation is 70 mm/a，while evaporation is about 3 000 mm/a. No yearlong stream and other surface water bodies exist in the area.

In 2002，geological investigation at a scale of 1∶50 000 was conducted in Yemaquan，resulting in the completion of a geological map. In the area，the candidate host rock is Yemaquan granite covering an area of 116 km^2，which is composed of 3 units：Hongqiquan Unit，Fanxiushan Unit，and Dongtan—Yaojing Unit，with isotope age of 290，278 and 200 Ma，respectively.

4.2 Surface geophysical survey

Detailed surface geophysical survey was conducted in Beishan area in order to identify the bearing of faults and their depth. Electormagnetic survey was proven the most effective surface geophysical method in identifying faults in granite. A STRATEGEM resistivity profile measurement system were used in Beishan，the results show that the fault zone in granite is characterized by low resisitivity (<100 Ω • m). Fig.1 shows the resistivity profile of the Shiyuejing Fault，indicating the dipping angle(85°)，depth(larger than 2 km) and width(60 m) of the fault，which is quite consistent with the trenching and drilling observations.

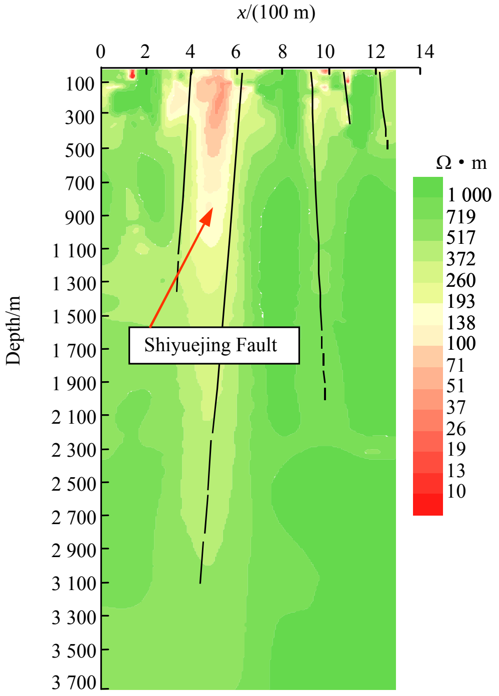

Fig.1 Electromagnetic profile of Shiyuejing fault in Beishan granite site

4.3 Drilling of boreholes BS01，BS02，BS03，BS04

BS01 and BS02 are the first two boreholes in the Beishan candidate site. BS01 is a vertical hole with a depth of 703.08 m，being drilled to evaluate the potential Bantan Granite unit，while BS02 is inclined，with a depth of 502.15 m，to evaluate the characteristics of Shiyuejing fault，and the key NE-striking fault. Diamond drilling was used，with pure water as the drilling fluid，and full core sampling was carried out in both boreholes.

Drilling for BS01 started on July 8，2000，and it was completed October 20，2000，at the expected depth of 703.28 m. Borehole television，borehole geophysical surveys(gamma，resistivity，temperature，pressure，U，Th and K content，borehole televiewer)，pumping tests，injection tests，sample collection，and geostress measurements have been conducted.

Drilling for BS02 started on July 26，2000，and was completed on May 17，2001，at the expected depth of 502.15 m. It cross-cuts the NE-striking Shiyuejing fault from its hanging wall through the fault zone to its foot wall. Perfect core samples for the fault have been obtained and the hydrogeological investigation has preliminarily shown that the fault is not a water-conducting fault.

In 2003，two more boreholes were completed：BS03 in Jiujing，and BS04 in Yemaquan. The depth of both boreholes are 500 m.

4.4 Borehole hydrogeological testing

(1) Pumping tests

For borehole BS04，the pumping tests were carried out successfully after the end of borehole drilling. The hydraulic conductivities calculated based on the testing are shown in Table 3. From the table，we can see that the water yield was only from 0.001 65 to 0.024 00 L/s when the drawdown was from 11.04 to 37.04 m. Correspondingly，the hydraulic conductivities were in 10^{-9} m/s order of magnitude. This indicates

Table 3 Pumping test results for borehole BS04 after drilling

Water yield/(L • s^{-1})	Drawdown/m	Hydraulic conductivities /(m • s^{-1})
0.001 65	11.04	1.278×10^{-9}
0.002 40	23.04	1.088×10^{-9}
0.024 00	37.04	9.606×10^{-9}

the area around the borehole BS04 is very low in water yield property and penetrability.

(2) Injection tests

Borehole hydrogeological tests have been conducted after drilling was completed. Six intervals with local fractures were chosen in BS01 to carry out injection tests by using a double packer system; and the results of injection tests are shown in Table 4. For BS03，18 intervals with fractures were chosen in borehole BS03 to carry out injection tests by using double packer system was completed. The results of injection tests indicate that the hydraulic conductivity of the granite is from 7.71×10^{-9} to 1.14×10^{-7} m/s.

Table 4　Injection tests for borehole BS01

No.	Test interval with fractures(depth)/m	Permeability K/(m • s^{-1})
1	120.50 - 128.50	$<8.0\times10^{-9}$
2	222.00 - 230.00	$<8.0\times10^{-9}$
3	315.00 - 323.00	1.74×10^{-8}
4	436.00 - 444.00	$<8.0\times10^{-9}$
5	476.00 - 484.00	$<8.0\times10^{-9}$
6	496.76 - 504.76	$<8.0\times10^{-9}$

4.5 Geostress measurement in BS03

Hydrofracturing was used to measure the in-situ stress in Borehole BS01 and BS03. The major results for BS01 and BS03are listed in Tables 5 and 6，respectively，showing that the maximum lateral principal stress has a direction between NE 25° - NE 45°.

In BS03，19 intervals were measured successfully. The results show that the maximum horizontal principal stress is 16.92 MPa at depth of 461.73 m，which belongs to the middle stress region. The minor horizontal principal stress is 4.83 MPa at the depth of 152.70 m. The direction of maximum horizontal principal stress ranges from NE65° to NE71.5°.

4.6 Borehole radar measurement in BS03

Borehole radar measurement was conducted in BS03 and BS04. Mala Geosceince Company in Sweden produced the instruments. The following are the parameters during measurement : (1) antenna frequency，250 MHz；(2) distance of transmitting or incepting，1.9 m；(3) sampling frequency，5 316 MHz；(4) sampling space，0.1 m；(5) time window，141 ns and 188 ns.

Table 5　Results of hydrofracturing geostress measurement at BS01

No.	Depth /m	Tensile strength T_{hf} /MPa	Vertical stress δ_v/MPa	Minimum lateral stress Δ_h/MPa	Maximum lateral stress δ_H/MPa	Direction of minimum lateral stress(δ_H)
1	161.5	5.29	4.36	4.56	7.72	
2	166.5	2.73	4.49	4.12	7.11	NE25°
3	250.5	7.74	6.76	5.06	8.18	
4	252.4	4.96	6.81	4.71	7.71	NE30°
5	332.4	1.33	8.97	6.10	8.99	
6	339.0	6.40	9.15	4.72	6.51	NE38°
7	413.3	5.94	11.15	8.37	12.65	NE45°
8	457.0	-	12.30	11.13	19.14	
9	493.2	-	13.31	14.85	25.66	

Table 6　Injection test results for Borehole BS03

No.	Test interval with fractures/m	Hydraulic conductivities /(m • s^{-1})
1	127.5 - 134.0	1.28×10^{-8}
2	135.0 - 141.5	7.71×10^{-9}
3	148.0 - 154.5	1.14×10^{-7}
4	156.0 - 162.5	1.75×10^{-7}
5	171.5 - 178.0	1.16×10^{-7}
6	187.5 - 194.0	1.22×10^{-7}
7	195.5 - 202.0	9.43×10^{-9}
8	209.9 - 216.4	5.37×10^{-8}
9	223.0 - 229.5	1.82×10^{-7}
10	252.0 - 258.5	4.12×10^{-8}
11	276.0 - 282.5	6.50×10^{-8}
12	313.5 - 320.0	5.17×10^{-8}
13	384.7 - 391.2	3.53×10^{-8}
14	392.2 - 398.7	2.90×10^{-8}
15	402.0 - 408.5	3.38×10^{-8}
16	455.0 - 461.5	1.79×10^{-7}
17	467.0 - 473.5	3.50×10^{-7}
18	487.0 - 493.5	2.00×10^{-7}

The interpretation results of radar measurement in BS03 show that there are 21 fractures and 1 punctual reflector along the borehole. The results reflect the effectiveness of this measurement.

5 PROGRESS IN BUFFER/BACKFILL MATERIAL STUDY

The concept of geological disposal of high-level radioactive waste in China is based on a multi-barrier system，which combines an isolating geological environment with an engineered barrier system. The buffer/backfill material is one of the main engineered barriers for the repository. In China，bentonite has been selected as the buffer/backfill material.

The basic requirement for the buffer is to retard radionuclide migration by restricting groundwater movement，providing a high sorption capacity for dissolved nuclides and acting as a filter for radionuclide-bearing colloids. To ensure safety over the long timescales of interest，it is necessary to demonstrate that no significant detrimental impacts on the physical properties of the buffer material. In parallel，it is also necessary to demonstrate the feasibility of manufacturing and installing the buffer. Natural clay is a material that can satisfy all the above functions，to a greater or lesser extent. Among the types of natural clay，bentonite，when being compacted，is considered as a superior barrier.

In order to select a suitable bentonite material，a comprehensive investigation has been conducted for the bentonite deposits in China. First，screening criteria for the deposits were proposed：(1) scale，the candidate bentonite deposit should be a large-scale one in order to meet the demand for a HLW repository being built 30 or 40 years later；(2) quality，as the reference material for buffer in a HLW repository，the bentonite must have extremely low permeability，high absorbability，high swelling property，suitable thermal conductivity and reasonable stability to ensure the safety over the long timescales of interest. As a result，Na-bentonite with high contents of montmorillonite and low contents of detrimental are of more interest because of swelling properties and in general higher cation exchange capacity；(3) economic limitation，the bentonite produced in future should be as cheaper as possible；and (4) location，transportation of bentonite from the mine to the candidate repository should be convenient and the cost should be as low as possible. The investigation shows that there are 84 main bentonite deposits discovered in China，while GMZ deposit was selected as the candidate buffer material for China′s HLW repository.

The GMZ bentonite deposit is a large-scale deposit，which is located in the North Chinese Inner Mongolia Autonomous Region，300 km northwest of Beijing. The transportation from the mine to outside is very convenient. The deposit，with beded ores，was formed in upper Jurassic period. Ore minerals include Montmorillonite，coexisting with illite；and Gangue minerals include feldspar，quartz，calcite，zeolites，cristobalite，unaltered volcanic glass. The mine area is about 72 km^2. The reserve is about 160×10^6 t with 120×10^6 t of Na-bentonite reserves. The major ore body of the deposit extends about 8 150 m with thickness ranging from 8.78 to 20.47 m.

The mineral composition of GMZ－1，an representative sample of GMZ bentonite，has been quantitatively analyzed by X-ray diffraction analyses. The results show that major mineral include：montmorillonite 75.4%，quartz 11.7%，crystaballite 7.3%，feldspar 4.3%，calcite 0.5%，kaolinite 0.8%. The methylene blue exchange capacity of GMZ－1 is 102 mmol/(100 g). The CEC(cationic exchange contents)is about 77.6 mmol/(100 g). The bulk chemical component of GMZ－1 is SiO_2 67.43 %，Al_2O_3，14.2%，P_2O_5 0.02%，TiO_2 0.12%，$TiFe_2O_3$ 2.40%，FeO，0.29%，CaO 1.13%，MgO 0.10%，MnO 0.02%，K_2O 0.73%，Na_2O 1.75%，loss of ignition 11.38%.

The preliminary study of basic properties on GMZ bentonite shows that GMZ bentonite is characterized by high content of Montmorillonite(＞70%)，low impurities；and researches conducted on swelling，mechanical，hydraulic，thermal property have shown that the GMZ bentonite is a kind of good buffer/backfill material (Wang，2004b). Comprehensive studies，including the coupled thermo-hydro-mechanical process of the bentonite，are still under way.

6 ADVANCE IN RADIONUCLIDE MIGRATION STUDY

The study on the migration behavior of radionuclide is a very important fundamental study for HLW disposal. Comprehensive studies have been conducted in this field. The radionuclides studied include：^{239}Pu，^{237}Np，^{241}Am，^{99}Tc，^{131}I，^{134}Cs，^{137}Cs，^{90}Sr，^{75}Se，^{57}Co，etc. The media studied include granite，bentonite，granite fractures and some metallic minerals. The important studies include：

(1) The sorption and diffusion of ^{99}Tc，^{237}Np，^{239}Pu and ^{241}Am on bentonite[7，8]，and the sorption of ^{99}Tc and ^{129}I on stibnite，tiemannite，jamsonite and active carbon of apricot-shell[9]：the results show that the sorption of Iodine for tiemannite and active carbon of apricot-shell are of the order of 10^3 mL/g，while the sorption ratio of TcO_4^- for jamesonite is of the order of 10^4 mL/g. Also，the sorption ratio of ^{99}Tc for the active carbon of apricot-shell is of the order of 10^4 mL/g. Those mineral materials could be considered as additives to bentonite，in order to prevent the migration of those active radionuclides such as ^{99}Tc and ^{129}I.

(2) Sorption of ^{237}Np，^{239}Pu and ^{241}Am on stibnite，the results show that the sorption ratio of ^{237}Np，^{239}Pu and ^{241}Am for stibnite can reach 1.7×10^3，$\geqslant4.2\times10^4$ and 1.4×10^4 mL/g，respectively.

(3) Establishment of a small-scale RADMIG device，which can simulate the conditions of repository. The specification of the device is T=100 ℃，P=5 MPa，$E_h < -200$ mV.

(4) The migration behavior of Np，Pu and Tc in the Beishan granite，including the measurement of sorption ration，diffusion coefficient. The experiments were conducted in low-oxygen glove boxes. Those results are site-specific results，which are quite useful for performance assessment.

(5) The migration behavior of ^{99}Tc in natural single fracture of granite，a two-dimensional model were established to describe the concentration distribution of ^{99}Tc[10].

(6) The studies on the speciation of Np，Pu，Tc，Am in ground water，especially the ground water from the boreholes in Beishan site[11].

7 ANALOGUE STUDY

The following natural analogue studies and anthropogenic studies have been conducted：

(1) Natural analogue study in Lianshanguan uranium deposit[12]. The content of ^{239}Pu in uranium ores and host rocks were analyzed，which shows there has been no ^{239}Pu migration from the uranium ores since they were formed 1 900 Ma.

(2) The geochemical behavior of ^{129}I in Lianshanguan uranium deposit[13]. The content of ^{129}I in uranium ore and ground water were analyzed by accelerator mass spectrometry(AMS)，the results show that the groundwater has leached out ^{129}I from the uranium ores，indicating that ^{129}I is a type of active radionuclide.

(3) Uranium-series radionuclide and element migration around the Sanerliu granite-hosted uranium deposit in Southern China[14]. The results show that the migration of U，Th and most trace elements in the uranium ores and host granite are limited，often less than 30-35 m over 51 Ma. Due to the existence of clay minerals in fractures，the migration of uranium-series radionuclides along the fractures is very limited.

(4) Migration of some elements and radionuclides across a granite-granite contact zone[15]. A granite-granite contact zone was used for natural analogue study，the results show that the migration distance of major elements，trace elements and uranium-series is less than 1－2 m.

(5) Study on the corrosion layers of unearthed bronze relics of Xizhou Dynasty，China[16]. Bronze ware dated back 3 000 years ago were used to study the corrosion mechanism，the results show that the depth of corrosion is less than 1 mm in the past 3 000 years.

8 CONCLUSIONS

High-level radioactive waste disposal is a challenging task to the sustainable development of

nuclear industry in China. Necessary resources have been arranged for the final geological disposal of high-level waste. Preliminary technical strategy and long term plan have been proposed. Since 1985， progress has been made in site selection and site characterization，backfill material study，radionuclide migration and analogue studies. Beishan，located in Northwest China′s Gansu Province has been selected as a potential site for China′s high-level radioactive waste repository. The first 4 boreholes were drilled at the Jiujing Section and Yemaquan Section in the Beishan area in 2000－2004. The findings have shown the advantages of the site. Continuous efforts will be concentrated on Beishan area， other associated laboratory research will also be conducted in the coming years， for the purpose to build China′s high-level radioactive waste repository around 2050.

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