The Fourth Decade of Underground Research at the Grimsel Test Site – What We Have Learned and Where We Go from Here – 15075

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ABSTRACT

At the Grimsel Test Site, NAGRA and its partners have celebrated thirty years' worth of essential contributions to the characterization of crystalline host rock, and the development and confirmation of safe geological disposal concepts. In operation since 1984, the underground research laboratory in the Swiss Alps shall not accept radioactive waste but can host experiments with radiotracers/radionuclides under strictly controlled conditions.

The strong drive for international cooperation at the Grimsel Test Site is reflected in the more than two dozen organizations and research institutes from twelve countries and the European Union which have participated in the research program to date. The program has been designed dynamically to always mirror the current requirements of national programs for the long-term management of radioactive waste, as well as attempt to anticipate the next steps. Early work featured the development of methodologies for formation characterization. Then followed a period concentrating on performance assessment issues, before radionuclide migration and barriers were investigated intensely. The past 15 years have been dominated by engineering demonstration experiments.

The research conducted at the Grimsel Test Site has complemented laboratory experiments, surface investigations and numerical modelling studies through the bridging of different scales and drawing off links between laboratory setups and natural analogues. The crystalline rock formations of the Aar Massif have provided an opportunity to do experiments in environments similar to those of future repositories. The facility also serves as a platform for continual knowledge transfer between generations of scientists and fosters synergies among disciplines. However, considering the ambitious schedule for repository implementation in several continuous, one may ask whether the era of generic underground rock laboratories is approaching its end.

INTRODUCTION

NAGRA's decision to construct its own site-independent rock laboratory dates back to the late 1970s. At that time, the feasibility studies for a geological high level waste repository in Switzerland focused on the crystalline basement. Consequently, NAGRA was very interested in a rock laboratory in a formation with similar geological conditions. The crystalline formations of the Aar Massif in the Swiss Alps met this requirement and the access gallery to an underground electrical power plant at the Grimsel Pass provided a starting point for the excavation of an underground rock laboratory (URL). The 1.1 km long gallery system of the Grimsel Test Site (GTS) is located at an elevation of approximately 1730 m above sea-level and about 450 m beneath the Juchlistock mountain top (Fig. 1).

The international community of organizations responsible for radioactive waste management and contributing researchers has always looked to the GTS with great interest. The facility lends itself to a large spectrum of geoscientific and engineering experimental concepts. A special feature is its radiation controlled zone which allows work to be carried out with radioactive tracers in the geosphere under close-to-realistic boundary conditions. NAGRA has used the GTS to provide scientific answers and technical experience for the Swiss national disposal program. However, the GTS is also an essential tool for public outreach which helps to improve understanding of the disposal program by the general public and provides answers to questions people may have.

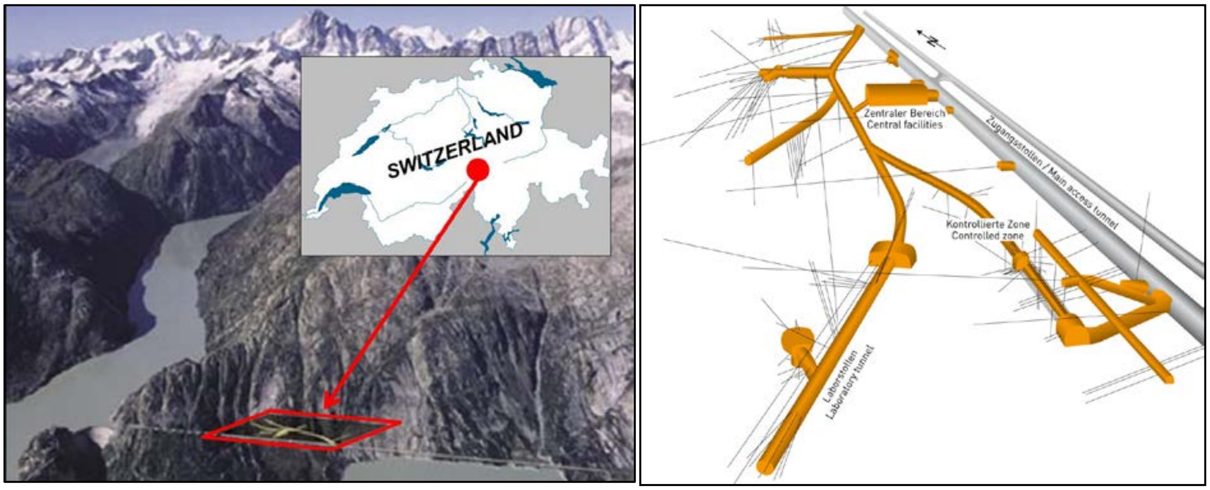

Figure 1: Location of the GTS underground rock laboratory in the Swiss Alps (left) and its layout with 1.1 km of 3.5 m diameter tunnels and an IAEA level B/C radiation controlled zone (right).

International cooperation with other national waste management organizations and research institutes has been an important component of the research program since day one. Geoscientific results and practical experience gained from joint experiments conducted at the GTS can be transferred to other repository concepts and the partners share the costs and knowledge invested. An added value stems from the synergy effects during analysis and interpretation. In its first thirty years of operation the GTS has hosted partnerships between NAGRA and more than two dozen organizations and research institutes from twelve countries and the European Union.

Another aspect of international cooperation practiced at the GTS is that of knowledge transfer through training. The GTS offers its infrastructure and databases for educational purposes. NAGRA staff and experts from the International Atomic Energy Agency (IAEA) and other organizations use the underground facilities to teach the next generation of scientists and engineers and to facilitate specific workshops for experienced specialists to support interdisciplinary knowledge transfer.

URLs AND NATIONAL REQUIREMENTS

A URL is an underground facility in which site characterization and testing activities are carried out along with technology development and demonstration activities in support of the development of deep geological repositories for radioactive waste [1]. Therefore the objectives of URL investigation programs are to acquire the data that will provide in-depth understanding of the long-term performance of the repository components in a geological environment, to acquire the data that will be used as a starting-point for the development and testing of safety assessment models and to demonstrate and optimize key components of the engineered barrier system. An important contribution of a URL often is that it enables to investigate the selected geological environment and to test models at more appropriate scales and conditions than can be achieved from the surface. A continually pursued secondary objective is the evaluation of the transferability of individual parameters, investigation techniques, data evaluation methods, process understanding, conceptual models, high-level conclusions (e.g. engineering feasibility, safety aspects) to a safety case for a future repository program [2].

Experiments in URLs meet two groups of needs [3]:

- Rock characterization and its response to perturbations, i.e. geological, hydrogeological, geochemical, structural and mechanical properties, and
- Construction and operation, i.e. to develop equipment to acquire know-how about the construction of all the components of a disposal program.

Whereas generic URLs are facilities at a site that will not be used for waste disposal, but provide information that may support disposal elsewhere, site-specific URLs are facilities that are developed at a site or close to a site that is considered as a potential location for waste disposal and may be a precursor to, or the initial stage of, developing a repository at the site. A special case of a site-specific URL is the performance confirmation facility which may stay open after its associated repository is closed, providing opportunities for long-term monitoring and verification of engineered barrier and repository performance for a certain period of time.

Note that a URL may also be located farther away from a repository and, therefore, not be part of it, but constructed in the same rock formation and the acquired data and results are transferable to the repository. For this case the term area-specific URL has been introduced in [4].

Right from the beginning, the GTS was explicitly defined as a purely applied research facility, i.e. a generic URL, and as such it has benefited from the support of the surrounding local communities. According to the geological siting regions for deep geological repositories currently considered in the Swiss national program, crystalline formations are no host-rock option [5]. Nevertheless, tailored research activities program pursued at the GTS have always been and continue to be closely linked to developments in the national waste management concept and progress in its implementation.

One guiding principle is to make available transferable data of the required level of detail at the time it is needed (after [2]). Generally speaking, in the early stages of safety case development the data need to complement the existing preliminary-stage information. In the mature stages of safety case development the data from a URL need to demonstrate that the site does not represent an exceptional situation, (i.e., is in line with other sites). At all stages of safety case development the URL has to advance developments of investigation techniques and conceptual models.

ROLE OF URL TO SUPPORT DGR RD&D

The implementation of a deep geological repository (DGR) involves a stepwise process that takes several decades, thus a comprehensive planning base for the scientific and engineering work is needed, which is presented in any RD&D (research, development and demonstration) plan. Nagra's RD&D plan [5] establishes the purpose, scope, nature and timing of various future RD&D activities, starting from the top level requirements and planning assumptions. Requirements are posed by the regulatory framework, the waste producers' needs, science and technology or may be derived from recommendations made by authorities or expectations from the scientific community and the public. They are evaluated in the context of a hierarchy for developing the repository design concepts, considering aspects related to both the function and level of detail required and to the timing of implementation of the repository. This is illustrated in Fig. 2 which also shows how the level of detail associated with the requirements increases with progress in repository planning.

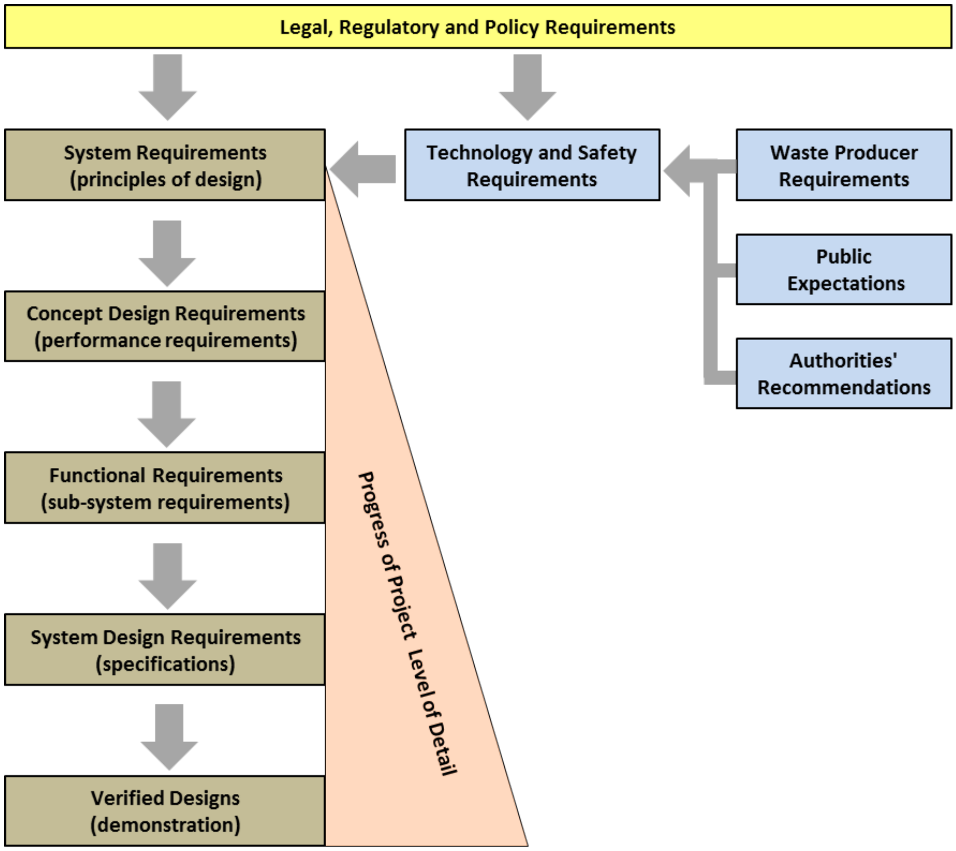

Figure 2: Simplified scheme of the management of requirements for repository implementation modified after [5].

The evolution of the requirements for repository planning and implementation necessitates that the supporting research program in a URL also evolves with time to reflect the changing requirements.

Three decades of dynamic development of the GTS research program reflect the evolving requirements from the progressing national disposal program [6]. The early experiments at the GTS started with the development of methodologies and tools suitable to characterize in detail the geological, hydrogeological and hydrochemical properties of the selected low-permeability formation. Much practical experience was gained for the investigation of potential repository host rocks and sites. Then followed a phase dominated by performance assessment issues, in particular the testing and verification of models for radionuclide transport, the study of effects imposed on the natural system by materials to be used in repository construction, and inquiries into the migration of repository-generated gas. In the mid-1990s focus shifted towards projects addressing radionuclide migration in the geosphere, and the engineered and natural barriers of a repository.

The past 15 years have been the era of engineering demonstration experiments (see www.grimsel.com Phase VI). As the realization of repositories draws closer, large-scale, long-term, integrated experiments have become essential in raising technical and public confidence. The research program has been designed to cover aspects of engineering feasibility, construction impacts on the host rock, repository operation, closure and monitoring.

RESEARCH ACHIEVEMENTS

Overall, the three decades of work at the GTS have successfully demonstrated how generic URLs may contribute to the understanding of safety relevant processes and the reduction of uncertainties, the development of reliable radioactive waste disposal components and concepts, and confidence building. Experiments have evolved step by step in the past and will continue to do so in the future. Many projects have been devoted to the study of fundamental properties of the geological environment and the verification of characteristic parameters of processes expected in a future repository environment. They have laid the foundation for long-term demonstration experiments simulating complex but realistic – i.e. repository relevant – boundary conditions. The many experiments at the GTS have also confirmed the transferability of key parameters and processes to other fractured rock formations which are considered as potential host rocks for repositories. Factors which may affect the transferability significantly are i) the tectonic history and metamorphism, ii) the complexity of the fracture systems, iii) the differences in mineralogy and matrix porosity and iv) the variations in strength and stress [7].

LESSONS LEARNED

- Specific topics where URLs have extended our knowledge base are related to: the right tools and techniques to test, characterize and observe repository systems underground,
- the key properties to characterize geological environments at realistic depths and scales, and under natural or perturbed conditions,
- to the upscaling of processes and parameters from laboratory scale to repository scale,
- to the transferability (applicability/limitations) of results from generic URLs to other locations or even different geological host environments,
- the function of components of the engineered barrier system and of the repository system under realistic conditions and how they can be further optimized, and
- the suitability of construction and excavation methods to meet the rigorous repository requirements.

Taking a closer look at long-term safety, URL investigations have contributed significantly to the aspect of radionuclide mobility and radionuclide retardation. The understanding gained with respect to advection, dispersion, matrix diffusion and colloid migration has played an important part in the reduction of uncertainties and confidence building. The current level of understanding has been achieved mainly through up-scaling experiments, studies of coupled phenomena in the engineered barrier system and host rock, and the testing, further development, calibration and validation of conceptual and numerical models of relevant processes for radionuclide transport.

In terms of repository construction and operation, invaluable experience has been gained under real-site conditions for the excavation and construction of a repository. Concepts for the emplacement of the wastes and of the engineered barriers have been tested and refined in a realistic setting. Basic lessons have also been learned concerning repository monitoring both during the operational and post-closure phases without affecting the long-term safety, but further work is needed to design robust and long-lasting monitoring techniques.

OPEN FUTURE

The current RD&D work in the Swiss national program is largely focused on providing the basis for the synthesis needed for the general license applications for the HLW and L/ILW repositories in the early 2020s [5]. The GTS will continue to contribute to the development and testing of repository engineering and sealing concepts and monitoring issues, as well as concepts for the engineered barrier system and its performance and compliance with requirements for repository design.

Looking farther into the future and worldwide, prompts a series of questions. How much longer will URLs be needed? Until all deep geological repositories have been closed? And what kinds of URLs will be needed? Will they be generic, area-specific, site-specific, performance confirmation URLs? Is there any sense in planning a new generic URL at this time, or even to continue work in an existing one like the GTS?

Ample international experience is readily available today on how to design and build a URL efficiently. However, many of the established URLs have emerged as internationally acknowledged research facilities for safe radioactive waste disposal in deep geological repositories. With the given options of international cooperation one may conclude that there is little reason to invest in new generic URLs. More likely, the future will bring new site-specific or area specific URLs as implementers construct underground facilities in the location of potential future repository sites.

CONCLUSIONS

Experience from more than 30 years of GTS and similar facilities has shown that URLs are an integral part in the overall strategy developments and planning refinements of any national geological disposal program. The contributions are manyfold as the URL's role evolves with time, stage of the disposal program, state of know-how and technology. A URL research program generally is characterized by a broad spectrum of scientific and engineering projects, close international collaboration and knowledge transfer, and active and transparent dialogue with the interested public and other stakeholders.

The need for constructing a generic URL may have various reasons and can be assessed only by an implementer in the context of a national program. Generic URLs with a portfolio of investigations as broad as that of the GTS had their prime in the 1980s and 1990s. Some are still going strong, are internationally recognized centers of excellence and are expected to continue to operate for many years. In the case of Nagra this type of URL contributes to the national program and, at the same time, serves as an important platform for international cooperation.

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