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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;

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Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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Executive summary

More than 40 years after the first geological disposal projects for spent fuel and high-level radioactive waste started, some projects are advancing towards implementation, with key decisions taken in some countries and encouraging prospects in others. Underground research laboratories (URLs) play an important role in the development of the various projects, in particular in support of research and the development of the technologies needed, but above all to prepare the teams and train the specialists needed in various fields. Through direct access to the geological formation, the URL is an essential step in generating the data that will be necessary for the safety demonstrations of geological repositories. The development times of the projects also make URLs excellent facilities for training and transmission of knowledge to new generations. Finally, the activities within the URLs make it possible to illustrate to the public and stakeholders the ability to conduct projects as complex as geological disposal.

Although they have been in progress for a few decades, geological disposal projects are still a new activity, for which international co-operation can only be beneficial. Several initiatives have emerged in this context, in particular from exchanges of information, benchmarking, and direct co-operation in the field. The NEA constitutes a privileged platform for organising these international exchanges. It also offers an administrative and legal framework that is suited to exchanges to setting up dedicated projects. It is within this framework that the underground laboratory of Horonobe (Japan) plans to intensify its international co-operation by setting up the Horonobe International Project (HIP).

List of abbreviations and acronyms

AI	Artificial intelligence
ALARA	As low as reasonably achievable
ANDRA	National Radioactive Waste Management Agency (France)
BAT	Best available technologies
BGE	Federal Company for Disposal of Radioactive Waste in Germany
CCNC	China National Nuclear Corporation
CDLM	Committee on Decommissioning of Nuclear Installations and Legacy Management (NEA)
CNNC	China National Nuclear Corporation
CRIEPI	Central Research Institute of Electric Power Industry
DGR	Deep geological repository
EBS	Engineered barrier system
EC	European Commission
EDZ	Excavation damaged zone
EGKM	Expert Group on Knowledge Management for Radioactive Waste Management Programmes and Decommissioning (NEA)
EU	European Union
ESDRED	Engineering Studies and Demonstrations of Repository Designs
FEP	Features, events and processes
FSC	Forum on Stakeholder Confidence
GTC	Grimsel Training Center (Switzerland)
GTS	Grimsel Test Site
HIP	Horonobe International Project
HLW	High-level waste
HRL	Hard Rock Laboratory
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal of radioactive waste Technology Platform
ILW	Intermediate-level waste

IGSC	Integration Group for the Safety Case
JAEA	Japan Atomic Energy Agency
METI	Ministry of Economy, Trade and Industry in Japan
Nagra	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NEA	Nuclear Energy Agency
NRC	Nuclear Regulatory Commission (United States)
PEM	Prefabricated Engineered barrier system Module
QA	Quality assurance
R&D or RD&D	Research and development, or research development and demonstration, used interchangeably depending on the programmes of the institutions
RWM	Radioactive waste management
RWMC	Radioactive Waste Management Funding and Research Center (Japan)
SDM	Site descriptive model
SKB	Nuclear Fuel and Waste Management Company (Sweden)
SNF	Spent nuclear fuel
TAG	Technical Advisory Group
TBM	Tunnel boring machine
TDB	Thermochemical database
TSO	Technical supporting organisation
URL or URF	Underground research laboratory or underground research facility (IAEA terminology)
US DOE	Department of Energy of the United States
WBS	Work breakdown structure
WMO	Waste management organisation
WP-IDKM	Working Party on Information, Data and Knowledge Management (NEA)

1. Introduction

The concept of engineered geological disposal has been developed for the safe long-term management of radioactive waste in deep underground repositories that provide the long-term safe containment and isolation of the waste, and subsequently, protect humans and the environment, as stated in the NEA Collective Statement (NEA, 2008). A radioactive waste repository can take decades to develop and uses the best available technologies and engineering design to achieve its long-term safety. Throughout the development of a repository, the feasibility, safety and appropriateness of the proposed system must be demonstrated by providing a safety case to all stakeholders before a decision can be made and the development process can progress. There are several such decisions underpinned by safety reviews until the licensing of the final closure of a repository, and there is a commitment on the part of all to continuously improve the technical solutions in a virtuous process of optimisation.

Decision making requires practical demonstrations of key technical elements in order to show the robustness of the proposed design as well as to establish confidence in a safety case. Underground research laboratories (URLs) play an important and multi-faceted role in these scientific assessments and demonstrations by providing a realistic environment for characterising and testing the selected technical approaches and materials. In areas such as demonstrating operational safety, acquiring geological information at a repository scale and in constructional and operational feasibility, only URLs can provide reliable in situ data, with relatively longer duration of experiments than in geological repositories under construction or in operation.

URLs can also provide tangible benefits in enhancing participation by the general scientific community and confidence among both technical and non-technical stakeholders. Many nuclear waste management programmes have progressed over the past decade. Construction work has started in Finland, the programme licence has been granted in Sweden, and the construction licence application is due to be submitted in early 2023 in France. The programmes in Canada and Switzerland are also advancing, with candidate sites identified, from which the next developments for their respective deep geological repositories (DGR) will be proposed. Other countries, such as Germany, Japan and the United Kingdom, are actively preparing for new phases.

All these programmes have made extensive use of URLs for research and development work, including important developments in optimisation of design elements; and have conducted or planned detailed site investigations through site-specific URLs. Other radioactive waste management programmes are commissioning or considering new URLs as integral components of staged implementation of geological disposal. New URLs are also being planned to further optimise the implementation of geological disposal.

As the URL activities continue to evolve, this document complements the information provided previously by integrating information directly from NEA member countries in a strategic framework. One of the important questions is to see how the advanced programmes can deliver their contribution to new entrants so that they do not have to repeat what already exists and focus their efforts on new developments likely to benefit many geological disposal programmes. Given the complexity of the programmes and the associated issues, international co-operation is also essential to optimise both the programmes and the resources, and to illustrate to the public the scientific and technical capacities to ensure operational and long-term safety. In this context, it was also important to discuss the contribution of new technologies to DGR projects.

The NEA and METI International Workshop on Joint Utilisation of Underground Research Laboratories for R&D Projects was organised in the JAEA Horonobe International Communication House (Horonobe) and Surfeel Hotel Wakkanai (Wakkanai), Japan, from 1 to 3 November 2022. It gave rise to fruitful exchanges which are reported in this document. The agenda of the workshop is attached as Annex A. The list of participants is provided as Annex B.

This document provides:

- background and preliminary framing (Chapter 2);
- an overview of URL development (Chapter 3);
- a presentation of the Horonobe Joint Project and its potential areas of international co-operation (Chapter 4);
- the perspective of countries at the initial stages of their DGR projects and the capacities of advanced countries for support of international co-operation (Chapter 5);
- prospects for international co-operation and modalities (Chapter 6); and
- a conclusion.

Terminology

While the terminology used in different national waste management programmes may vary, the following key terms are often associated with URL activities and are therefore defined at the onset:

(Site) Characterisation. In situ investigations to provide basic understanding of the geologic, hydrogeologic, geochemical, structural and mechanical properties of the host rock.

Demonstration. Illustration, at full or reduced scale and under real and/or simulated repository conditions, of the feasibility of the repository design or of the behaviour and performance of various components of the repository. For example, demonstrations of sealing, waste emplacement or retrieval techniques. Demonstration may also be disposal trials of actual radioactive waste in facilities (i.e. pilot facilities) in which the necessary licences are required.

Testing. A broad term to cover various activities during the development of a repository in order to evaluate in situ: i) the feasibility and performance of certain operations such as excavation methods, disposal, sealing and closure techniques; ii) the performance of engineered materials.

Technology development. The development of equipment, techniques and expertise for site characterisation, testing, monitoring techniques for repository construction, waste emplacement (and retrieval), construction of engineered barriers, and repository closure.

2. Background and preliminary framing

Achieving final disposal of highly radioactive waste and spent fuel is a common challenge for all countries with nuclear power plants. Given the importance of the issues, particularly in the case of such a recent discipline and without much experience of concrete implementation, it appears necessary to strengthen international co-operation to accelerate the efforts made by each country. On the occasion of the G20 Ministerial Meeting on Energy Transitions and the Global Environment for Sustainable Growth in June 2019, a roundtable discussion was launched by Japan's METI, the US Department of Energy (DOE) and the NEA to respond to this request.

Fifteen representative countries, the NEA and the International Atomic Energy Agency (IAEA) participated in the two roundtables which followed on 14 October 2019 and 7 February 2020.

2.1. Outcomes from the roundtables

The key messages from the roundtable summary report *International Roundtable on the Final Disposal of High-Level Radioactive Waste and Spent Fuel: Summary Report* (NEA, 2020) associated with decision-making processes that are "core" to a successful DGR project that emerged from the roundtable discussions were as follows:

- A stepwise, adaptive and fully transparent decision-making process that involves key stakeholders, including implementers, regulators and the general public is effective. Beginning at the outset of the national programme, step-by-step implementation builds confidence in a DGR project and increases the probability of success. Engagement with stakeholders should be recognised as a long-term process that occurs continually throughout the decision-making process and life cycle of a DGR.
- According to their national policies, some countries have industry-led approaches, others have government-led approaches, but the approach an organisation takes does not matter as much as long as the process used involves the public and all other stakeholders effectively.
- Stakeholders' trust and confidence in the local DGR project increases when they can see that other countries are approaching the solution to high-level waste (HLW) and spent nuclear fuel (SNF) disposal in the same way as the local project. It is good practice for the international community to support countries during the advancement of the process.
- While financial support for the host community can be important, it is not deemed to be a primary factor in gaining confidence in and assuring the final success of a DGR. There needs to be an "added value" aspect. The support plan needs to indicate benefits of a DGR project over the long term to the host community. Affected communities and local governments are more inclined to accept support if it is aligned with regional economic development, improvement of the overall well-being of the community or educational support, for example. There are cases, for example in Finland, where countries are able to make positive progress with a support plan that does not include financial support.
- Involving younger stakeholders in the decision-making processes is not only imperative, as they will inherit the project in the future, but also effective. Engaging

with young stakeholders may require new and innovative communication approaches. The use of social media and video, for example, helps to establish and maintain dialogue with younger stakeholders.

- Clear communication about safety using the safety case can be a challenge for a regulatory body and for the radioactive waste management organisations (WMOs). If communication is unclear, even academic experts may challenge the concepts of the repository and the associated safety case. Communication and dialogue should be explored with a wide range of scientists and experts, including those outside of the domain of nuclear science and engineering. In order to bolster public confidence in the safety of a DGR, it is important to make an effort to ensure confidence in the safety case.

The roundtable participants recognised the value of international collaboration to maintain and strengthen the technological capabilities in the management of HLW and SNF disposal programmes. Collaboration in the development of technological capabilities can also have a positive influence on improving confidence in stakeholders.

- There has been a history of successful international collaboration on technical aspects of DGRs since the 1980s. Participation of both the present and next generations in such programmes should be encouraged. Examples of those programmes are: the international research project Development of Coupled Models and their Validation against Experiments (DECOVALEX); or the Clay, Crystalline and Salt Clubs of the NEA for developing and exchanging scientific information. The Integration Group for the Safety Case (IGSC) of the NEA assists countries in the development of effective safety cases supported by a robust scientific technical basis. The IAEA organises various DGR-related projects, such as the Underground Research Facilities Network for Geological Disposal – URF Network. European countries have also established international co-operation projects such as the Implementing Geological Disposal of radioactive waste Technology Platform (IGD-TP) and Engineering Studies and Demonstrations of Repository Designs (ESDRED) to support their radioactive waste management programmes. Many other international projects are undertaken through the European Commission, IAEA and NEA mechanisms.
- Financial and human resources for R&D related to DGR development can always benefit from wider exchanges within the international community. International collaboration on technical aspects, utilising facilities and research in other countries, is a cost-effective way to further strengthen the technical understanding for DGR programmes. Some countries are actively participating in and collaborating on international R&D programmes under bilateral or multilateral frameworks.
- Underground research facilities made available in other countries are invaluable resources, especially for those countries in early stages of the DGR decision-making process that have not yet identified a host rock environment, for example. Developing those resources domestically involves a substantial investment, and both the timing (i.e. whether in the siting or licensing phase) and configuration (i.e. as a separate facility or one integrated with the intended DGR) of a URL should be carefully assessed.
- An additional benefit of international collaboration is being able to demonstrate to stakeholders that the efforts undertaken locally (on safety assessment, risk communication and dialogue with stakeholders) are similar to those being

undertaken worldwide. This approach has been proven to be effective through groups such as the NEA Forum on Stakeholder Confidence (FSC).

In the wake of the roundtables and to continue strengthening international co-operation in the field of development of DGRs, it was decided to organise an international workshop on the common use of URLs in research and development projects. NEA and METI decided to hold a joint workshop with the aim of finding opportunities of international co-operation in R&D programmes utilising URLs.

This workshop was organised to present a global overview of URLs worldwide, to exchange national URL programmes from both countries with advanced programmes and countries with needs in international co-operation, and to discuss capacities of international co-operation in URLs through the support of international organisations. In the context of the COVID crisis, a preparatory session for the workshop was held on 22 September 2021 in web conference format.

2.2. Web conference preparatory session

In his opening remarks, Nobuhiro MUROYA, Deputy Director-General of the NEA, indicated that this workshop would be a good opportunity to discuss increasing needs in international collaboration in R&D to address common challenges among countries in developing geological disposal and to strengthen international co-operation in developing solutions.

Tomokazu SHIMOHORI, from METI, referring to the present programme in Japan, emphasised the importance of learning from the knowledge and experiences regarding DGR programmes in other countries and strengthening international co-operation in underground research facilities for the efficiency of financial and other resources.

General information can be found on the NEA website (NEA, 2021).

2.2.1. *Session 1: Review of R&D programmes*

The first session was devoted to a review of international and national R&D programmes in URLs.

Rebecca TADESSE, head of the Division of Radioactive Waste Management and Decommissioning in the NEA, presented the outcomes of the International Roundtables on Final Disposal of High-level Radioactive Waste and Spent Fuel. She explained that the key conclusions of the roundtables were that international co-operation is valuable in terms of policymaking, stakeholder engagement, R&D and human resource development, and that transparency and early involvement with local communities in DGR programmes are crucial for the successful implementation of DGR programmes. Using the framework of international organisations was also found to be effective and worth considering in further discussions. After the roundtable, the NEA decided to hold this workshop with METI in order to deepen the discussion on international collaboration in URLs (see also the section “Outcomes from the roundtables” of this chapter).

Stefan MAYER, team leader for radioactive waste disposal in the Nuclear Energy Department of the IAEA, provided an overview of underground research facilities (URF) around the world. International RD&D has been implemented in over 15 national DGR programmes for more than 60 years. With the help of those countries with RD&D projects in URF, the IAEA is going to publish the Compendium of global URF RD&D, which provides fundamental information about URFs and a historical overview of RD&D experiments conducted in URFs. He gave a brief introduction on the structure of the Compendium, some examples of the information sheets, and expected outlooks of plans in

URFs in the near future. He explained that understanding the overview of RD&D could help countries to develop more design-specific R&D objectives and that continuous international projects with different URFs and DGR programmes would enable the transfer and sharing of knowledge and expertise.

Stratis VOMVORIS, Director of International Services and Projects Division at Nagra, presented the status of national URLs in Switzerland. He explained the responsibility of Nagra in radioactive waste management, the development history of programmes for high-level waste management and timelines for future development. Nagra has RD&D projects with successful international collaboration in two underground facilities with different rock and RD&D approaches: the Grimsel Test Site (GTS) and the Mont Terri rock laboratory (MT). Their RD&D plan for URL activities is reviewed and updated accordingly every five years based on the achievements from previous RD&D activities and emerging needs. He explained the difference of nature of experiments in R&D programmes in generic sites and site-specific facilities; experiments in generic sites support general site application and broad international participation, while site-specific facilities can respond to specific needs of supporting construction and licence application with advanced demonstration-type experiments. He concluded that active international collaboration is playing a strong role in DGR programmes in various areas like competence building, optimisation of resources, and knowledge management, and that URLs provide platforms for such international interactions.

Wilhelm HUND, head of the Research and Development/Knowledge Management division of BGE, presented the status of national URLs and R&D projects in Germany. He gave a brief introduction on the overview of German authority in radioactive waste management and timelines of RWM projects in Germany. He explained that a key requirement in RWM programmes is to consider the reversibility of decisions and the retrievability of waste from an early stage of repository planning. Germany is proceeding with a site selection procedure without exploration activities as intended by the German Site Selection Act in the current phase, and therefore a lot of effort is put into maximising the transparency and comprehensiveness of decisions. It is expected that international co-operation will make it possible to gain experience and knowledge from other countries and that this knowledge can be incorporated into the national programmes. The stepwise approach in RWM programmes is important in terms of making use of findings through international co-operation in URL research. He also noted that early URL projects are necessarily generic and that the requirement on projects will become more specific as RWM programmes progress. BGE is trying to participate in collaborative projects in generic URLs to better understand repository systems, the optimisation of techniques and safety enhancements, and to anticipate joining projects in site-specific URLs in the future. Participating in international collaboration in generic URLs will help to build competency and the sharing of underground facilities for the successful implementation of RWM programmes.

Liang CHEN, of the CNNC, presented the newly built underground research facility in Beishan and the project plans for the URL. The Beishan area was selected through the site selection process and site characterisation investigation, and construction of the URL was approved in 2019. The Beishan URL will function as a research facility to study site characterisation for the evaluation of disposal feasibility and to demonstrate the long-term performance of multi-barrier systems and technology for construction and operation of disposal sites. The URL is also expected to work as a platform for public communication. The facility will be developed in a phased approach with implementing studies and demonstrations based on the safety case study. Construction of the Beishan URL started in June 2021 and 9 projects will be carried out during the construction to characterise the site and to develop technologies for excavation. CNNC is also paying attention to public communication in parallel with the URL construction. The facility is open for international co-operation and will provide an opportunity to other countries for technical development for site characterisation. The Beishan URL is planning joint research projects on on-site characterisation, multi-barrier systems and excavation technologies in the crystalline rock as well as personal exchange and technical communication. An international project has been started in the study on evaluation techniques of hydraulic response during excavation to improve understanding of the deep hydrogeological site and to develop modelling technology.

Michihiro HORIKAWA from METI presented an outline of the full-size, in-person workshop planned to be held jointly with NEA in 2022 in Horonobe URL, Japan. The workshop will have presentation sessions to exchange information on RD&D programmes and break-out discussion sessions on international co-operation. The expected outcome of the workshop is to exchange discussion on prioritising the topics and to reach conclusions on the role of URLs. He also mentioned that Japan is considering launching a new framework of RD&D in the Horonobe URL and that a call for participation in the project would be announced soon.

2.2.2. *Session 2: Panel on the role of URLs*

Session 2 was organised as a panel discussion on the role of URLs in deep geological disposal project development; a set of questions was submitted to the panellists, who were able to provide insights based on their national experiences.

On the role of URL programmes in the development of DGRs, Patrik VIDSTRAND (SKB) pointed out that Äspö is a URL in support of R&D programmes aimed at understanding geology and demonstrating the disposal concept. The R&D and long-term safety studies that have been developed there are the basis of the DGR site investigation programme. Äspö co-operates closely with universities through training courses. The site is openly shown to politicians and the public through tours. It builds public awareness and trust, which could be a key point for further business in URLs. The Äspö URL is also important for considering partnerships in view of the construction of the DGR.

In Switzerland, the two URLs have an important role in R&D programmes, particularly in sedimentary programmes. Nagra utilised the URLs to also develop technologies in both crystalline and sedimentary environments. Nagra co-operates with its suppliers to develop know-how for its technologies, models, and underground tests on disposal concepts. R&D projects also benefit from collaboration with partners, whether companies and institutions or international collaborations.

Regarding the challenges and needs when creating a URL, Liang CHEN explained that in Beishan the challenge was to go beyond previous fundamental studies and find the most suitable options for the concepts and materials for a future DGR. One of the issues that needs to be addressed is that of communication with the public, from the start of the programme. In the absence of experience in the operation of international projects, co-operation is necessary to share information and to build the confidence of the public in the region.

Masahiro SHIBATA explained the current situation of URLs in Japan; JAEA has successfully implemented R&D programmes in both crystalline and sedimentary rocks in a phased approach and compiled the results of surface-based investigations and investigations during tunnel excavation in the synthesis reports. These could be useful for newcomers. The R&D programme at the Mizunami URL was ended in 2020, and it was decided to continue the R&D programme at the Horonobe URL, which would be extended by excavating underground to a depth of 500 m. JAEA plans to invite international contributions to maximise the outcome of the ongoing and future R&D programme at Horonobe. R&D subjects need to focus particularly on the long term, considering the long duration of repository implementation. Promoting an advanced approach could be a challenge for the Horonobe URL programme, like establishing an advanced 3D solute transport model for fractured sedimentary rock for more realistic safety assessments. The systematic integration of repository technology options is challenging. Transfer of knowledge and of know-how to the next generation could also be an important challenge.

International co-operation between more advanced and less advanced DGR programmes is essential for Frédéric PLAS (ANDRA), whatever the type of geological environment. ANDRA developed its programmes and methodologies, including its URL, based on feedback from more advanced programmes at the time. International co-operation saves significant time and resources for research teams and partners. ANDRA prepared the DGR feasibility report in France, following a relevant methodology, which can help countries with less advanced programmes. The comparison between specific cases from different countries is essential to share the differences in repository concepts design and according to the radioactive waste inventory. It is also interesting as a reference for the programming of the long-term development of the DGR. International co-operation will help less advanced programmes through feedback from more advanced programmes in the areas of constructing, operating and maintaining URLs. It was noted that it is important to remain cautious but not limited to existing concepts, and to take into account the progress that is seen elsewhere and could benefit less developed programmes.

Stratis VOMVORIS highlighted two main achievements in the Swiss URLs. One of the first in situ radionuclide migration experiments was carried out in co-operation with Japan on the Grimsel Test Site; it directly contributed to the development of conceptual models then used for the safety analysis. The gas migration test in the bentonite barrier at GTS is also an example that shows the contribution of international co-operation in URLs, benefiting the project partners. The horizontal raise-boring tests at Mont Terri directly contributed to the development of high-level waste disposal concepts at ANDRA. The new project at Horonobe is promising as JAEA has been actively and successfully working both on its own facilities and in co-operation on overseas facilities.

In terms of public confidence, Masahiro SHIBATA said that relevant technologies for the implementation of DGR have already been demonstrated, which is likely to build trust. One of the roles of the Horonobe URL is to welcome visitors there and show them the concept and technical credibility of the DGR. Showing what is going on in the URL will help with public acceptance and build public confidence.

The expectations are different for each of the stakeholders, reminded Stratis VOMVORIS. Consideration should therefore be given to ways of explaining the details of the experiments and showing the facilities according to the background and expectations of different stakeholders such as non-scientific decision makers, regulators or the general public. An important aspect is to involve relevant technical staff in such communications and capture and transfer their enthusiasm in transmitting such information successfully.

Seeing the actual installations is necessary for a good understanding of the future DGR, explained Patrik VIDSTRAND. Maintaining confidence among staff involved in URLs is also important for passing on knowledge and as a way of learning faster for subsequent generations.

Frédéric PLAS confirmed the importance for the public to see the reality of disposal facilities and the technological aspects, and he recalled that the DGR is part of a long development process.

As regards the preparation of regulators, a consensus has tended to emerge that encourages them to follow experiments of a rather generic nature and participate in intercomparison exercises. On the other hand, it is difficult to associate them with the experiments because they will have to judge the results within the framework of their review of the safety files.

Finally, it should be kept in mind that the programming of experiments in the URLs is essentially intended to meet the needs expressed by the development stage of the DGR projects.

The information exchange and discussions at the web conference were useful and the outcome was reflected in the development of the Agenda of the In-person Workshop at Horonobe URL Japan (See Annex A).

3. An overview of URL development

3.1. Opening session

The NEA and METI International Workshop on Joint Utilisation of Underground Research Laboratories for R&D Projects was organised in Horonobe and Wakkanai (Japan) from 1 to 3 November 2022. The workshop was opened by its two co-chairs, Magnus Holmqvist and Hiroyuki Umeki.

Hitoshi Nonomura, Mayor of Horonobe, in turn welcomed the participants to the workshop, emphasising the honour of having hosted the JAEA teams since 1998 for the construction and the operation of the underground laboratory. Many organisations and research institutions have since jointly contributed to research development in the Horonobe underground laboratory. The next stage of development is the extension of the infrastructure with a deepening to 500 m. He wished fruitful exchanges between the institutions of the different countries present for the continuation of the R&D programmes in Horonobe.

Rebecca Tadesse, Head of the Radioactive Waste Management and Decommissioning Division at the NEA, thanked Hitoshi Nonomura, Mayor of Horonobe, for his words of welcome, then METI and JAEA for their efforts in organising the workshop, and finally the programme committee as well as its two co-chairs, Magnus Holmqvist and Hiroyuki Umeki, for their commitment and their efforts over two years in the organisation of the workshop. In 2019 and 2020, METI of Japan, the US DOE and the NEA co-sponsored the international roundtable on the geological disposal of radioactive waste and spent fuel, with the participation of 15 countries, NEA and IAEA. On the occasion of the work of the two sessions, it was recognised that international co-operation is important to maintain and strengthen the technology, to increase the capabilities for the establishment of geological repositories, and to improve stakeholder confidence. Significant progress has already been made in a few countries such as Finland, Sweden, France and Switzerland. The NEA recognises the value of international co-operation in research undertaken in underground laboratories. The workshop was an opportunity to discuss the strengthening of international co-operation to develop solutions for the disposal of radioactive waste and spent fuel. The NEA supports initiatives in this field through its Radioactive Waste Management Committee and its various groups, whose experts from the most advanced countries share their approaches and experiences with those from less advanced countries. The workshop in Horonobe was the fruit of the exchanges held within the roundtables. It was initially planned for 2020, then had to be postponed because of the COVID-19 pandemic. During this period, webinars made it possible to maintain activity to better prepare the workshop. These webinars made it possible to propose a precise programme for the workshop, for the implementation of an effective and efficient project covering the long-term implementation of geological disposal. This will cover waste technical understanding, to be shared with incumbent and new generations, in a framework of financial and human resources for R&D related to DGR development benefiting from wider exchanges within an international community. Underground research facilities made available in other countries are invaluable resources, especially for those countries in early stages of the DGR decision-making process that have not yet identified a host rock environment. New opportunities for collaboration were identified, such as developing a methodology using big data applied for more realistic safety assessments, or development of robotic technologies for operational efficiency and safety, and optimisation of the design of the repository during construction and operational phases. From these perspectives, existing URLs can constitute an effective platform for intensifying international collaboration.

After thanking the participants for their attendance and welcoming them, Tomokazu Shimohori, Director of the Radioactive Waste Management Policy Division, at the Ministry of Economy, Trade and Industry (METI), recalled the services provided by nuclear energy, also in the context of climate change. The production of nuclear energy results in the production of radioactive waste, for which safe disposal must be designed in a geological environment. One of the challenging stages is the search for a host site. The other major challenge is to develop the necessary knowledge, which is done, among other things, thanks to the underground laboratories. In the wake of the exchanges that METI had with the US DOE and the NEA, it appeared necessary to broaden the debate on a better sharing of resources, in particular for themes of common interest. The workshop provides an opportunity to discuss possibilities for reinforced co-operation within an international framework.

Masahiro Shibata, Director of the Horonobe Underground Research Center, JAEA, welcomed the participants and expressed his pleasure in hosting the NEA and METI International Workshop on Joint Utilisation of Underground Research Laboratories for R&D projects. He noted the exchanges in the workshop would focus on the promotion of co-operation using underground laboratories, including Horonobe URL. For JAEA, research into geological disposal began in the 1970s. International co-operation was quickly set up within the first underground laboratories, under the co-ordination of the NEA. JAEA got involved early on. In 2001, the underground laboratory project at Horonobe came into being. With now over 20 years of research and investigation, the time has come to promote its activities on an international level by fostering co-operation, with the support of the NEA.

3.2. Session 1: Overviews of URL development

Session 1 provides an update on the benefits provided by URLs. They are the privileged place for research and technological development with a view to the construction and operation of DGRs. They allow the development of processes and the demonstration of their reliability. It is in the context of URLs that a great deal of data is produced to feed the various modelling and safety demonstrations. The various interventions focus on the issue of trust. The first challenge is to strengthen the confidence of the teams in charge of studies of URLs, and more generally of the DGR. It is also important to construct the URL to explain the approaches and achievements to the main stakeholders, in particular those directly involved in the development process of the geological repository. These include waste producers, authorities responsible for nuclear safety, and the various administrations responsible for energy or the environment. The trust of the public as a whole is also an important aspect and URLs play an important role in reassuring local residents and the wider population. URLs also provide an important component for team training and for the transmission of knowledge and know-how between generations that will follow one another during a DGR implementation programme. Radioactive waste management being a relatively recent discipline, the various teams have a particular interest in co-operating. URLs are privileged places for co-operation, including international co-operation. They make it possible, through joint projects, to compare approaches, technologies and methodologies for the benefit of all. The particularly long duration of DGR development projects also involves technological developments that URLs can test for appropriation within the framework of DGR projects.

The URL offers exclusive opportunities for DGR R&D and personnel preparation.

A panoramic assessment of the achievements at the level of the European Union as well as that of the IAEA is also presented.

3.2.1. Introduction from the session chair Tomokazu SHIMOHORI (METI, Japan)

In the field of geological disposal for radioactive waste, URLs allow for generic as well as site-specific research. R&D is intended to identify the most suitable design solutions and to support the selection of the host rock. The results acquired in URLs are intended to feed the safety case; they also allow the implementer to engage in dialogue with the regulator as well as with other stakeholders at a rather early stage of the DGR programme. There are several URLs proposing developments within the framework of international co-operation. International projects are helpful for countries engaging in the development of geological disposal projects. The international R&D within the URLs allows a transfer of knowledge accumulated by the most advanced programmes to the less advanced ones, saving a lot of time and resources. This type of co-operation is also useful for fledgling programmes. During the workshop, a panoramic overview of the achievements in the different countries will be provided, before engaging in discussions on new possible international co-operation.

3.2.2. Review of the roundtables, Rebecca Tadesse (NEA)

The roundtable discussions began in 2019, on the occasion of the G20 Ministerial Meeting on Energy Transitions and the Global Environment for Sustainable Growth. The METI asked the US DOE and the NEA to initiate discussions on the issue of geological repositories of high-level radioactive waste and how international co-operation could promote the development of projects. The objective was to identify the remaining issues and assess the possibilities of addressing them. It is broken down into three levels: the strengthening of international co-operation to advance the development of disposal of high-level waste and spent nuclear fuels, sharing experience and knowledge in developing/implementing HLW and SNF disposal policy, and facilitating multilateral R&D collaborations to enhance technical capabilities and knowledge transfer.

The first roundtable was held in 2019 and focused on three sets of questions: collaborating internationally for the advancement of HLW&SNF disposal and the role of government in facilitating that co-operation; international co-operation on sharing knowledge and experience in enhancing public confidence; and international efforts to strengthen technological capabilities for the development and implementation of geological disposal. The findings are summarised below.

The roles of governments in DGR projects are firstly to develop national policy, legal frameworks and regulation for nuclear safety and security, to promote communication and engagement with stakeholders and to support RD&D programmes. Government should also play an active role in building and maintaining interactions with the public and local communities. Governments must foster international co-operation for the development of DGRs to demonstrate that a DGR is an internationally accepted concept for disposal of high-level waste. Lastly, it was also recognised that governments must actively involve all stakeholders during the development of a national policy and strategy on DGR, during the development of nuclear regulation, as well as during the early stage of the site selection process.

The theme of international co-operation and the commitment of stakeholders in the field of radioactive waste is widely covered within the framework of the FSC led by the NEA. Best practices and lessons learnt are discussed here, and it is not just a one-time issue. They cover the governmental policy framework, public engagement, the decision-making processes, financial support to local communities for their economy development, as well as the role of the regulator and of its involvement. To have a successful project, a stepwise, adaptative and fully transparent decision-making process is needed that involves key stakeholders, including implementers, regulators and the general public. Stakeholders' trust and confidence in the local DGR project increase when they can see that other countries are approaching it in the same way. By referring to projects abroad, in the process of obtaining their licence, confidence increases in the technologies implemented. Financial support to the host community can be important; there must be an added value aspect. The support plan should outline the benefits of a long-term DGR project to the local community. This does not mean that it is a question of paying funds to the local community for the closure of the DGR, but rather of accompanying it to equip itself with infrastructures, schools and services which will benefit the community in the long term. DGR projects are very long-term projects, and it is therefore important to involve the younger generations of stakeholders as early as possible in the decision-making process. Lastly, communication about safety, based on the safety case, can be challenging. Communication and dialogue should be explored with a wide range of scientists and experts.

In terms of technology and advancement, it was discussed that there is a need to come together on how to maintain and strengthen technology capabilities to support the development of DGRs, by identifying what the programmes undertaken can bring as well as the areas requiring new developments. Sharing R&D resources is also an effective way to progress under better conditions, and for this it is necessary to identify opportunities for international co-operation as well as bi- or multilateral collaborations.

Although there has been a history of successful international collaboration on the technical aspects of DGRs over the past 20 to 30 years, the participation of the current generation and the new generation in these programmes should be encouraged. Financial and human resources for R&D related to DGR development can always benefit from wider exchange within an international community. The underground research facilities made available in other countries are invaluable resources, especially for countries at an early stage in the DGR decision-making process that have not yet identified a host rock environment. New opportunities for collaboration were identified, such as developing a methodology using big data applied for more realistic safety assessment, or the development of robotic technologies for operational efficiency and safety, or optimisation of the design of the repository during construction and operational phases.

A report on the International Roundtable on the Final Disposal of High-Level Radioactive Waste and Spent Fuel was published by the NEA (NEA, 2020). The key messages of this report are that a stepwise, adaptive and fully transparent decision-making process must be developed. The involvement of young stakeholders in the decision-making process is valuable. The benefits of a long-term DGR project for the host community are necessary. Communication and dialogue with a wide range of scientists and experts, including those outside the field of nuclear science and engineering, are important. And finally, international collaboration on technical aspects, use of facilities and research in other countries is valuable.

3.2.3. Status of URLs in Japan and R&D projects in Horonobe and Mizunami URLs, Teruki IWATSUKI (JAEA)

The development of the geological disposal project in Japan is under the responsibility of NUMO, the implementer. JAEA is in charge of R&D for geological disposal technology and safety assessment methodology. Its research began in generic underground laboratories in 1996 at Mizunami, in a crystalline rock environment, then in 2001 at Horonobe, a sedimentary rock geological environment. In both cases, the majority of the R&D was related to geoscience. In addition, studies on disposal technologies and safety assessment methods are conducted based on the results from the Horonobe URL, with the objective of promoting public understanding. R&D activities at the Mizunami URL have ceased, with a backfilling of the tunnels, which is followed by a monitoring phase. In Horonobe, the extension of the programme until the end of March 2029 has been approved by the municipality, with the bulk of the R&D focusing on the disposal operation phase.

The investigations at Mizunami made it possible to propose a 3D geological model, then to derive the construction methods as well as a repository design. The hydraulic response in the environment of the URL allows the definition of different hydrogeological compartments in Mizunami. Solute transport tests in the URL made it possible to describe the transfers through the network of fractures, as well as in the rock matrix. The 20 or so years of R&D at Mizunami have enabled the development of investigation methods adapted to the geological context, the development of construction methods, and the identification of the operating conditions of the structures. Finally, the major experience at Mizunami concerns the full-scale backfilling of structures and the monitoring of operations and the environment, planned until the end of March 2028.

The Horonobe site was selected in particular following preliminary studies from the surface and the expected geometric characteristics of the formation. Geological studies, including estimates of the mechanical strength of rocks and hydrogeological and geochemical behaviour, led to the design of the architecture of the URL. The superficial zone is dominated by advection, resulting in the chemistry of the waters by a mixture of shallow water with fossil seawater. The deeper zone contains fossil seawater older than a million years and would be hydraulically closed. The current R&D programme has focused on the -350 m level. Many tests have been carried out so far, on the engineered barrier system (EBS), the corrosion of overpacks, the characterisation of the excavation damaged zone (EDZ), solute transport, and the thermo-hydro-mechanical coupled process (THM) modelling. The future developments planned at -500 m will make it possible to describe the transport of solutes in more favourable conditions for the future DGR, and to renew the constructability and implementation tests of the EBS in this new geological environment.

The experience of work in URLs, at Mizunami as at Horonobe, has made it possible, thanks to the organised visits, to familiarise the public with this type of installation and the problems of the geological disposal of radioactive waste. The numerous publications, hosting of young researchers and the presentations within schools and universities make it possible to raise awareness of the problem among a wider population.

The Horonobe project is already evolving in the international context, with its participation in Decovalex, its partnership within the framework of the Pacific Rim Partnership, and lectures to students and young researchers from Asian countries. At present, the Horonobe International Project (HIP) is being set up with the support of the NEA, for a period of seven years, around three tasks relating to the transport of solutes, the systematic integration of repository technology options, and the full-scale experiment in the dismantling of EBS.

3.2.4. A holistic vision of the URL's role in DGR projects' development, Hiroyuki UMEKI (NUMO)

Despite the experience already acquired in URLs, these laboratories are more important than ever. Whether generic URLs or site-specific URLs, there is a continuous need to increase knowledge, develop and test technologies, verify and validate models, and increase training and communication with the public. National DGR programmes increasingly lack generalists with a panoramic view of the scientific and technical bases of geological disposal. Representations by numerical modelling lack cases of validation given the timescales involved, and consequently the propagation of uncertainties over time is difficult to control. In order to meet these challenges, it is necessary to introduce lateral thinking to conventional R&D programmes. This should be characterised by an integrated approach to designing programmes in line with the DGR project milestones, and the synergies between academic research and needs for geological disposal should be increasingly explicit.

To design work in next-generation URLs, it is necessary to identify the limitations of current approaches, and in particular to integrate the requirements for operating DGRs. It will in fact be necessary to envisage operations for the emplacement of radioactive waste packages and the construction of EBS in a repetitive manner many times, while ensuring the continuous quality of the achievements, all this over several generations and under public scrutiny. URL programmes should take into account the requirements of different stakeholders, including implementers, regulators and host communities. The perspective must cover the entire period of operation, until the closure of the DGR, after about a century of operation, emphasising a holistic approach and the opportunities for multidisciplinary training.

Thanks to the programmes in the URL, the regulator will develop its experience and its capacity to review licence applications at the same time as the implementer completes its knowledge and develops its own experience. The regulator will focus its reflection on compliance with the various requirements and on the treatment of uncertainties. By getting involved in URL projects, the regulator will acquire first-hand experience, likely to consolidate implementation and support public confidence. One of the important questions is that of the knowledge transfer through the generations that will be involved in the DGR project. The evolution of boundary conditions over time requires the involvement of every stakeholder, in a spirit of openness and transparency towards stakeholders. One of the ways is to rely on URLs to support the DGR programme and at the same time consolidate public confidence. URLs can be the training centre for the next generations, in particular for generalists who will have to manage the safety case. Knowledge management and quality assurance (QA) procedures must accompany the project, which must also allow effective communication with stakeholders and the public.

By way of illustration, the privileged domains of generic URLs are presented, as well as aspects of site-specific URLs. Note the ability to conduct very long-term tests in generic URLs, which is unrealistic for a site-specific URL. On the other hand, in the latter case, the conditions are those of the disposal site, unlike the generic URLs. The generic URL also makes it possible to start the appropriate technological developments very much in advance of the phase compared to the site-specific URL. Model validations will have their full meaning in site-specific URLs, but over more limited durations than in generic URLs. Despite the number of generic URLs, it is still necessary to develop them to respond on the one hand to the growing demand for new DGR programmes and on the other hand to develop increasingly sophisticated tests. In any event, they will not exempt confirmations in the DGR conditions.

3.2.5. International research programmes in URLs (opportunities, needs, perspectives), Seifallah BEN HADJ HASSINE (DG RTD, Euratom Research, EURAD)

As part of the European Union's Horizon Europe 2021-2027 programmes, around EUR 52 million will be devoted over 5 years to radioactive waste management and geological disposal. Additional budgets are also reserved for research infrastructures, such as URLs, training and mobility. The budgets are intended to support the projects, to stimulate co-operation between the programmes of the EU member states, to avoid duplication, and to encourage international co-operation.

For more than 40 years, the EC has supported research on radioactive waste management, in a first phase with individual partners, with the objective of supplementing national programmes, then through projects involving several partners, before evolving towards large integrated and co-operative projects such as IGD-TP, and now through joint programmes.

Thus, since 1975, many projects have been supported by the EC. In the field of URLs, it was first the HADES project, in the clay of Mol (Belgium), then the salt in Asse (Germany). At the same time, the first safety studies were developed, with the PAGIS and MIRAGE projects, then the first SAFIR report focused on demonstrating the safety of geological disposal. At the same time, the development of modelling and other study methods has been developed. The link between studies in URLs and safety studies became explicit in the mid-1990s. Developments of a more technological nature were then supported, while maintaining a substantial volume of activities in the fundamental disciplines for the DGR, in particular on the transport and retention of radionuclides in a geological environment. In terms of technologies, the demonstration of the design and construction of EBS, as well as substantial developments in monitoring and surveillance can be noted. An important step was taken in 2011 with the publication of the Waste Directive on the management of radioactive waste in Europe. It was also during the 2000s that studies for enhanced co-ordination and co-operation between member states were developed, giving rise in 2019 to the implementation of the EURAD project, bringing together all the stakeholders, but above all the world research with implementers, and the SITEX project, a platform intended for technical supporting organisations (TSOs).

EURAD is a joint programme on radioactive waste management. Its objectives relate to the establishment of a robust state of the art for science and technology programmes, to conduct studies of a strategic nature necessary for all, advanced countries as well as less advanced countries, to establish knowledge management between member states and between generations, and to foster mutual understanding, including with civil society, in order to build trust. EURAD brings together 23 EU member states as well as three international partners, with a total of more than 100 participating organisations and institutions. The programmes in connection with the predisposal, until now co-ordinated within the framework of PREDIS, will integrate EURAD in 2024, which will ensure greater coherence between the various stages of the management of radioactive waste, until their disposal. All information related to EURAD and its many publications is available on its website www.ejp-eurad.eu/.

3.2.6. RD&D in underground research facilities and international co-operation: Two pillars fundamental to successful implementation of geological disposal, Stefan MAYER (IAEA)

To date, 32 countries have nuclear power generation. Having a DGR for spent fuels and HLW is the solution recognised by all. A large body of knowledge is already available for the development of these DGRs, and the IAEA set up a URF network in 2001 to allow the exchange of information and encourage the training of professionals for geological disposal. Concrete DGR projects are progressing, particularly in Finland, France and Sweden, followed by significant progress in Canada and Switzerland. Other programmes are also progressing, including in Japan for site selection. The IAEA supports projects at different stages of their development, in particular with the significant production of documents and guides as contributions to the transfer of knowledge.

URF activities support national DGR development programmes through all planning, design, construction and maintenance tasks. They allow in situ characterisation, scientific research and technological developments as well as the implementation of demonstrators. URFs are also an excellent tool for training and raising awareness among stakeholders. These tasks can also be carried out via international co-operation, with URFs abroad, something that may be especially useful during the early development phases of DGR programmes. Given that mined geological disposal is a relatively recent discipline, without as yet any routine operation of HLW disposal to refer to, the sharing of expertise, costs and results in the continuous quest of successful progress benefits everyone, including the most advanced programmes.

Over 30 URFs have been built and operated around the world, with the earliest activities carried out more than 60 years ago, and over half of the historical URFs have already ceased their activity. With the support of all current or prior operators of these URFs, the IAEA has compiled a global Compendium along with the most significant experiments conducted in all these URFs, which is being prepared for the publication process. International co-operation has been an important component of the experiments conducted in most of the global URFs, based on shared interest and the mutual benefit of co-operating partners. Such co-operation provides many benefits, among which the ability to develop the skills and competences needed when initiating a new programme, and improving the resources available to conduct RD&D. The co-operation established within the URFs RD&D programme also constitutes a good platform for consistent dialogue at the technical level between representatives of distinct DGR programmes, providing further potential to identify optimisation leads for DGR design, construction or operation.

Several examples of generic URFs illustrate this point, starting with Whiteshell in Canada, in granite, the closure of which was an opportunity to experiment with the sealing of the shaft. In a clay environment, HADES is the oldest purpose-built URF, in Mol in Belgium. Among the first experimental objectives were characterising and establishing the specific rock mechanical properties of the plastic clay formation. As in most other URFs, the focus of the experimental RD&D programme tends to evolve from characterising and modelling rock properties to establishing the basis for coupled process models, to full-scale demonstrators and testing and adjusting construction technologies. In Äspö (Sweden), technologies associated with the transfer and emplacement of the disposal container, buffer and seals considered by design for the future DGR in granite have been tested. Beishan, China, provides for a continued site characterisation from baseline over response to construction to establishing in situ properties as well as studies on excavation techniques. The Grimsel Test Site, in Switzerland, has also seen numerous tests in granite since 1982, including those on the behaviour of bentonite at high temperatures.

In recent years, significant progress has been made towards the start of disposal operations, with the DGR programme in Finland planning first trial disposal operations in 2023, Sweden preparing for construction and France submitting its licence application in 2022, whereas the Swiss programme recommended a site in September 2022 and Canada planning its preferred site selection in 2024. These advanced programmes, including others such as those in Germany, Japan and the United Kingdom with their scientific and technical expertise and 60 years of RD&D experience in URFs, establish a substantial knowledge base and a solid foundation on which more recent programmes can rely and build on.

International co-operation in URFs has the potential to increase the skills of new DGR programmes, support URF projects in preparation for DGRs, relying on international experience to design specific experiments, to share expertise, costs and results, and to exchange views increasing optimisation.

4. Session 2: Horonobe Joint Project and potential areas of international co-operation

Session 2 provided an overview of the programme in Japan and activities at the Horonobe URL. The HIP project is intended to strengthen co-operation between Japanese teams as well as internationally. The NEA provides a framework for international co-operation that is well suited to the HIP. The need for technologies suitable for a DGR, and requiring testing in URLs, systematic technology integration plans for implementing EBS, a step-by-step approach for flexible optimisation of design options, and finally R&D programmes for tracers and material ageing centrifugation tests, will greatly contribute to the development of activities in the Horonobe URL and therefore in the HIP. Many interdependencies exist between the different programmes. The results and successes of some programmes also benefit others, thereby increasing the trust and acceptance of future DGRs, an additional reason to promote international co-operation.

4.1. NEA capacity supporting international co-operation, the Horonobe International Project "HIP", Rebecca TADESSE (NEA)

The NEA brings together 34 countries around the themes of nuclear safety, technologies and policies. Its actions are organised around 8 committees and more than 80 working groups. The NEA also manages specialised databases on nuclear data and codes. The back end of the cycle is dealt with through two standing technical committees, the Radioactive Waste Management Committee, and the Committee on Decommissioning of Nuclear Installations and Legacy Management. Among the groups directly related to the URLs, the Integrated Group for the Safety Case (IGSC) covers aspects of the development of the safety case as well as operational safety. Several other groups are also worth mentioning, such as the Expert Group on Building Constructive Dialogues between Regulators and Implementers in Developing Disposal Solutions for Radioactive Waste (RIDD), the Expert Group on Knowledge Management for Radioactive Waste Management Programmes and Decommissioning (EGKM), the Regulators' Forum and the Forum on Stakeholder Confidence.

Alongside these structures, the NEA has also put in place the means to manage joint projects, in particular to bring the parties together around identified themes of common interest. In this case, the NEA essentially plays a role of secretariat and facilitator, according to Article 5 of the NEA Statute. Joint projects are initially set up for 3 years, with the possibility of extension. The costs are borne by its members, and therefore the results belong to them, generally for 7 years. The results are then entered into the NEA database and become accessible to NEA members. The role of the NEA is to provide administrative support, to keep the Steering Committee informed of current activities, to provide secretarial services for the Management Board, the Technical Advisory Group (TAG) and the Presidents, and to manage the respective contributions according to the financial rules of the OECD.

The proposal for the Horonobe International Project (HIP) arose from the discussions of the METI/DOE/NEA international roundtable on the use of R&D facilities, which were to be supplemented by exchanges between R&D experts in the field of management of radioactive waste and spent fuel during this workshop at the Horonobe URL. Key topics to be addressed in HIP relate to solute transport experimentation and modelling (Task A), systematic integration of repository technology options (Task B), and dismantling of the full-scale engineered barrier system (EBS) experiment (Task C). The Horonobe URL is dug in an environment which could approach that of a future DGR. It thus makes it possible to develop a good understanding of subsurface processes and offers the opportunity to develop techniques and models in a real geological environment. For two decades, the Horonobe URL has been used to address site investigation and engineering issues related to DGR and post-closure safety assessment. It constitutes a platform for international collaboration in Der as well as for training. The HIP is planned until 2029. The organisation provides for a Management Board, which is informed on a technical level by the Programme review group. Steering is provided by a project manager, the operator remaining the JAEA. The NEA ensures the co-ordination, the secretariat and the financial management of the project, including with the contractors. Signing of the agreement for the HIP as a NEA Joint Project is expected by December 2022. Publications related to the joint project will bear the NEA logo.

4.2. Advanced technologies needed for URL (and future for DGR), Takeshi EBASHI (NUMO, Japan)

The DGR will be an exclusive construction, characterised by its duration of operation, by the time scales taken into account for the safety assessment, by the specific regulatory requirements and by increased public awareness. The complexity of the project implies using advanced technologies for an increasing integration of knowledge to ensure the maintenance of the best state of the art during the successive generations and the dialogue with stakeholders. Many developments and testing of technologies can only be done in URLs. In particular, new technologies can greatly contribute to optimising projects that have been underway for several decades. Often, efforts have focused on post-closure, but it is now also necessary to consider safety during the construction, operation and closure of DGRs. The durations of DGR projects and the sensitivity they represent demand the use of the best available technologies (BAT), which requires trials and tests under DGR conditions, which can mostly be done in URLs. In particular, it is necessary to be able to manage large quantities of information and knowledge, taking into account their evolutions and uncertainties.

Reliable technologies have been developed so far, but progress is still needed concerning, for example, EBS materials, automation of disposal operation, EBS and natural barriers monitoring, simulation, and the introduction of artificial intelligence (AI). The deployment of robotics and remote-controlled systems is envisaged for repetitive operations, both construction and operation. Automation is also a response to future human resource problems. It can not only make up for the lack of manpower, but also improves safety and logistical conditions, for example with the help of the fully automated jumbo drill. The different waste placement methods as well as tunnel excavation methods have also given rise to comparative tests and analyses between traditional methods and automated ones. Disposal hole drilling technologies have also been tested and compared with remote-controlled methods, including a test in Horonobe. Robotics and remote system were also tested for tunnel excavation, aiming to reduce EDZ and improve the rate of placement of waste packages. The use of AI is also promising for different applications, such as for example for mapping the system of fractures on the walls of tunnels, or for estimating the origin of water, deep or more superficial. In the area of programming site investigations, tests have been carried out by JAEA but the processing of information still needs to be improved, particularly given the large amounts of data.

Finally, the URL is also useful for exchanges with stakeholders and to create public acceptance. This role can even be extended to maintain acceptance during the institutional control phase.

4.3. Plan for systematic integration of technologies towards EBS emplacement, Akira HAYANO (JAEA, Japan)

The design and construction of the geological repository involves proper consideration of the geological structure, its fractures and its hydraulic properties, in particular to assess their impact on the long-term stability of EBS and on the migration of radionuclides. It is therefore necessary to characterise the geological medium in detail to be able to manage the zones of fractures and faults. It is necessary to be able to mobilise and integrate the technologies available to characterise the environment, specify the concepts, and define the conditions for the construction of the disposal pits.

The characterisation of the fault system in the Wakkanai formation at Horonobe reveals two types of faults, some of which allow water circulation. The design of the experimental galleries at the Horonobe URL had to be adjusted accordingly to take into account water inflows and the size of the cement grouting. Specific design criteria will be required for the future DGR. It is also important to avoid or limit the formation of EDZ behind the walls of tunnels and other excavations in order to avoid favouring hydraulic connections. It is also important to avoid or limit the formation of EDZ behind the walls of tunnels and other excavations in order to avoid favouring hydraulic connections. At Horonobe, at a depth of 350 m, an increase in permeability of five orders of magnitude could be observed at the level of the EDZ compared to the intact rock. The evolution of water transfers could also be modelled.

In the upcoming programme, at a depth of 500 m level, the challenge will be to demonstrate the implementation of the technologies necessary for the geological characterisation, the design and construction of the structures and the installation of the EBS. Data on faults and EDZ data will be generated, including their hydraulic and mechanical properties. The necessary experiments have been modelled, and the procedure for carrying out the tests has been described. It covers the excavation of experimental galleries, the borehole drilling and excavation of pits, and the installation of EBS.

The design of the DGR requires an approach integrating the geological characteristics of the site, the results of the investigations, the modelling as well as the requirements and the safety functions. The various technological options must be optimised within a rational method according to the concepts and evaluation criteria.

4.4. Stepwise R&D on operational technology options including robotics towards flexible optimisation, Minoru EMORI (RWMC, Japan)

In Japan, a stepwise approach has been adopted, updating facility development to the information available during investigations and underground activities. Currently, the literature surveys are underway on the two candidate municipalities for the first phase of the siting process. Progressiveness allows continuous adaptation by taking into account future uncertainties such as new information both on the geological feature and in political and social matters. It is necessary to have flexibility to be able to take the necessary measures in view of the uncertainties. Uncertainties will be able to be managed through the "diversity of technologies", working with a range of design options and a set of technology options applied for the operation of the DGR.

International discussions have shown the DGR design optimisation concept associated with the BAT and ALARA concepts, not only for radiological protection aspects but also on the basis of optimisation evaluation criteria. On this basis, comprehensive evaluation factors for optimisation for facility design can be developed. A set of factors for evaluating the optimisation of the design of the DGR is proposed, accompanied by indicators for each of the factors. For example, safety before repository closure, like long-term safety, can be optimised by working on the reliability, predictability and controllability of uncertainties. The reversibility of the disposal project will be based on the technical feasibility of the options, the ease of retrieval of the waste packages and on the period during which retrievability remains possible.

NUMO, the implementer of DGR projects in Japan, exemplified two disposal design options in its safety case. It will be necessary to refine the design in more detail and consider operational technology options to support their feasibility. In any case, various technologies must be considered for the construction, operation and closure of the DGR. This ensures flexibility with respect to requirements, specifications and desired quality, and also to be able to adapt to various geological conditions. Several examples illustrate the subject, the waste package retrieving technology, the sealing and backfilling of galleries, or even monitoring into the DGR. The optimisation evaluation factor can be analysed for each technology, independently of the design options, thus allowing the effective consideration of the characteristics and respective functions of each of the technologies. The evaluation factors are different between the design of the DGR and each of the operational technologies. By setting detailed evaluation factors individually, according to the features of each operating technology, the optimisation can be more effective.

The introduction of robotics is desired for various reasons, such as radiological protection, the quality of repetitive operations, or the rationalisation of human resources. The implementation of robots is analysed through the optimisation of technological options. However, it can only be done at a more advanced stage of the design of the DGR and the description of its operating conditions. On the other hand, they can now be the subject of developments within the framework of R&D, such as remote control technology, digging without human, manufacture of PEMs, installation of EBS or even retrieving of waste packages. In addition, alternative design options can be studied, allowing easier implementation of advanced technologies and robotics. This can lead to new R&D programmes, such as the emplacement of smaller-sized PEMs in tunnels that are also of smaller cross-section.

4.5. Research and development on tracer test and centrifugal test, Takuma HASEGAWA (CRIEPI, Japan)

The Central Research Institute of Electric Power Industry (CRIEPI) is involved in research for the DGR. Its R&D fields relate to geology, hydrogeology and EBS. Programmes are also conducted jointly with NUMO, JAEA, RWMC and overseas projects. As part of the HIP, CRIEPI plans to contribute to experiments and modelling of solute transport (Task A) and to the full-scale EBS dismantling experiment (Task C).

One of the important questions for the DGR safety demonstration relates to the transport of solutes. Tests using tracers remain necessary to allow a better description and modelling of the dominant processes, in particular in a fractured geological system. Some tests were carried out at the Mizunami URL, in granite, where the injection device through a packer and follow-up could be tested. The diffusion effect in the rock matrix could be characterised thanks to the shift in response time between two non-reactive tracers. The adsorption effect could also be characterised using cationic tracers. The modelling carried out made it possible to restore the results, also corroborated by other observations in the boreholes or in the laboratory. Within the framework of Task A, it is envisaged to deploy all of the acquired knowledge on tracer tests in a single well. Preparatory tests were carried out in the laboratory on simulated fractures. The results obtained are in conformity with those from the modelling. Based on laboratory tests and data obtained in situ at the Horonobe URL, the objective is to assess the parameters necessary for the safety assessment.

Concerning Task C, the idea is to carry out ageing tests of the EBS material under accelerated conditions using centrifugation tests. The results should make it possible to simulate the THM evolution of the material. Modelling and numerical simulation is an important tool to support these tests and in particular to compare the results with those obtained during centrifugation tests.

Finally, behind the participation of CRIEPI in the HIP project and international co-operation initiatives is also the concern of preparing human resources for laboratory and in situ tests.

4.6. The URL's role in demonstrating DGR safety and building public confidence, Magnus HOLMQVIST (SKB, Sweden)

The experience of URLs began in Sweden at the end of the 1970s in the Stripa mine. The project, initially carried out within the framework of co-operation between Sweden and the United States, became more international in 1980, within the framework of the NEA. The need to study geology, hydrogeology and geochemistry in 1995 in an undisturbed environment by previous mining activities led to the creation of the Äspö URL. The URL makes it possible to conduct R&D in many fields, for site investigation technologies, for radionuclide migration tests, to understand the mechanisms of chemical interactions between materials and so on. It also allows the development of methods for constructing, operating and closing the repository.

Initially, the URL giving direct access to the geological environment makes it possible to describe and understand the physical and chemical processes of which it is the seat. At this stage, it is a question of accumulating knowledge and know-how, which makes it possible to reinforce confidence, internally as well as vis-à-vis stakeholders and the public. Understanding the processes, in particular using tracer tests, is a key element in the demonstration of the safety of the future DGR.

Secondly, the URL allows technological developments, construction methods and operation of the DGR. Integration and functionality tests demonstrate the technical feasibility of the disposal, elements feeding the licence application for operations. The accumulated data is used for the post-closure safety assessment, as well as to build confidence in the KBS-3 concept capabilities and functionality.

The other interest of the URL is to increase the public's confidence in the DGR, thanks to the visits and the dialogue which is established in complete transparency with the public, and in particular experts, promoting opinion relays. International co-operation in URLs also strengthens this trust.

4.7. Role of URLs in education and training programmes, Ingo Blechschmidt (Nagra, Switzerland)

URLs are above all infrastructures for RD&D, allowing studies with more realistic boundary conditions. As the RD&D needs change with the progress of the DGR projects, the URL programmes also need to be adapted gradually. These programmes are characterised by a broad spectrum of scientific and engineering projects and intensive international co-operation. Knowledge transfer and transparent dialogue with stakeholders and the general public play an important role. URLs are an integral part of DGR programmes and their RD&D programmes must be conducted in the context of DGR programme status and needs. As a result, once the DGR site is selected, studies in generic URLs (site-independent URLs) will transition to site-specific studies (on-site URLs) for example for site confirmation.

The nature of RD&D within the URL changes over time. Initially, the objective is to characterise the geological environment, in particular in relation to its capacity to confine radioactive waste. Secondly, it essentially involves characterising and describing the processes likely to occur during the lifetime of the repository. Finally, the URL offers the possibility of carrying out long-term experiments and testing technological demonstrators. Switzerland has two URLs: the first in granite at Grimsel, in operation since 1984, and the second in Opalinus clay at Mont Terri, in operation since 1995. These two URLs have enabled the training of several generations of young researchers and engineers specialised in the field of radioactive waste disposal.

In the field of education and training, the first objective is to raise students' awareness of the disciplines related to the disposal of radioactive waste in the DGR, including geology and all other sciences and technologies. To this end, e.g. lessons are held in schools and visits to the URLs are organised.

The training, which requires a high level of expertise, is aimed more at professionals from organisations involved in radioactive waste management, as well as researchers from the various laboratories and universities working on the subject. The aim is to familiarise them with working in the underground environment and to ensure the transfer of knowledge under ideal conditions.

To promote exchanges and the transfer of knowledge, and to provide training in the skills necessary for the management of radioactive waste, the Grimsel Training Center (GTC) has been set up. Several training events (courses, workshops, scientific visits, etc.) are organised each year, as well as visits at the request of, for example, the IAEA or the WMO or other stakeholders. Among the recent trainings, there were the properties of bentonite, or the implementation of tracers in URL, or geophysical data and their modelling. Most of the activities of the GTC are very practice-oriented and are carried out by tutors with many years of experience who are provided by the various international partners.

In addition to disposal topics, the GTC also offers courses on URL operation aspects or radiological protection training for handling radioactive material for in situ experiments or summer schools and workshops for university programmes. Public relations activities contribute to education and training, with numerous technical visits, exchanges with political representatives and civil society in general, TV and radio reporting, communication between scientists and non-scientists and numerous publications presenting the activities of Nagra. All these activities are carried out in close international co-operation.

4.8. Experience from the URL at the Yucca Mountain Project, William BOYLE (US DOE)

The Yucca Mountain project was suspended in 2010 but it continues to be polarising in the United States. Unlike the cases seen so far, the Exploratory Studies Facility at Yucca Mountain was a site-specific URL, for a possible disposal project. The first excavation took place in about 1993, and numerous tests and experiments were undertaken there. After just over 15 more years of work and studies, the activities were suspended, simply by suspending funding. A significant research effort has been devoted to Yucca Mountain, with the greatest expenditure going into its construction and operation.

The information accumulated from the site is invaluable, especially for the licence application for the DGR. One of the challenges was to characterise and describe the fracturing system at Yucca Mountain, which was not possible from only boreholes from the surface. The licence application was submitted to the NRC, which reviewed it and considered the level of scientific and technical information was sufficient to support the DGR's safety demonstration.

Given the mass of information generated, and in view of the licence application for the DGR, it was imperative to have an effective and appropriate QA system. All project participants were aware of this and complied with the QA requirements. The QA system was flexible enough that when the large-scale heater test was a DECOVALEX Task, the DOE participants adhered to the QA requirements, but the non-DOE participants did not have to adhere to the Yucca Mountain QA requirements. It was useful to send the message to project participants that QA should be viewed positively, rather than as an additional burden. QA is ultimately good business, good science and good engineering; it simply consists of writing what you will do, describing the processes and procedures, writing what has been done, what constitutes your documentation, and finally comparing one with the other. It is recommended, even for a generic URL, to give consideration of the QA system at the earliest stage.

Visits to Yucca Mountain were popular, with an average of approximately 10 000 visitors per year. At present, visits are only reserved for those with a demonstrable need to be there. One of the interesting aspects is, to borrow a quote from the movie *Field of Dreams*, the notion of “build it and they will come”. If you have a URL, it will attract different organisations and institutions, researchers will want to access the URL, each to conduct research in their particular area.

Finally, it is also recommended, as is already the case for the teams in Japan, to participate in the work of DECOVALEX, an excellent platform for international scientific co-operation.

4.9. SKB’s approach and experiences regarding site characterisation - site descriptive modelling, Magnus ODÉN (SKB, Sweden)

The Hard Rock Laboratory (HRL) in Äspö, dug in granite, was commissioned in 1995. The Äspö HRL has been central for the development of methods regarding disposal of nuclear waste in Sweden. During the pre-investigation phase, surface investigations were carried out to locate a suitable site for the laboratory and predictions were made of the geological, hydrogeological and rock mechanical conditions to be observed during the construction. The experiences from this phase were later implemented successfully during the site investigations in Forsmark. During the construction phase, investigations were carried out in parallel with construction and an evaluation of the predictions was made. The prediction/outcome analyses during these two phases were identified as important for demonstrating site understanding. This yielded important experience that is now implemented in the programme for characterisation during construction. During the operational phase a great number of different experiments have been conducted for the technological development of methods and technologies for a final repository.

The monitoring of hydrogeological conditions is the basis of the description and understanding of the site. Monitoring equipment should be installed in boreholes as soon as possible after the investigations are done in order to capture the responses from various perturbations, from new boreholes or from the tunnel excavation. The R&D from the URL is intended to characterise the site with a view to understanding the properties of the rock volume. It must also focus on the radionuclide retention processes in the rock and in the engineered structures, and the information generated will directly feed the safety assessment and the safety case. Finally, the URL makes it possible to develop and test the construction technologies of the DGR, the EBS and the equipment necessary for operations.

Moving on to the DGR project, the characterisation programme at the Forsmark site was primarily intended to verify that the site was suitable from the point of view of long-term safety, constructability and volume available for disposal. The information collected is used for selecting the repository concept, in the safety assessment, for the DGR design, and in the environmental impact assessment. The success of the characterisation programme depends on the good interaction between the on-site investigations and the teams in charge of the site descriptive modelling. The latter, at the centre of the system, also interacts with safety studies, repository design and environmental impact assessments, and ensures feedback towards site investigations, all in an iterative process.

The site descriptive model (SDM) reports the understanding of the site. It integrates all the information available in a coherent 3D representation, also making it possible to check the validity of the information at each measurement or observation point. It makes it possible to evaluate the uncertainties and therefore the degree of confidence that can be granted to the model. The data obtained on the site require processing in order to be used. They are first quality assured and then stored in databases. Then, the data are analysed and visualised within each discipline before being integrated into the SDM and finally being used for the various assessments, including that of long-term safety. At each iteration of the SDM modelling process it is necessary to freeze the data set used, which makes it possible to properly analyse the different information and interpretations, and to identify which uncertainties must be addressed in the next step.

The site selection process began in Sweden in 1993, and in 2009 the decision fell on the Forsmark site. Different site-specific questions in Forsmark had to be addressed, including ore potential, the 3D extension of tectonic lens, on the occurrence of gently dipping fracture zones, and on the occurrence of high rock stresses. The models by discipline have been integrated into the Forsmark model, including the conceptual fracturing model and the hydrogeological model. The site characterisation programme will continue during the construction of the DGR at Forsmark. It will include the accesses and also the deposition areas. The objective will be to verify the predictions obtained by the modelling, particularly in terms of fracturing characteristics and density, and therefore of their hydraulic properties. One of the important aspects is to assess the confidence in the modelling carried out. This can be done by comparing the data between those obtained from the surface and those obtained underground. The other method is to compare observations with model predictions. Characterisation during construction may also lead to rejection of some deposition tunnels/holes.

4.10. URL RD&D in support of technology innovation and demonstration, Frédéric PLAS (ANDRA, France)

The DGR project officially began in France in 1991, resulting in Cigéo’s licence application, which will be submitted to the safety authority in early 2023. It therefore took more than 30 years of investigations, RD&D and study, in a stepwise approach including successive Safety Cases addressing a specific challenge at each step and a continuous monitoring by the French Parliament. The success factors of the DGR development process in France are linked to clear governance of the project, in interaction with the various stakeholders, to a roadmap with well-defined milestones, to a RD&D programme, in particular at the Bure URL, and of course to international co-operation. The RD&D activities at the Bure URL accompanied the different steps of the development of the Cigéo

DGR project, with a progressive deployment of the necessary scientific disciplines and, since 2012, their progressive evolution towards the technological aspects coupled with science.

The major stages of the activities in the URL consisted in the first phase of demonstrating the feasibility of the DGR, and in a second phase of selecting the repository location in the Callovo-Oxfordian clay formation. The third phase was dominated by the definition of the safety options, including testing the first disposal cells for HLW and sealing tests. Finally, the phase that ends with the licence application will have been mainly devoted to technological aspects. At each phase, the process will have consisted of consolidating the approach, optimising it and improving its operability. The RD&D programme in the Bure URL will have focused on the characterisation of the host rock and in particular its transport properties, on the characterisation of the mechanical response of the host rock to the various mechanical, thermal and chemical stresses, on the evolution of the EBS materials in interaction with the geological formation, and on the technological demonstration of the construction and equipment of the repository, while ensuring that the safety functions are maintained in the various design options.

ANDRA has carried out work for some 40 years, both in underground laboratories abroad, at Stripa (Sweden) and HADES (Belgium) within the framework of international co-operation, through international projects and benchmarks, and now within the framework of EURAD.

Concerning the DGR project, the robustness of the approaches and options is one of the characteristics of the safety demonstration, generally relying on the BAT. However, this in no way excludes innovation, particularly given the development times for projects. Indeed, innovation today could become BAT tomorrow. Innovation must therefore find its place, particularly in URLs, for tests and adaptations with a view to the DGR and its safety demonstration. Innovation operates in three directions. Everything related to construction, including the waste packages and the installation of engineered barriers, benefits from current technical and technological developments and innovations. In the field of monitoring, from the detection of signals to their transmission and analysis, innovations are numerous and rapid. Finally, important there are developments in data mining and AI and more generally in the digital sector in connection with robotics.

As far as excavation is concerned, in addition to conventional boring processes, a tunnel boring machine (TBM) has been developed and tested. A micro-tunnel machine has also been developed for digging the HLW disposal cells. Important technological developments were also necessary to cross the galleries of large section for the intermediate-level waste (ILW). These developments allow good control of the EDZ in the deep clay environment. An interesting innovation should be noted concerning the development of compressible wedges and their integration into the walls of the tunnels. The concept has proven to be effective, in particular by supporting the convergence of the walls. The association of TBM excavation with the implementation of a compressive segment solution is interesting not only for the DGR, but also more generally for the construction of tunnels, for example railway tunnels. The technology allows for better management and stability of the intersections of large-section galleries. Micro-tunnelling has also seen significant and progressive development, now with the installation of a metallic sleeve. In the field of sensors and signal transmission, applications range from on-demand measurement to continuous monitoring. From sensors on board robots to non-destructive geophysical measurements coupled with optic fibres, or even monitoring of the thermomechanical load or corrosion, a multitude of solutions have been tested and implemented. AI, for its part, gives interesting perspectives on the data chain, particularly for tracking and monitoring.

The first developments are encouraging, for example for the interpretation of non-destructive data or even in terms of robot control.

4.11. Ways of integration of URL R&D (international) results into projects of concrete DGRs, Tina JALONEN (POSIVA, Finland)

At Onkalo, the first disposal tunnels have been dug, as well as the first spent fuel disposal demonstration cells. Unlike the other facilities presented so far, Onkalo has been designed as a repository, with its stopping points and its experimental areas for studies and research, from the characterisation of granite and its transport properties, up to the tests for setting up the engineered devices and full-scale deposition tests.

Studies at Onkalo began with site investigations, description of its features and physical processes. The information obtained made it possible to constitute the safety case for the licence application. Mechanical, hydrogeological and hydrogeochemical information was integrated to result in the Integrated Site Description, which in turn fed into the safety case, demonstrating the suitability of the rock and supporting the design of the DGR and its methods of construction. A rock suitability assessment method was developed, with a classification providing clear criteria for disposal areas. The characterisation and modelling data were compared to those of the classification to help in decisions on the different excavated structures. The rock construction method was developed to ensure that the rock properties are disturbed as little as possible during excavation, and to ensure that the disposal cells are carried out according to the requirements, with a predefined tolerance. The emplacement of the EBS into the deposition boreholes also gave rise to tests, the objective also being to test the mechanical means implemented. The final test before the operation of the DGR consists in carrying out a full-scale in situ test that is fully instrumented to collect data from the operation and the first phases of performance of the EBS. The Trial Run of Final Disposal is intended to cover the encapsulation of the spent fuel and the final disposal, all using the devices that will be implemented for the operation of the repository.

POSIVA was able to prepare its project in part through co-operation, particularly at Äspö and the Grimsel Test Site.

5. Potential for international co-operation

The needs of countries embarking on new DGR programmes and the capacity of countries already advanced in this field were discussed during two roundtables at the workshop. Participants were guided by a set of questions that were prepared by the Programme Committee of the Workshop to structure their contributions. A synthesis of the discussions is reported here, the objective being to bring to light any possible instances where demand meets supply.

5.1. Perspective of countries at the initial stages of their DGR projects

5.1.1. *How can existing/generic URLs be used for building confidence in your programmes? Follow-up questions: Disadvantages of not being domestic?*

The participation of teams in generic URL programmes has several advantages. First of all, it makes it possible to acquire experience in order to be able to engage in the development programmes of DGR. It also makes it possible to maintain the skills that will be necessary, both for the characterisation of geological environments and for tests and experiments, including in the R&D phase within a domestic URL. One of the essential questions of a DGR programme is that of the safety demonstration. Here again, the participation of the teams in the URLs programmes constitutes an important support, in terms of both data input and demonstration methodology. The scientific and technical teams can thus increase and strengthen their ability to engage in a site-specific URL and then DGR programme.

Decision makers and stakeholders may also be interested in the participation of national teams in the programmes of other URLs. Moreover, URLs can accommodate foreign visitors who are preparing their own political decisions and who have the possibility to get a first idea of what a URL and a future DGR represent.

In terms of public perception, a URL on national geological formation is an opportunity to present the DGR project in its various aspects, including those of R&D and the technological developments undertaken. In any case, it is much more significant to carry out experiments and R&D on national territory than in foreign URLs. The public seeks above all to understand the approaches and assumptions made in their national project that underlie the experiments and RD&D.

5.1.2. *Can modern technologies be used to overcome long distances for visits? Seeing is believing – but do stakeholders need to see in real life or would virtual reality do the trick?*

Modern technologies probably have a role to play in making different audiences aware of the work and R&D in underground laboratories. Virtual tours can be more adapted for younger audiences as well as remote tours. This is particularly true for a site like Horonobe, which is relatively difficult to access for Japanese citizens. The VR-videos and 3D images of Morsleben and Konrad in Germany were highly appreciated by different audiences. Nevertheless, nothing will replace the experience of spending a few minutes visiting the bottom of a URL.

Virtual reality is also to be considered for visiting future DGRs and seeing how they work. It can also be used to describe the phenomena likely to take place in a repository and as such can illustrate in a reduced space-time what can happen over hundreds of thousands of years.

5.1.3. Advanced programmes have many times already completed the early R&D phases needed to develop a disposal concept. How can the learning by doing be implemented in existing/generic URLs to obtain know-how by new/starting programmes?

For a country that does not have a URL, it is important to engage with others to learn and to prepare teams and their skills for national DGR programme development. Participation in experiments with existing URLs provides an introduction to the design of experiments, their launch and management, as well as methods for analysing the results. It is thus also an opportunity to understand the models that are associated with them and which will have to be implemented in one way or another for the safety demonstrations of the national DGRs. Existing URLs make it possible to learn, conceptualise approaches and identify additional R&D needs. They provide an excellent foundation from which to design new experiments to meet the site-specific context. In a nutshell, accessing other URLs reduces the learning curve. One of the key questions that the URL programme must be able to answer concerns the safety demonstration. For example, in Horonobe there is a fracture system that is very different from those in other geological environments. It is therefore important to study it, and foreign experiences as well as international co-operation have helped to develop a dedicated specific programme.

The other aspect to highlight is the cost of a URL. When working on several geological environments, it becomes advantageous to be able to co-operate with existing URLs.

Co-operation can, under certain conditions, contribute to pooling resources and costs. This becomes all the more important when R&D and studies have to be carried out on several geological environments.

5.1.4. *Can info, data and know-how from generic URLs contribute to excluding geologies at an early stage? Follow-up questions: Is there a risk of excluding potentially good geologies at an early stage? If not, can info, data and know-how from generic URLs be used to rank geologies from a robustness perspective?*

Geological conditions may seem simple but are usually complicated to describe. Groundwater flow, a key information for studies and safety demonstration, is challenging to predict and cannot be anticipated from non-destructive surface measurements. To properly describe the hydrogeological environment in deep underground, it is necessary to have direct access to the geological formation and to carry out numerous specific measurements and tests there.

Panellists and participants agree that a clear distinction must be made between the question of the host rock and that of the site. The experience acquired in the URLs has shown that none of the formations studied presented unfavourable characteristics for the creation of a DGR. It should be recognised that the choice of URL sites is made initially on the basis of geological knowledge, avoiding the exclusion of the geological formation or the site. The challenge for specialists will be to design a repository capable of fulfilling all the required safety functions; for this there are technological arrangements capable of fulfilling these functions for different geological environments and even for different sites in the same geological environment. Under these conditions, there is no reason to envisage an exclusion, nor even to compare the geological environments.

About 35 URLs have been built to accommodate RD&D for radioactive waste disposal. They were built in four types of geological formations: crystalline, clayey, salt and tuff. Specific skills are available to design and conduct experiments in each of these geological formations. The URL should be viewed positively and therefore focus more on confirming the feasibility of the DGR than eliminating it. Nor is it reasonable to classify the formations in relation to each other, especially since the disposal of radioactive waste constitutes a system comprising the host environment as well as the technical provisions to ensure safety.

The term "exclusion" seems strong. Most URLs are designed to build trust and enhance concepts. The key is to characterise the acceptable degree of variability within the formation in order to consider geological disposal there and demonstrate its safety.

5.2. Capacities of advanced countries for support of international co-operation

5.2.1. *What are the roles of generic URLs even after final DGR sites are selected?*

The panellists recognised the interest of generic URLs for learning, training and communication, but also and above all for long-term experiments, which are difficult to envisage in a DGR in operation. They also offer a degree of flexibility and adaptability to the respective needs within the framework of international co-operation that a site-specific URL could not provide, having to follow a much more targeted programming on objectives.

Other circumstances also show the benefit of continuing work on generic URLs, as illustrated by the cases of France, Sweden and Switzerland.

The construction of the URL of Bure (France) began in 2000, with detailed investigations and experiments effectively starting in 2002. The agenda set by law left only four years to submit the Dossier 2005 presenting the results of the R&D carried out. The Dossier 2005 was to serve as a basis for the decisions taken by Parliament in 2006 for the continuation of the project, in particular by moving from the research phase to that of the development of the DGR. The production of this Dossier 2005 in such a short time was only possible because ANDRA had a solid background, with 20 years' experience in generic URLs abroad. The teams learnt to work there and to prepare their own characterisation and experimentation programmes for the Callovo-Oxfordian argillite. Access to Bure's site-specific URL did not prevent the continuation of certain programmes in the generic laboratories, in particular with regard to long-term experiments. Information acquired from other URLs supplements that generated at Bure, and although the intensity of ANDRA's participation in other URLs has been reduced, it is recognised that the information is likely to complement, and even strengthen, information obtained elsewhere.

The SKB programme began in the 1970s at the Stripa mine, also with interests in overseas URLs. It continued in 1995 on Äspö, whose vocation was to be a site-specific URL. However, site selection in 2009 picked out the Forsmark site, so Äspö became a generic URL. Since 2009, developments and experiments have continued in Äspö. The technology options were proposed for the application licence based on Äspö’s achievements. They must be validated on Forsmark for updates to the licence application. The Äspö URL remains a key tool also for the preparation of the teams, the development of skills and to maintain confidence internally as well as for the public. So, the generic Äspö URL has yet to contribute to the SKB programme and to foreign programmes.

In Switzerland, two generic URLs are in operation. It should be kept in mind that the role of the URL evolves over time, in particular according to the progress of the development of the DGR project. The R&D programme must meet the needs of the DGR project by providing the information necessary for the safety case. The advantage of generic URLs is that they are able to carry out long-term experiments, such as on the evolution of EBS or monitoring, the results of which are necessary to confirm the safety case. Once the site has been selected, a new RD&D programme will be needed there. However, effort will also be needed to optimise technologies and for safety case updates, and the contribution of generic URLs could still be valuable.

5.2.2. What is the key technical knowledge on the development of R&D programmes at URLs and their results that should be generally transferred to those countries at initial DGR stages?

Much work has already been carried out in this field and there is certainly no need to redo everything. It is important to remember that there is a great deal of information available and much of it can be transferred. For example, what the US DOE learnt at Yucca Mountain can be shared with other DGR programmes. Much data and information, independent of the nature of the host rock and the geological environment, can be transferred to other geological environments or to other disposal concepts. In the field of technologies, those on EBS are more easily transferable. Large databases are available on the methodologies and systems implemented, which is always a good starting point for new programmes. This covers in particular issues of organisation, project management, experience of underground work, or even the development of RD&D programmes or the development of a roadmap. Existing know-how is an important resource for any new programme and saves time and money. As said before, a report is being published by the IAEA on the contribution of URLs and this will constitute a good basis for new programmes (see Section 3.2.6). It is essential that these new programmes do not repeat the same errors, but they can also dispense with redoing a certain number of tests whose results are already available.

However, since each phase of a DGR programme aims to respond to particular issues, it is important to never lose sight of the context for which they were produced and to remain cautious as to the context in which they could be transferred. Natural or induced processes must in any case be studied specifically on each site, such as those describing the migration of radionuclides. Some knowledge is specific to the geological environment, or even to the site. These can benefit others, but with extreme caution; they will have to be checked on another site and adapted to the particular context. It is in any case necessary that the new programmes focus above all on their own project and the priorities they have identified. Finally, it is important to emphasise that any new project must be prepared to adapt their programmes according to the discoveries; there may indeed be surprises, good or bad, which must be taken into account.

5.2.3. What are the tools for the transfer?

Everything that is written is easily transferable; practically everything is published in the form of reports and is the subject of communication in workshops. The transfer can also be organised to meet specific requests, as well as with training sessions or via co-operation agreements, which allow guided access to data sets already processed and used for Safety Cases. It is also interesting to understand the process of moving from raw data to used data, within the framework of structured databases, with all the justifications that accompany the process. It is indeed necessary to distinguish the different levels of data for a URL or in a DGR project. Their transferability is not immediate because from the raw data, a certain number of treatments are carried out so that the data can be used at the level of the safety case. Added to this is the question of data qualification, all within a QA framework allowing good traceability and good configuration management. This is also an integral part of building trust and confidence. For a new programme, structured databases must be established as soon as possible in order to be able to trace the evolutions of knowledge, which the authorities will not fail to request. One of the aspects to also keep in mind is that of knowledge management, particularly on the duration of DGR projects. The NEA has set up working groups (WP-IDKM: Working Party on Information, Data and Knowledge Management) on these subjects, which project leaders must be made aware of because it is well understood that data formats will evolve, computers will change, and it will be necessary to be able to transmit information from generation to generation. It is reasonable to think that the younger generations are more receptive to new technologies, particularly in the field of information, as well as in digital approaches.

5.2.4. Do you have any experience of the usefulness of the knowledge base and of the R&D programmes in URLs for the regulator?

Regulators need to develop their own experience. They must be able to train on their own. It would be tricky to consider training the regulator at the same time and under the same conditions as the prime contractor. It is important to clearly distinguish between the respective missions, which cannot be prepared within the same framework either. In any case, the regulator will never have the same level of knowledge as the implementer, but this does not matter because the regulator is expected to perform very different functions from those of the implementer. They take a different look at the files prepared by the implementer and it is absolutely necessary to avoid confusion. The implementer must demonstrate that safety will be achieved, while the regulator's mission is to assess the quality and approach as well as the results of the safety demonstration. In France, the regulator follows the activities in the URL on the aspects of programming, quality assurance, organisation and traceability, but never on the substance of the experiments. There is therefore no competition between the regulator and the operator, maintaining the independence of the regulator from the implementer. The regulator must also put itself in a position to carry out its assessments, and therefore to build up its own knowledge base. It will analyse the information provided by the implementer and may also request additional information to refine its position. For the Yucca Mountain project, the NRC permanently had two employees on site. They had access to all relevant information produced there, which was positive in that it helped to keep the regulator well informed.

5.2.5. What are key areas/issues of technical development to be pursued at URLs? (Your expectations for the future R&Ds at URLs)

Since the URL in Stripa was established, a significant amount of knowledge has been accumulated through various URL projects. The question for any new programme is how to identify the additional information needed to take the step towards a DGR. R&D managers will always have new proposals. It is management’s responsibility to assess the expected contributions of programmes. It is impossible to know everything, but it is possible to know enough to move on to the next phase.

Licence applications are established on the basis of available information and demonstrated technologies. Nevertheless, given the time constants involved in DGR projects, URLs have an important role to play in terms of optimisation. With few exceptions, the DGR is not designed for optimisation. In France, it includes an area to be dedicated to construction work and an area in operation. However, it is possible that within a few decades a space dedicated to demonstrators may be considered. The latter could prove necessary after the closing of the URL, the cost of which is quite substantial. Under these conditions, the URL could also serve as a demonstrator for the closing and sealing of underground structures. Until then, RD&D must therefore be able to develop in the Bure URL, with the aim of reducing the complexity of concepts, for example of seals. It will also be used to consider breakthrough technologies, including alternative materials like the steel of waste overpacks, in order to limit the production of corrosion gases. The URL must remain open to the future and prepare for progress. Finally, whatever the case may be, the URL is the privileged place to prepare the demonstrators and carry out the tests, before setting them up in the DGR.

For Nagra, the priority for the next few years is to provide information and knowledge for the licence application. Long-term experimentation will continue in the generic URL. The characterisation methodologies of the DGR site are also developed in the generic URL before being deployed at the future DGR site. Some experimentation will nevertheless be necessary to confirm what has been learnt in the generic URLs on the selected DGR site.

In Sweden, two concepts have been developed, a vertical disposal concept and a horizontal disposal concept. A priori, the first is in reference, but the studies and analyses continue in the URL of Äspö. It is possible that new requests be also mentioned in the licence, which would induce new projects within the URL.

5.2.6. You've been working on databases for a while, and there are still issues about organising the data. Is it important to establish a standardised data structure for future URLs, and if so, what would be your recommendation?

It is always a challenge for the management to release the necessary resources for data management. Many lessons have been learnt, particularly in terms of databases. The databases are organised differently for each stage of development of the DGR project because each stage involves answering questions of a different nature. In addition, within each organisation, the databases were constituted according to the specific questions to which answers had to be provided, and therefore necessarily the structures of the databases are each time adapted to the particular technical or scientific questions. Some databases have also been set up to monitor particular experiments and are therefore very specific. It seems in these conditions difficult to recommend a standard structure for the data. Moreover, the methods of organising databases have evolved and continue to evolve.

It is difficult under these conditions to envisage standardisation. At most, recommendations can be imagined. In France, there is also an explicit request from the regulator to prepare a database for the DGR; its preparation is done according to engineering standards.

5.2.7. *In terms of project management, R&D plans, and roadmaps, you have extensive experience. Are there some things we can develop as generic tools which can be utilised by others?*

The IAEA has thought about a project to establish a DGR implementation roadmap. It turned out that it could only be generic; on the other hand, it is possible to consider guidelines for the development of a roadmap specific to individual DGR programmes, referring to the IAEA generic roadmap.

In France, project management is imposed by the regulator. For the new DGR phase, ANDRA is setting up a traditional management system, based on existing standard tools such as the WBS.

What is more original is the link that can be established with ongoing RD&D activities.

The US DOE as well as the other WMOs are open to participate with the NEA in the developments that would be envisaged in terms of management tools.

5.2.8. *URLs offer services. Are there opportunities to work with universities and consider hosting students in R&D programmes?*

All URLs interact actively with universities. Welcoming doctoral and post-doctoral students is a common practice and a recognised added value for the projects. However, in the more advanced phase of construction and operation of a DGR, these are industrial phases less conducive to hosting doctoral students, and more suited to hosting trainees with a high technological level.

The Bure URL is close to the University of Nancy. An agreement has been made between ANDRA and the university to train their students, independently of ANDRA's programmes; access to such an infrastructure is exceptional for students. The co-operation between the Bure URL and the university is a win-win process, as in the example of the development of robots in Bure. This initiative is interesting because it also gives the opportunity for exchanges with young people.

In Sweden, relations with universities have always been excellent, in particular with the reception of doctoral students within the framework of characterisation and experiments in URL. With the new phase of the DGR, the industrial phase, it will be necessary to reflect on new ways of welcoming students.

In Switzerland, many URL projects are carried out with the direct involvement of universities, for example in the context of Master's, PhD and PostDoc programmes. These projects allow important access to the necessary know-how and laboratory infrastructure in the various research institutions and to possible future collaborators. In addition to the projects supporting the radioactive waste management programme, the Swiss URLs (as research infrastructures) are also available for other research topics, e.g. fundamental geosciences, geothermal, CO_2 sequestration, technology development and testing. In the United States, interactions with universities have always been intense in the field of radioactive waste as in other fields.

6. Break-out session and general discussion

Three break-out groups were requested each to address five topics defined by the programme committee and from the panel discussions (see Chapter 5). The findings of the groups reported at the final session are summarised in this chapter.

6.1. Expectations of countries staying at the initial stages of their DGR programmes from the international co-operation in both technical and non-technical areas

6.1.1. Technical and scientific aspects (soft and hard)

A very general concern relates to project management. The DGR is an extraordinary project for which there are no or very few references. Projects must take place over very long periods of time and involve a multitude of disciplines, which is unusual in other fields.

Countries initiating a DGR project will typically seek to build on the achievements of existing URLs and look for models to design their own R&D programmes. In the scientific and technical field, the expectations of the new programmes relate to the initial data allowing the selection of the host rock and the other decisions which will have to follow. The priority in the technical field is to characterise the site and its environment and to understand how the system works. They will seek to refer to the existing experiences to analyse characterisation strategies and methodologies leading to URL, and then to the programme of in situ characterisation and experiments. They will thus seek to understand how the experiments were designed and programmed, to share information relating to the experiments and to have access to the data already produced.

The new programmes will also seek to acquire reliable analysis models, for which they will want to be reassured by carrying out benchmarks of codes from identical data sets. The challenge is to be able to describe and model the site and its repository structures in order to subsequently be able to carry out the simulations necessary for the safety case.

They will also require benchmarking of technical solutions, in particular to justify their own options to decision makers.

Through these expectations, countries undertaking a programme are interested in the development of methodologies and tools for their future DGR, including technologies that could be adapted to build the disposal facility.

International co-operation provides a framework for exchanging and storing information, data and knowledge, and offers the tools for this. The useful information concerns not only the facilities in operation, but also the already closed URLs, for which the archives, although in old formats, remain relevant and useful. The exchanges of information, data and knowledge between organisations and with the public is an important aspect of confidence, but there may also be a commercial part that remains closed.

The areas of exchange between advanced programmes and new programmes relate more to organisational aspects and strategies of the development of a DGR. All generic aspects can be the subject of exchanges, the generic safety case or the generic concepts, and how to design and build a DGR. It is important to create co-operation networks very early in the programmes.

6.1.2. Societal aspects (public and personnel)

With regard to the societal aspects, the objective is to create consensus among the public, the regulator and the decision makers to prepare decisions on a DGR. The example of URLs in operation makes it possible to illustrate to stakeholders and the public the justification of developing new URLs in relation to the DGR programmes that are committed. Site visits, which are necessarily limited at URLs, must primarily target local stakeholders, decision makers and the media. International networks are important for the exchange of scientific and technical information, as well as for sharing knowledge.

The experience of other countries is always enriching, even if the contexts are different. Finally, one of the important aspects is to build skills for the implementer and for the regulator.

There is generally no other particular expectation of international co-operation for social aspects. Expectations are generally local, with a financial contribution for development. An interesting case which is likely to inspire other programmes is that of France, where the local population has shown pride in having a URL, which is an infrastructure that provides high scientific, technical and technological added value to the area.

6.1.3. Economic aspects (benefits for national programmes)

In the economic field, what can be brought to new programmes is the experience of the most advanced ones. International co-operation at URLs saves resources, the greatest economic benefit being the sharing of information and knowledge. Initially the investment may seem high, but the return is obvious in the long term. The evaluation of the benefit brought by the experiments must be taken into account.

On the economic level, all the programmes seek to optimise their management; international co-operation can also lead to lower costs for everyone. Feedback from others can help control costs. The question that arises collectively is that of optimising the use of existing URLs.

6.2. Vision of the role of joint projects in URLs to help address expectations

Joint projects in a URL provide decision makers with the needed information on the host rocks and disposal concepts of a potential DGR, thus meeting expectations related to the technical, scientific, societal and economic aspects of the project. International co-operation and the benchmarking it implies are likely to strengthen the robustness of approaches and to share achievements and knowledge. Projects carried out in co-operation will always have more weight with the general public and stakeholders than those carried out alone. It should also be remembered that if the starting points of the different projects are different, the objectives remain the same, and that different paths make it possible to achieve them. Finally, relying on the experiences available makes it possible to start or restart on a substantial basis and also to avoid the mistakes of the pioneers.

The general public and stakeholders will tend to have more confidence in experiments and results when they know that similar results are being generated by other teams. Trust is also built by the participation of high-level scientists in exchanges with the public, for example within the framework of meetings organised by the NEA FSC. The interest shown by the foreign teams is also appreciated by the local populations; it appears as a factor of confidence. From a societal perspective, public access to URLs, developed solutions and illustrations of safety demonstrations will build confidence. The use of advanced technologies such as virtual reality allows for greater dissemination of information. The

URL is an important tool to convince society and decision makers of the possibility of creating safe DGRs.

URLs can also accommodate personnel for their training, for new programmes as well as for more advanced programmes.

It is worth recalling the economic interest of joint projects. In brief, co-operation is profitable and scientifically beneficial. The main vision on the role of URLs is to integrate the long-term benefits of their contributions, in particular to increase capacities and skills in terms of the operation, experimentation and modelling of DGRs.

6.3. Sharing the experience of advanced programmes

6.3.1. What must be taken into account when planning participation in joint projects in URLs?

Advanced programmes can make available their studies and experiences, including their present R&D results; they can also share their overall approach, strategies and experience in developing their DGR projects. It is important to keep in mind the objectives of the experiments and to share them with all the participants in case of international co-operation; care should be taken not to deviate from it solely on the grounds of international co-operation. For joint programmes, it is imperative to prioritise the respective needs, taking into account the degree of advancement of the DGR programmes of each of the participants, and their knowledge and resources. The relevant approach consists of defining common needs in order to be able to propose joint projects more easily. DECOVALEX is a good illustration of how to do this. Then, it is imperative to take care not to always reinvent the wheel, as there is already knowledge available from which new projects can advantageously be prepared.

International co-operation in the field of experimentation can only be conceived in the long term, with participation in different forms, such as financial, material or human. Projects must be led by experienced staff, accompanied by young professionals. The lessons learnt from the experiences must be discussed among the participants. Their good and bad experiences are sources of lessons for all.

6.3.2. How can the most benefit be obtained from international co-operation in URLs?

Understanding other programmes is key to explaining to actors and audiences the main differences with the domestic programme.

In order to learn the best lessons from international URL co-operation, proper documentation should be kept up to date, with well-organised data and proper knowledge management under quality assurance. Advanced programmes could improve access to their information within a framework of transparent and open communication. Online and face-to-face exchanges between experts of the respective programmes are also desirable to make the most of international co-operation on URLs more beneficial.

Within the framework of a co-operation, it is possible to be a passive participant or observer, or to participate actively in experiments, even though this is more costly. Learning can also be mutual, with new entrants bringing new ideas and/or technologies.

6.4. How can the advanced technologies (AI, VR, robotic/remote systems, etc.) applied in URLs increase the URL's role in DGR concept development?

The URL is not necessarily where new technologies are developed, but rather where they are implemented. The URL is more appropriate for testing technologies that will be implemented in the DGR, such as the EBS experiment in Horonobe.

The licence for the DGR is usually granted on the basis of an application based on proven and well-stabilised technologies. It is difficult at this stage to highlight new technologies which will not fail to be developed before their implementation in the DGRs in operation.

In the realm of advanced technologies, digital twins can contribute to long-term safety assessments, in particular to describe the physical processes related to URL experiments. New technologies allow also for greater precision in carrying out experiments and more detailed analysis of data. Demonstrators integrating robots and remote control facilitate the control of operations without human intervention.

The public is also sensitive to new technologies, the implementation of which will facilitate the acceptance of the DGR. The development of wireless transmissions and long-term resistant sensors in the DGR is in this sense likely to reassure the actors and the public. Virtual reality is well suited to training teams to intervene in the future DGR. Machine learning is also a promising tool. These enhancements ensure accountability and data preservation.

6.5. How do you envision the role of the NEA in co-ordinating the expectations of countries at the initial or advanced stages of their DGR programmes on future R&D at URLs?

The NEA can be in a position to co-ordinate R&D programmes that could be set up between countries that have advanced in their DGR projects and new entrants. It presents a well-established framework for this type of co-operation, which can of course be adapted to URLs.

The intervention of the NEA can contribute, with the help of the most advanced countries, to expressing the needs for the development of new DGR projects. The experience acquired should be valued to avoid duplication of R&D or experimentation, except when it comes to seeking confirmations in a particular geological context. The objective is to progress together and take advantage of the new information produced by the new projects.

The NEA is also a suitable structure within which the results of R&D can be shared, as is done for the Clay Club, Crystalline Club or the Salt Club. The privileged sharing tools could be workshops, conferences or associated publications. The NEA could also play a role in encouraging the participation of young researchers and students in these exchanges.

Generic databases are also co-ordinated by the NEA, usually for the lists and databases containing features, events and processes (FEPs) of relevance to safety and performance assessment studies for DGRs (NEA International FEP List and FEP Database) or for the TDB (Thermochemical Database) project. On the other hand, the diversity and quantity of data generated on the sites do not make it possible to envisage a shared data structure. Recommendations could help all programmes to plan their own data structure for their different applications. The NEA can be a point of convergence between the offer based on what already exists and the expression of demand from new programmes. The WP-IDKM can contribute to provide general views in this regard.

The benchmarking of codes has not been highlighted much for about 30 years. Exercises with newer and more sophisticated codes are beneficial for everyone and provide an excellent platform for collective learning. They could be extended to uncertainty analyses and sensitivity analyses intended to specify the respective weight of the various parameters. The NEA works all the better if it can unite all the players. The NEA is in a unique position to encourage specialists to exchange within the framework of forums and to share information on URLs between member countries. The NEA also has the capacity to publish technical reports and other reference documents.

The NEA could also consider stimulating the establishment of a framework to provide financial support for training. Finally, co-ordination on the subjects of URLs and DGRs with other international bodies, such as the IAEA and the EC, is essential.

Conclusion

In the field of geological disposal of radioactive waste, programmes are constantly evolving. In recent years, there have been major advances, in particular with the start of construction of the Onkalo underground repository in Finland, the licence for the disposal of spent fuel in Forsmark in Sweden and the licence application for Cigéo in France. Major progress has also been made with the identification of candidate sites in Canada and Switzerland. In Japan, the literature survey, as the first stage of the siting process, has been initiated in two municipalities, while the government is considering strengthening its efforts to implement the survey in as many areas as possible.

These developments have been made possible thanks to extensive work in the fields of research, engineering and approaches to the safety assessment, which provide a basis upon which to develop a safety case for underground repositories. Many studies and much research have been undertaken at underground research laboratories (URLs) built for this purpose. Whether generic or specific to a site, they provide the knowledge needed to understand the local functioning of the geological environment. They also make it possible to test the methods of construction and closure of the disposal structures, as well as the equipment that will be necessary for their operation and for the necessary monitoring.

The key to obtaining a licence for the creation of a deep geological repository (DGR) is to demonstrate that its safety during construction, operation and closure can be ensured.

Regarding the construction and operation phases, the demonstration is often based on experience available in both the nuclear and mining sectors. However, it is necessary to demonstrate their implementation under the conditions required for the geological disposal of radioactive waste, which is practised in underground laboratories.

The long-term safety demonstration requires not only understanding the functioning of the geological environment, but also evaluating its behaviour in the presence of the engineered barriers, including radioactive waste. It is essential to demonstrate by developing a safety case that the geological disposal system, i.e. the assembly containing the waste packages, the engineered structures and the geological environment, will be able to confine and retain the radionuclides for as long as they present an unacceptable risk for the environment and humans. Given the time scales involved, demonstration is hardly possible through experimentation alone. It is necessary to resort to digital simulation for safety assessments, the quality of which will depend heavily on the physical understanding of the phenomena likely to occur in the repository and their representation by modelling.

To implement a reliable safety assessment by which it is possible to have confidence in a safety assessment, it is therefore necessary to start with high quality science and engineering, which is the goal of research at URLs.

Since the NEA report on URLs published in 2013 (NEA, 2013), many advances have been made in the URL projects, with plans to construct new URLs in many countries. URLs have functions that go beyond merely facilitating research and technological studies. Given the timeframes of DGR projects, URLs make it possible to train the successive teams that will have to build and operate the geological repository over decades or centuries. URLs also make it possible to illustrate to stakeholders as well as to the general public what a geological repository will be, to provide all the explanations on the research and technological developments that are practised there, and to thereby increase confidence in the geological disposal. Certain tests benefit from being carried out in a URL, in particular those requiring measurement durations or dimensions that would not be compatible with the life of a repository, whether in the construction phase or in the operating phase. URLs are also a good place to consider technological developments and tests based on new technologies. Indeed, licences for disposal are granted by the authorities on the basis of demonstrated and confirmed technologies. However, progress made in the URLs should be subject to additional authorisations once the performance of new technologies or processes has been demonstrated.

In order to better support the development of geological disposal projects, the G20 Ministerial Meeting on Energy Transitions and the Global Environment for Sustainable Growth in June 2019 emphasised the need to strengthen international co-operation. METI (Japan), the US DOE and the NEA then initiated the organisation of roundtables on the subject, which resulted in a web conference preparatory session on 22 September 2021 and the workshop in Horonobe (Japan) on 1-3 November 2022, jointly organised by the NEA and METI.

The various aspects mentioned above were extensively discussed at the workshop. All the participants share the interest of strengthening international co-operation, with in the first place the possibility of completing the Horonobe URL programme of the JAEA with an international component, the Horonobe International Project (HIP). To this end, the NEA provides an adequate framework, facilitating administrative and legal arrangements to enable international co-operation under well predefined conditions.

The participants also expressed the wish to strength international co-operation through more frequent organised exchanges, either in workshops or conferences. They recalled their interest in code benchmarking and intercomparison, a practice that has been carried out less over the past 20 years but whose relevance has re-emerged, in particular thanks to digital innovation.

The NEA is in a position to promote these activities at the international level based on the following conclusions from the workshop:

- URL investigations are crucial to the DGR project development; the importance of generic URLs is greater now than decades ago due to the significant experience and knowledge collected in previous R&D, and this experience and knowledge can/should be used to help new DGR programmes.
- International co-operation in URLs remains of high interest for countries developing their DGR programmes; it is considered beneficial for technical development, building stakeholder confidence and economic aspects for both countries with advanced programmes and countries at the beginning stages of their programmes; it is important to organise the transfer of knowledge from experienced programmes to beginners to avoid mistakes and to save resources.
- There is a great variety of scientific programmes, including international ones, being realised in existing generic URLs in different countries. In planning new projects, it is necessary to take into account the scope and results of other international programmes and the long-term benefits of programmes to build DGRs.
- International organisations have an important role in the effective transfer of experience and knowledge from advanced programmes to those that are at the earlier stages; the NEA should continue supporting relevant international activities and keep its leading role in support of DGR projects.

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Annex A. Workshop agenda

NEA and METI International Workshop on Joint Utilisation of Underground Research Laboratories for R&D Projects

Horonobe, Japan

1-3 November 2022

Day 1, 1 November 2022 (Tuesday)		
	Introductory Session *Magnus HOLMQVIST, Hiroyuki UMEKI (Co-Chairs)*	
13:00	**Opening remarks** *Hitoshi NONOMURA (Mayor of Horonobe town)* *Tomokazu SHIMOHORI (METI)* *Rebecca TADESSE (NEA)* *Masahiro SHIBATA (JAEA)*	20 min
	Session 1: Overviews of URL Development *Session Chair: Tomokazu SHIMOHORI (METI, Japan)*	
13:20	**1.1 Introduction from the session chair** *Tomokazu SHIMOHORI (METI, Japan)*	10 min
13:30	**1.2 Outcome of the International Roundtable on Final Disposal of High Level Waste and Spent Fuel** *Rebecca TADESSE (NEA)*	15 min
13:45	**1.3 Status of URLs in Japan and R&D projects in Horonobe and Mizunami URLs** *Teruki IWATSUKI (JAEA, Japan)*	30 min
14:15	**1.4 A holistic vision of URL role in DGR projects development** *Hiroyuki UMEKI (NUMO, Japan)*	20 min
14:35	**1.5 EURATOM Research and Training Programme** *Seifallah BEN HADJ HASSINE (EURAD)*	20 min
14:55	**1.6 RD&D in Underground Research Facilities and International Co-operation: Two pillars fundamental to successful implementation of geological disposal** *Stefan MAYER (IAEA) *online participation*	20 min
15:15	**Coffee Break (15 min)**	
	Session 2: Horonobe Joint Project and Potential Areas of International Co-operation *Session Chair: Magnus HOLMQVIST (SKB, Sweden)*	
15:30	**2.1 NEA capacity for supporting international co-operation – Horonobe International Project (HIP)** *Rebecca TADESSE (NEA)*	30 min
16:00	**2.2 Advanced technologies needed for URL (and further for DGR)** *Takeshi EBASHI (NUMO, Japan)*	20 min
16:20	**2.3 Plan for systematic integration of technologies towards EBS emplacement** *Akira HAYANO (JAEA, Japan)*	20 min
16:40	**2.4 Stepwise R&D on operational technology options including robotics towards flexible optimisation** *Minoru EMORI (RWMC, Japan)*	20 min
17:00	**2.5 Research and development on tracer test and centrifugal test** *Takuma HASEGAWA (CRIEPI, Japan)*	20 min

17:20	**End of Day 1**	

Day 2, 2 November 2022 (Wednesday)		
9:00-12:00	**Technical Site Visit to JAEA Horonobe Underground Research Center** *Detailed schedule will be provided to participants*	
12:00	**Lunch Break (90 min)**	
	Session 2: Horonobe Joint Project and Potential Areas of International Co-operation *Session Chair: Hiroyuki UMEKI (NUMO, Japan)*	
13:30	**2.6 Brief Overview of Day 1** *Magnus HOLMQVIST (SKB, Sweden)*	10 min
13:40	**2.7 URL role in demonstrating of DGR safety and building public confidence** *Magnus HOLMQVIST (SKB, Sweden)*	20 min
14:00	**2.8 Role of URL in educational and training programmes** *Ingo BLECHSCHMIDT (Nagra, Switzerland)*	20 min
14:20	**2.9 Experience in the URL at the Yucca Mountain Project** *William BOYLE (DOE, United States)*	20 min
14:40	**2.10 SKB's approach and experiences regarding Site Characterisation - Site Descriptive Modelling** *Magnus ODEN (SKB, Sweden)*	20 min
15:00	**2.11 URL R&D in support of technology innovation and demonstration** *Frédéric PLAS (ANDRA, France)*	20 min
15:20	**2.12 Ways of integration of URLs' R&D results into a concrete DGR** *Tiina JALONEN (POSIVA, Finland) *online participation*	20 min
15:40	**Coffee Break (20 min)**	
	Session 3: Panel Discussion 1 – Perspective of countries at the initial stages of their DGR projects *Session Chair: Magnus HOLMQVIST (SKB, Sweden)*	
16:00	**3.2 Panel Discussion on Technical Perspective** *Panel-Chair: Magnus HOLMQVIST (SKB, Sweden)* *Panellist:* • *Axel LIEBSCHER (BGE, Germany)* • *Katsuhiro HAMA, (JAEA, Japan)* • *Haeryong JUNG (KORAD, Korea)* • *Dave MCCARTHY (BGS, UK) *online participation*	60 min

17:00	**3.3 Conclusions from the panel discussion** *Magnus HOLMQVIST (SKB, Sweden)*	10 min
17:10	**End of Day 2**	

Day 3, 3 November 2022 (Thursday)		
	Session 3: Panel Discussion 2 – Capacities of advanced countries for support of international co-operation *Session Chair: Hiroyuki UMEKI (NUMO, Japan)*	
9:00	**3.5 Panel Discussion on Technical Perspective** *Panel-Chair: Hiroyuki UMEKI (NUMO, Japan)* *Panellist:* • *Frédéric PLAS (ANDRA, France)* • *Magnus HOLMQVIST (SKB, Sweden)* • *Ingo BLECHSCHMIDT (Nagra, Switzerland)* • *William BOYLE (DOE, United States)*	60 min
10:10	**3.6 Conclusions from the panel discussion** *Hiroyuki UMEKI (NUMO, Japan)*	10 min
10:20	**Coffee Break (20 min)**	
	Session 4: Break-out Session and General Discussion	
10:40	**4.1 Introduction to the break-out session** *Vladimir LEBEDEV (NEA)*	5 min
10:45	**4.2 Break-out session** *Group leaders* *Magnus ODEN (SKB, Sweden)* *Ingo BLECHSCHMIDT (Nagra, Switzerland)* *William BOYLE (DOE, United States)*	80 min
12:05	**Coffee Break (10 min)**	
12:15	**4.3 Exchange groups' results, general discussion in the whole group, conclusions** *Magnus HOLMQVIST, Hiroyuki UMEKI (Co-Chairs), Group leaders*	35 min
12:50	**4.4 Closing Remarks** *Rebecca TADESSE (NEA)*	10 min
13:00	**End of the workshop**	

Annex B. List of participants

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