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Proceedings of the Scientific Visit on Crystalline Rock Repository Development

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PROCEEDINGS OF THE SCIENTIFIC VISIT ON CRYSTALLINE ROCK REPOSITORY DEVELOPMENT

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ABSTRACT

A scientific visit on Crystalline Rock Repository Development was held in the Czech Republic on September 24-27, 2012. The visit was hosted by the Czech Radioactive Waste Repository Authority (RAWRA), co-hosted by Sandia National Laboratories (SNL), and supported by the International Atomic Energy Agency (IAEA). The purpose of the visit was to promote technical information exchange between participants from countries engaged in the investigation and exploration of crystalline rock for the eventual construction of nuclear waste repositories. The visit was designed especially for participants of countries that have recently commenced (or re-commenced) national repository programmes in crystalline host rock formations. Discussion topics included repository programme development, site screening and selection, site characterization, disposal concepts in crystalline host rock, regulatory frameworks, and safety assessment methodology. Interest was surveyed in establishing a “club,” the mission of which would be to identify and address the various technical challenges that confront the disposal of radioactive waste in crystalline rock environments. The idea of a second scientific visit to be held one year later in another host country received popular support. The visit concluded with a trip to the countryside south of Prague where participants were treated to a tour of the laboratory and underground facilities of the Josef Regional Underground Research Centre.

ACKNOWLEDGEMENTS

This document is a compilation and summary of the presentations and discussions that occurred during the scientific visit. The authors gratefully acknowledge the input of the participants – they provided the primary content for this document. We are also grateful to Laura Connolly for her wizardly word-processing.

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PROCEEDINGS OF THE SCIENTIFIC VISIT ON CRYSTALLINE ROCK REPOSITORY DEVELOPMENT

1.0 OVERVIEW

A scientific visit on Crystalline Rock Repository Development was held in the Czech Republic on September 24-27, 2012. The visit was hosted by the Czech Radioactive Waste Repository Authority (RAWRA), co-hosted by Sandia National Laboratories (SNL), and supported by the International Atomic Energy Agency (IAEA). The purpose of the visit was to promote technical information exchange between participants from countries engaged in the investigation and exploration of crystalline rock for the eventual construction of nuclear waste repositories. The visit was designed especially for participants of countries that have recently commenced (or re-commenced) national repository programmes in crystalline host rock formations. Discussion topics included repository programme development, site screening and selection, site characterization, disposal concepts in crystalline host rock, regulatory frameworks, and safety assessment methodology. The visit concluded with a trip to the countryside south of Prague where participants were treated to a tour of the laboratory and underground facilities of the Josef Regional Underground Research Centre.

2.0 PARTICIPANTS

Invitations to participate in the exchange were sent to individuals in approximately 30 different countries. The IAEA extended invitations to each member of the Underground Research Facilities Network (URF), and RAWRA and SNL extended additional invitations to many others. In addition to the acting managing director of RAWRA, 45 participants from 13 countries attended. The countries represented were

- Czech Republic
- Germany
- Korea
- Lithuania
- Mexico
- Pakistan
- Poland
- Romania
- Slovakia
- Spain
- Switzerland
- United Kingdom
- United States of America

A full list of participants and their contact information is included in Appendix A.

Group photograph on Day 1. Left to right: Hardin, Sorescu, Vokál, Slovák, Pueschel, Kim, Královcová, Šembera, Koh, Kováčik, Orrell, Mikšová, Sirvydas, Freeze, Swift, Mariner, Dogaru, Hasnain Shah, Whittleston, Banach, Vomvoris, Woller, Steininger, Vencl, Prachař

3.0 PRESENTATIONS

The meeting was conducted in the form of a scientific visit. The schedule for the first three days consisted of the presentation of status reports from the participants of the various countries represented, technical presentations given by experts in the field, topical group discussion sessions, and the planning of potential future collaboration. The full agenda is located in Appendix B, and the presentation slides are provided in Appendix C in the order listed in the agenda.

In the text that follows, the presentations are summarized at a high level to indicate the topics discussed and some of the important points made. Details of the presentations can be found in the presentation slides (Appendix C). In some cases, notable discussions spawning from the presentations are included in the summaries.

3.1 Welcome

The meeting began with a warm welcome by the host country. Jan Prachař, the Acting Managing Director of RAWRA, and Jiri Slovák, the Head of the Geological Repository Development Department at RAWRA, welcomed all participants, thanked all for attending, expressed hopes for the exchange, and thanked SNL and IAEA for their help in facilitating the event (Appendix C, pp C-1 and C2). Andrew Orrell, the Director of Nuclear Energy and Fuel Cycle Programs at SNL, also expressed his gratitude for all who made the event possible and then elaborated on the goals of the exchange. Each participant then introduced himself/herself in turn around the room. (Page C-2)

3.2 Status Reports

The first day focused primarily on status reports, beginning with the host country, the Czech Republic. The agenda in Appendix B shows the order of the presentations. The status report for Spain was presented on the second day due to a scheduling conflict. Here, the reports are briefly summarized in alphabetical order. The associated slides, which have much more detail, are provided in Appendix C.

3.2.1 Czech Republic

Presenter: J. Slovák, RAWRA

Mr. Slovak reviewed proposed SNF management facilities in the Czech Republic, including 1) an underground centralized interim storage for spent fuel; 2) an underground research laboratory (URL) to be constructed near a uranium mine at Bukov site; and 3) site characterization activities for which planning and negotiations are underway. The Czech disposal mission requires disposition of approximately 9,000 MT of spent nuclear fuel (SNF) from six existing and two new reactors. CASTOR storage systems will be used extensively, then the SNF could be disposed in as many as 6,000 waste packages.

In response to questions Mr. Slovak said that payments to localities were planned, on the order of 3 CZK per 10 square meters to be surveyed for potentially favorable siting conditions. Further payments are anticipated as siting and characterization advance. In the ensuing discussion, this situation was contrasted with other national programmes that made or offered payments, without necessarily ensuring progress in achieving siting objectives.

The URL plan was briefly discussed, recognizing that movement of natural radionuclides can be observed in such settings and is an important analogue to repository performance. There was strong interest among participants in potential technical collaboration at this URL.

3.2.2 Germany

Presenter: W. Steininger, Karlsruhe Institute of Technology (KIT)

In response to the 2011 Fukushima incident, 8 NPP went off-line and the Federal Government decided that nuclear is to be phased out by 2022. Presently, Germany has 8 nuclear power plants and 9 reactors operational. The Government´s decision is accompanied by a change in the German energy policy, i.e. energy supply mostly by renewables (mainly wind and solar), in the transition time by natural gas and fossil power plants. New laws will govern the technical-economic challenges connected (e.g. baseload supply, grid extension, increasing prices, supply security, etc.).

There will be new laws and regulations to govern future high-level radioactive waste (HLW) and SNF disposal in Germany. Within this legal frame it is intended to start a new site selection process. These activities might have impact on the further exploration of the Gorleben site, which is well advanced.

An important task to be done in the next years is implementing EC´s Radioactive waste and spent fuel management Directive" into national legislature.

Closure licensing for the Morsleben facility (LLW/MAW) is expected to be fully underway by 2014.

The construction of the KONRAD repository (a deep geological repository for non-heat-generating waste) at the former Konrad iron mine is underway, and disposal operations are expected to begin in 2019.

After the expiration of the 10yrs- moratorium in 2010, site exploration was on-going till the end of 2012. The Gorleben exploration process is now at rest.

A so-called Preliminary Safety Analysis of the Gorleben Site is being performed. The reference concept used for disposal of SNF in a deep geological repository in domal rock salt (like Gorleben) is in-drift disposal in Pollux casks, and borehole disposal of HLW. A backup concept is disposal of both of SNF and HLW in vertical boreholes (the BSK-3 concept). The issue of retrievability is considered as very important. Therefore it is explicitly addressed in the safety requirements of the Ministry of the Environment and was one of the prerequisites in the PSA when formulating the repository concepts.

Considering RD&D activities, Germany continues to look – in addition to rock salt - at other host rocks (clay and crystalline) to acquire knowledge and expertise in order to make scientifically based judgements on these host rock formations. Moreover, scientists from Germany collaborate internationally on many fronts, in several projects with European and non-European partners and in groups like OECD/NEAs Salt Club and Clay Club and the EC "Implementing Geological Disposal of Radioactive Waste – Technology Platform."

Mr. Steininger suggested a recent book entitled "Managing Sensitive Projects" by D'Herbemont and Cesar (translated by Curtin and Etcheber) as basic literature helping to in managing WM projects.

3.2.3 Korea

Presenter: Y.K. Koh, KAERI

Korea has 21 nuclear power plants in operation producing 30% of the total electricity in 2011. This percentage is expected to double by 2030. The impact of the Fukushima situation is not as strong as in some other countries because the Republic of Korea has few other energy options. Seven plants are currently under construction and four are in the planning stages. Storage of PWR spent nuclear fuel (SNF) and CANDU SNF is a major undertaking with CANDU SNF stored in concrete silos. Construction of a final repository for LILW has been delayed to 2014.

Future policy will be decided through public participation. The long-term plan is to start disposal of CANDU SNF by 2050 and PWR SNF by 2070. For LILW disposal, the Gyeong-Ju site was chosen. The disposal method is underground silos, and major tunnels have already been excavated. R&D includes consideration of an advanced nuclear fuel cycle with pyro-processing for recycling of reactor fuel. Experiments to evaluate geologic disposal options are being conducted in the laboratory and in situ at the KURT (this URL is discussed in another presentation).

3.2.4 Lithuania

Presenter: A. Sirvydas

Lithuania has one nuclear power plant (Ingalina, an RBMK design) that at one time supplied about 70% of all electricity in the country. Its two reactors, however, have been shut down as a condition of Lithuania's entry in the European Union, and the waste to be disposed includes various amounts of low level and short-lived waste, 6500 m3 of low and intermediate level long-lived solid waste, 40000 spent sealed sources, 22000 spent nuclear fuel assemblies (about 2500 tons of uranium). Predisposal management of solid and liquid radioactive wastes is underway.

LLW, ILW and HLW from decontamination and decommissioning (D&D) of the INPP will be stored at the Solid Waste Management and Storage Facility (which is under construction now). LLW will be encapsulated in cement, while oils and organics will be incinerated.

The earlier Maisiagala facility for institutional waste disposal was closed in 1989, however, later it was licensed as a facility for storage not for disposal. A facility for disposal of very-low-level waste has been developed based on the concept proposed by Sutdsvik Radwaste AB (Sweden). The availability of a repository for low and intermediate level short-lived waste is planned for ~2018.

SNF is currently stored in "open air storage" which is full. The remaining SNF will be stored in a newly built Interim spent nuclear fuel storage facility (operation foreseen in ~2014). All SNF containers will be stored for about 50 years while a final management concept is developed. The Lithuanian Geologic Survey is working on siting a geologic repository, with assistance from Swedish consultants, in crystalline and clay geological formations. The reference concept is based on the Swedish concept (KBS-3) developed by SKB. Another possible option is disposal in an EU established regional repository. Siting for a national repository may start as early as 2030.

3.2.5 Mexico

Representative: R. Vázquez Ponciano

No status presentation delivered.

3.2.6 Pakistan

Presenter: Z. Hasnain Shah

Pakistan currently operates one CANDU reactor (137 MWe) and two PWRs (600 MWe). Two PWRs (340 MWe) are under construction by Chinese contractors, and an additional ~8800 MWe is in the planning stages. Pakistan also has two research reactors. Wastes are currently stored at sites designated PINSTECH, KANUPP, and C-1/C-2 site.

Disposal concepts being considered are near-surface and geological, primarily in granite or clay. Salt is not currently under consideration because of its economic value. The major challenges for Pakistan are unstable political conditions, seismo-tectonic conditions, and public acceptance. The siting process is underway and repository concepts are in the planning stages. Thirty-nine sites/formations around the country have been evaluated for their potential as disposal sites.

3.2.7 Poland

Presenter: M. Banach

Poland currently stores radioactive wastes from the medical industry, science programmes, and other industries at a surface facility at a former Russian military fort. This facility, managed by Zakład Unieszkodliwiania Odpadów Promieniotwórczych (ZUOP), is scheduled to be replaced with a new surface facility in 2020. ZUOP (under the Ministry of Economy, Department of Nuclear Energy) is responsible for technology development, D&D, and all activities for managing radioactive waste. These activities are regulated by the National Atomic Energy Agency.

SNF from a decommissioned Russian EWA reactor at various degrees of enrichment (10% to 80%) from two light-water reactors, currently totaling 4179 assemblies, must also be disposed. In addition, future SNF from new nuclear power plants in the planning stages (3,000 MWe) must also be disposed. SNF will be disposed in a geologic repository currently planned for operation in 2075. Siting is underway and 19 sites in 12 communities have been chosen for geological research. Potential host rocks include clay, salt, and crystalline rock.

3.2.8 Romania

Presenter: A. Sorescu

Romania has two 720 MWe CANDU type reactors (in operation since 1996 and 2007) and will construct two more CANDU reactors by 2020. In addition, Romania has a TRIGA type research reactor and spent fuel from a VVR-S type research reactor that was shut down in 1997. The waste management implementing organization is the National Agency (ANDR), while the regulating authority is the National Commission for Nuclear Activities Control (CNCAN).

Long-lived LILW and SNF are bound for geologic disposal. A deep geologic repository (DGR) is needed for 14,500 MT of CANDU fuel (4 reactors operating 50 yr). At least 50 years of dry storage is planned. The proposed geologic repository concept is based on the Canadian concept for CANDU SNF. The Baita Bihor Repository constructed in an old uranium mine has been in operation since 1985 for short-lived LILW (capacity 21,000 drums). A near-surface facility in the Cernavoda NPP area is proposed for additional short-lived LILW. The path forward is expected to include new regulations in 2012, continued storage and licensing of storage facilities, and D&D. The CNCAN is expected to endorse IAEA waste management principles. A new law governing waste disposal may be passed in the coming years.

3.2.9 Slovak Republic

Presenter: M. Kováčik, EN-GEO Consult

The Slovak Republic has four reactors and two under construction. Nuclear power accounts for 50% of electricity. Slovakia began its geologic repository programme in 1996. From 1996 to 2001, the Slovakian programme accomplished much R&D: modeling of the near field and far field, site screening and characterization, assessment of the source term, and development of technical designs for sedimentary and crystalline host rocks. Several types of geology have been considered: magmatic, carbonate, flysch, molasse, volcanics, and sedimentary.

Assessments of the advantages and disadvantages of sedimentary and crystalline repositories and the prospective areas were studied in depth. Granitic (crystalline) terrain is available close to waste sources, and the geology is stable, although the deposits are heterogeneous. Geohydrologic data are sparse, especially at depths likely to be appropriate for repository implementation (500 m). Argillaceous claystone, siltstone, or other soft sediments are also available. Some of these deposits have saturated hydraulic conductivity of 3E-11 m/sec or lower, which is promising for waste disposal application. Landslides are observed at the surface indicating the soft character of these sediments, and chemical conditions in situ are likely to be reducing.

Since 2001, however, little progress has been made. A decisive factor is public acceptance. For further progress, the repository programme must be restarted. Current plans are to commence siting activities and complete licensing activities by 2030, followed by construction, and repository operation by 2055. Previous schedules with repository operation by 2037 were unrealistic. The matter of greatest immediate importance is to decide on the rock type, or geologic setting. Slovakia is amenable to an international solution.

3.2.10 Spain

Presenter: J. Molinero, Amphos21

Mr. Molinero described the current focus of ENRESA, a public-private partnership formed for waste management and decommissioning. Spain has 10 reactors, 8 of which are operating. There are approximately 4,000 MT of SNF in existing pools, and another 2,700 MT will be produced (including equivalent HLW from reprocessing). The Trillo, Cabrera, and Asco NPPs have dry storage facilities (ISFSIs) existing or under development.

The priority in Spain has shifted to consolidated storage. The facility (to be called “ATC”) will probably be located at the Villar de Canas site, near a decommissioned NPP. Dry storage in Spain is being implemented using 21-PWR size canisters. The consolidated storage facility (CSF) will include capability for unloading casks, encapsulation (packaging), dry storage, and a research center and business park. The siting process relies on volunteerism by municipalities and approval of the local council.

The reference disposal concept is in-drift horizontal emplacement in a crystalline host medium, with a compacted clay buffer and carbon steel disposal overpack. Eight sites have been proposed with possible down-selection in 2012 and consultations with regional governments. Characterization of these alternative sites is underway.

3.2.11 Switzerland

Presenter: S. Vomvoris, Nagra

The Fukushima situation also impacted policy in Switzerland. The Federal Government has proposed to phase out nuclear power by 2034. This will be accomplished by not building any new reactors, although license extensions for existing reactors may be allowed. This decision-in-principle has been approved by the Parliament, and the next step is to start deliberations on the new law for nuclear energy (expected in the second half of 2013) as part of an energy policy through 2050. The new law is subject to an optional (but with a binding outcome) national referendum. Such a referendum would take place about 2 to 3 years after the decision of the Parliament.

The reference concept for disposal of SNF and HLW in Switzerland is in-drift disposal in a clay formation, with carbon steel packages resting on compacted bentonite blocks in drifts completely backfilled with granular bentonite.

A new siting process was approved by the Federal Government and enacted in 2008. It consists of narrowing down to a set of proposed sites in 3 stages. Each stage ends with the approval by the Federal Government (following reviews by the authorities and public consultation) of the proposals made by Nagra. Stage 1 of this process (2008-2011) has been completed. Nagra identified six regions, each of several hundred square km, for siting two facilities: a repository for SNF and HLW, and a facility for geologic disposal of LLW and ILW. These facilities could be co-located at the same site, perhaps vertically separated. A total of 202 communities in these regions are involved in the participation process for the next step, which will culminate with the selection of at least 2 sites for each type of repository. Six regional conferences have been established, each one representing the interests of each region and providing their input to the selection process. They consider the social, economic and environmental aspects of potential sites. The third stage will culminate with a general site license application, following detailed investigations of the sites selected at Stage 2.

This siting process is “owned” by the Federal Government (not Nagra or the utilities). Nagra has been studying safety (pre- and post-closure) for postulated facilities in each region.

3.2.12 United Kingdom

Presenter: R. Whittleston, Nuclear Decommissioning Authority (NDA)

The United Kingdom has approximately 11,200 m^3 of spent nuclear fuel, 1,400 m^3 of HLW, 364,000 m^3 of ILW, and various amounts of LLW, plutonium, and uranium wastes. The Radioactive Waste Managing Directorate of the Nuclear Decommissioning Authority (NDA RWMD) is the implementing body committed to programme R&D and preparation and planning for geologic disposal. The NDA was formed in 2005 as a non-governmental organization for disposition of “civil” nuclear wastes. Funding on the order of 2.8B British pounds, pays to maintain and remediate 19 BNFL and UK atomic (AEA) sites. NDA is currently involved in the search for volunteer communities.

The current UK concept involves a facility located anywhere from 200 to 1,000 m depth, comprising panels for segregated disposal of different waste types with a multiple barrier approach utilising both engineered and natural barriers to provide both isolation and chemical containment. Current ILW disposal concepts include its encapsulation within cement in vented steel drums, and the current concept for HLW/SNF disposal within hard rock would follow a similar approach to the Swedish KBS-3 concept.

A call for volunteer communities produced interest from several communities within the North of England. Should they choose to participate to the next stage of the site selection process (desk based studies), they would maintain the right of final withdrawal right up to the point of repository construction. Geology in the area comprises hard rock overlain by sedimentary succession. Community decisions on whether to participate in the next stage of the process are expected in January 2013. Should the process progress, waste emplacement is envisaged in 2040.

Press in Britain has been largely negative, but the siting process and overall effort for disposition of civil nuclear wastes receives wide public support. Recent developments are 1) the government proposed to discuss the possible acceleration of the programme with the aim of emplacement by 2029 and 2) increased research and international collaboration, and larger scale experiments.

3.2.13 USA

Presenter: P. Swift, SNL

The U.S. has 104 operating reactors and 14 that are shut down. The cumulative discharged used nuclear fuel is currently around 70,000 MTHM and may double in the next 40 years. With the future of the Yucca Mountain license application on hold, the current direction of the repository R&D programme in the U.S. is generic disposal. There are several generic disposal R&D activities that can be accomplished (e.g., evaluation of alternatives, identify data needs, develop science and engineering tools, etc.), as identified in the slides presented. The four options being analyzed in depth are three mined repository options (crystalline rocks, clay/shale, and salt) and deep borehole disposal in crystalline rock.

The R&D needs for the disposal programme were identified by evaluation and prioritization of R&D opportunities, as documented in “Used Fuel Disposition Campaign Disposal Research and Development Roadmap,” completed in 2011 (update in progress). One outcome is renewed interest in international collaboration by the U.S. Department of Energy because the U.S. has no underground laboratories or site characterization activities that are currently authorized.

3.2.14 Discussion

Lead: A. Orrell, SNL

This discussion was conducted with the objective to produce a summary of approaches used by participating countries, and of eliciting a joint statement and identifying potential actions.

The following summary was presented by the chairs, organized along major topics:

- Decision Making – Public involvement is a common aspect. Decisions are usually staged, and may be challenging given moratoria and other delays. The authority for site selection is important but not always clear in the legal and regulatory framework.
- Long-Term Project Concerns – We have little experience with long-term projects. Volunteerism among participating communities must be sustained. Multiple sites may be needed to manage long-term uncertainty in site access. Delays in the implementing programme impact staffing and may impact the waste disposal mission itself. Measuring and demonstrating progress can be difficult over such long time frames.
- Role of Interim Storage – Given the repository implementation will take 20 to 60 years, all planned programmes involve interim storage. We have not yet worked out how to optimize the use and cost of interim storage, within a broader system culminating in disposal. For example, storage underground could be part of a longer term project resulting in permanent disposal.
- URL R&D – Uses of generic vs. site-specific data have not been well defined. Whereas generic data are readily available through participation in international cooperative URL programmes, such data have limited value for decision making. A more formal process for international data sharing (e.g., for data acquired nationally, outside of cooperative programmes) could extend the availability and use of analogous data. Formats and standards for such data could facilitate sharing.
- R&D Agenda – Examples of systematic approaches for identifying relevant R&D include the European Union Framework Program #7 (FP7) research agenda, the U.S. Used Fuel Disposition R&D campaign, and various examples of international cooperation. Long-term knowledge management is an important part of success, for both generic and site-specific data, for projects that may last 50 years or longer. For crystalline rock the importance of scale-dependent discontinuities, means that prediction of performance can involve large quantities of data, and the effectiveness of characterization may depend on efficient, effective data collection and management.
- Alternatives to the Copper Waste Package – Whereas alternative waste package materials have been proposed for use in crystalline repositories, such as carbon steel, the relative cost and performance have not yet been thoroughly investigated.
- Disposal System Design – Optimization of a disposal system design should also consider the impacts of upstream activities in the fuel cycle. Small nuclear power programmes (few reactors, limited waste) can optimize storage, transportation, and disposal functions. As examples, extended storage could conceivably be used to facilitate disposal in a multi-national repository. Also, selection of canisters for storage should be done with a view to eventual disposal. Disposal concept development information (e.g., engineering, cost, etc.) should be shared. Examples include details of horizontal vs. vertical emplacement, subsystems for package conveyance and emplacement, and details of public acceptance.
- Crystalline Club – The OECD/NEA "Clay Club" and the recently formed "Salt Club" were founded on a personal basis. A "Crystalline Club" could also extend the effectiveness and credibility of repository R&D programmes focused on crystalline host rocks.

The ensuing discussion of this summary identified other principles that are important to the represented countries pursuing geologic disposal in crystalline rock and other media:

- Security – Physical security of nuclear materials is important in storage, transport, and disposal.
- Generational Equity – The enterprises that generated nuclear wastes, and the stakeholders who benefited from the electricity produced, should to the extent possible, pay for waste disposal. Extending the time frame for disposal to 100 years or longer virtually guarantees that much of the disposal cost is deferred to later generations. Whereas funds can be held in escrow, this has not generally been achieved. Thus, waste management strategies should account for how every step will be paid for, and by whom.
- Preclosure vs. Postclosure Risk – Public perception of risk may be skewed or exaggerated, but must be acknowledged and addressed by implementing organizations and regulators.
- Shaft vs. Ramp Access – The availability of geology and land access suitable for development of alternatives, and the criteria for selection, have not been described in a common or systematic way.
- Cost – Whereas trading of safety against cost is not generally acceptable to the public, it must be done at some level so that disposal is affordable. A margin of performance against quantitative dose or release standards is needed to defend decisions that lower disposal cost. The Swiss programme has developed a context for comparing uncertain alternatives (e.g., disposal concepts) with respect to safety, which may be useful to other countries. Over the long term, society may neglect waste disposal and its funding, so the disposal science community has an immediate obligation to make disposal technically possible (and affordable) now.
- Public Acceptance – One of the greatest challenges to success of a geologic disposal strategy is changing attitudes, i.e., how can public acceptance be defined when the "public" will not be born for another 50 years?

The representatives from each country were asked: What is the most important issue currently faced by the implementing organization in your country?

- Romania – The question of what should be included in a "nuclear park?" What type of local involvement should be allowed or encouraged? What type of financing is adequate, stable, and politically viable? These common concerns were labeled as the "Legislative and Regulatory Framework" issue.
- Slovakia – The country needs any type of active waste management program, i.e., an organization with the mandate and resources to take responsibility for nuclear waste. This concern is part of the Legislative and Regulatory Framework issue.
- Korea – Turnover in the legal, regulatory, and political functions. This concern was labeled the "Political" issue.
- United Kingdom – Public acceptance is the most important issue, exacerbated by past mistakes and previous lack of disclosure. This concern was labeled the "Public Acceptance" issue.

- Czech Republic – Public acceptance with the geological exploration of the potential sites, transparent decision making process and also optimizing the cost of the disposal system, along with expediting disposal, and doing so within a coherent strategy. This concern was labeled the "Cost Optimization" issue.
- Lithuania – Financial support is a critical problem for small programmes. In Lithuania, the EU funding for INPP related tasks was insufficient. This concern was labeled the "Financial" issue. Acquiring qualified staff with local knowledge is important, as are public acceptance and the methodology for site selection.
- Mexico – Public acceptance is the most important issue, as identified in the "Public Acceptance" issue above.
- United States – Public acceptance is the most important issue, and must include acceptance by the technical peer review community as part of the public.
- Switzerland – Whereas there is no crystalline rock repository programme in Switzerland, if any one country fails, the impact is felt everywhere. Programmes in individual countries need momentum but not too much, if it drives a programme forward to complete or partial failure.
- Pakistan – The most important concern is physical security of nuclear materials; this concern was labeled the "Security" issue. Other concerns include public acceptance and finance.
- Poland – The important concerns include public acceptance, legislative/regulatory framework, and finance.
- Germany – Communication to the public is an important concern, given the large numbers of stakeholders and the influence of minority, activist groups. This concern was labeled as the "Communication to the Public" issue, and is a condition for public acceptance.

Finally, the group identified an issue common to all programmes, the question of defining how good is good enough? Thus, in the description of a disposal plan that includes safety, engineering, cost, schedule, and other attributes, how does one represent the proposed solution among alternatives? Importantly, the programme must be prepared to do this, and to thereby make progress toward long-term objectives, whenever changing externalities such as politics or funding availability permit. This concern is part of all the other issues in this list, so that progress can be uniformly achieved.

The foregoing discussion is then summarized by a list of important issues:

- Legislative and Regulatory Framework
- Political
- Public Acceptance (includes technical peer community, and communication to the public)
- Optimizing Cost
- Financial

- Security

3.3 Development of a Repository Programme

On the second day, many of the presentations focused on the general development of a national crystalline rock repository programme and the technical bases that must be established to meet regulatory requirements, screen potential sites, assure quality, develop repository designs, and build confidence in the assessment of long-term performance. These presentations are briefly summarized below along with any notable discussions generated. The presentations of countries' specific experiences in site selection and site selection are summarized in Section 3.4. Slides from all presentations can be found in Appendix C.

3.3.1 Overview of Repository Programme Development

"Repository Programme Development from Concept to Licensing," presented by A. Orrell, SNL

The material for this presentation was based on reports and documentation (see Appendix C) from IAEA, Organisation for Economic Co-operation and Development (OECD), U.S. National Academy of Sciences (NAS), Nuclear Energy Agency (NEA), and other institutional reports and personal experiences. The development of a repository programme faces a combination of technical, scientific, engineering, and sociopolitical challenges. A successful programme satisfies the needs of the various stakeholders and the implementer, with safety as a common goal. The life-cycle of a repository programme moves from a pre-operational phase, involving disposal concepts and site selection, to the operational phase and then to a post-closure phase. Activities within each phase can draw from international experience. During these phases, the government, regulatory body, and operator/implementer assume key responsibilities. Of particular note are the IAEA safety requirements on slides 12, 13, 14, and 16 and the safety assessment and safety case. During the pre-operational phase a license application is prepared by the operator/implementer for the regulatory authority(ies). Primary elements of this application are the safety assessment, the safety case, and the supporting data. Thus, licensing is a process that lasts throughout the repository program. Because trust is of paramount importance and can be easily and quickly eroded by a single event, developing a repository programme requires attention to integrity and transparency over long time frames.

The use of international professional associations was discussed; the Technology Platform, and technical associations were mentioned. There currently exists no union of scientific workers in waste management that might exert influence on policy or technical decisions made in national programmes.

3.3.2 Technical Bases

"Technical Bases for Repository Construction in Crystalline Rock," presented by P. Mariner, SNL

Technical bases are data and arguments that build confidence that the repository will meet functional and safety objectives. Technical bases are used to identify and select potential sites, develop the repository design, and build and support the safety case. In this presentation the spectrum of technical bases was divided into categories and each category was examined individually. The emphasis was on striving to develop the documentation of all technical bases (data collected, methods used, calculations performed, etc.) needed to withstand the scrutiny of regulators and stakeholders. Much of the documentation can build on data collected and arguments developed in international repository programmes. For disposal in crystalline rock, technical bases must show substantial performance of the waste package and engineered barriers. Specifically, they must show how the attributes of the crystalline rock environment and the designed engineered barrier system will protect the waste packages and limit radionuclide release rates, how the natural barriers will prevent unacceptable exposures in the biosphere to radionuclides that are released, and how various human and natural event scenarios are improbable or inconsequential. Features, events, and processes (FEPs) important to dose calculations in performance assessment calculations were identified. In addition, a methodical process for prioritizing site characterization activities was presented, and a list of relevant safety assessment reports and links was provided.

There was a discussion of how sufficiency is determined in the regulatory, technical, and socio-political contexts. There is always a risk to success, from excessive requirements at all steps of implementation. One argument is that sufficiency in data and information is the amount and quality of data and information the implementer believes is necessary to convince the regulators and stakeholders that additional data and information is not required.

There was also discussion as to the relative benefit of the minimal rock pressures and the associated rigidity of excavations in a crystalline rock repository. While canisters can be designed to withstand high rock pressures, minimal rock pressures on canisters and rigid excavations are characteristics of a crystalline repository that set it apart from clay and salt and therefore allow for unique engineered barrier designs. These hard rock characteristics potentially allow for EBS designs that enhance long-term canister performance. In addition, they could simplify testing and modeling (due to rigid boundary conditions) and facilitate retrievability in the short and long term (though this may be irrelevant depending on objectives and regulatory criteria). There was agreement that a joint statement of the advantages and disadvantages of crystalline rock compared to other disposal media would be helpful in development of disposal concepts. There was also agreement that disposal concepts for safe disposal in crystalline rock are likely to rely more on engineered barriers such as a clay buffer around each waste package, than other concepts, for example those in salt.

Other notes and comments were 1) that laboratory and field work should be more prominently identified in post-closure safety technical bases; and 2) microbial processes may also be an important FEP.

3.3.3 Design Concepts

"Disposal Concepts in Crystalline Rock" presented by E. Hardin, SNL

This presentation discussed variations on the KBS-3V and KBS-3H concepts. Prefabrication of the waste package and buffer, prior to transport and emplacement underground, is important for controlling costs and assuring as-built quality. For both the vertical and horizontal modes, there will be emplacement criteria concerning the potential for a flowing fracture to intersect the buffer. For the horizontal mode (boreholes approximately 100 m long) it will be more challenging to collect accurate in situ data on fracturing. Grouting is likely to be used, especially for the horizontal mode, and will present additional costs and complications.

Prefabrication offers other potential advantages: as proposed by McKinley et al. (see presentation materials) it could be used to elaborate the EBS structure within the buffer. The “reservoir” proposal is a sandstone layer around the package to provide mechanical support, and to promote phase segregation, i.e., separation of gas and liquid phases. The prefabricated package can be enclosed in an impermeable steel canister (compared to the expanded-metal sleeve used in the Posiva drawings). This impermeable canister could be engineered to remain essentially intact through the thermal period and thereby to protect the dehydrated clay buffer material from thermal-hydrologic-chemical alteration. The canister would be vented, but only to bleed pressure differences.

The KBS-3 concepts were compared with other concepts that allow larger waste packages (i.e., containing more than 4 PWR fuel assemblies). Several concepts were discussed: an enclosed emplacement mode in salt, an open mode in unsaturated crystalline rock, and two concepts for disposing of dry-storage casks directly. The CARE concept from Apted et al. would emplace CASTOR (or equivalent) storage casks directly into caverns in crystalline rock, and a decision would be made in 100+ years whether to recover the SNF or seal the cavern for long-term waste isolation. The DIREGT concept from DBE-Tec would emplace CASTOR casks directly in salt, using a horizontal borehole emplacement mode. For direct disposal, long-term storage casks require some accommodation for FEPs, and the most challenging appears to be in-package nuclear criticality.

Finally, costs were compared across a range of enclosed and open emplacement mode concepts, using data prepared by the U.S. program. There is a 3-fold range of costs possible depending on how elaborate an EBS, vs. reliance on natural barriers. The KBS-3 concept is near the high end of the range because the EBS is complex, with buffer and backfill installation, and high-cost copper packages. This can be compared with direct disposal of carbon steel packages in salt.

With regard to repository programme development, the disposal concept should be developed as part of the safety case, as a step in building consensus as to the features, events and processes that are important to repository performance. The safety case, and by inclusion, the disposal concept, should be iterative throughout siting, characterization, and licensing. Inability to change the disposal concept can lead to inflexible responses to external changes such as regulatory requirements, external reviews, and imposed limitations on funding and other resources.

Disposal concepts can be diverse within a system or repository, e.g., waste types can be segregated in different parts of the repository with different packaging, barriers, etc. Similarly, disposal concepts can be partial so that only a portion of the available SNF or HLW is disposed of, and the remainder can be dispositioned in a different repository, or reprocessed, etc. Disposal concepts can be site-specific and need not be limited to generic concepts, e.g., a constructible but permeable host rock can be “protected” from groundwater circulation by impermeable, non-host layers. Finally, generic disposal concepts are generally all retrievable and recoverable (the former is for safety reasons, the latter for economic reasons). The low likelihood of retrieval and the poor economics of recovery for disposed SNF mean that there is no significant, universal need to build retrievability into the disposal concept from inception.

3.3.4 Safety Assessment Methodology

"Application of the Safety Assessment Methodology" presented by G. Freeze, SNL

A safety case is "an integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility" (NEA 2004, Section 1).[1] The safety case includes quantitative information and qualitative supporting evidence and reasoning that gives confidence in the underlying science. "The safety case has to be developed progressively and elaborated as the project proceeds. … The formality and level of technical detail of the safety case will depend on the stage of development of the project, the decision in hand, the audience to which it is addressed, and specific national requirements" (IAEA 2011, Section 4.12). The quantitative information in a safety case is typically provided by a safety assessment, which is the "quantification of the overall level of performance, analysis of the associated uncertainties, and comparison with the relevant design requirements and safety standards" (IAEA 2011, Section 4.10).

The safety assessment methodology is an iterative evaluation of application objectives, site characterization, FEP analysis, scenario development, PA model implementation, and assessment results, each of which is presented in more detail in the slides. Thermal-hydrologic-chemical-mechanical-biological-radiological (THCMBR) processes must be evaluated including their spatial and temporal variability and uncertainty. To ensure that a safety assessment considers all processes that are potentially relevant to long-term repository performance, a systematic FEP analysis should be performed (see cited examples in presentation). The NEA international FEP database (NEA 1999, 2006) provides a good starting point for developing a FEP list. From a comprehensive list of potentially relevant FEPs, FEP screening is performed. Through FEP screening, a subset of important (included) FEPs are identified that defines the range of possible future states (i.e., scenarios) of the disposal system, and FEPs that are of low probability, low consequence, incompatible with regulations, or are physically unreasonable are screened out (excluded). Scenarios, well‐defined, connected sequences of FEPs that outline of a possible future condition of the repository system, can be formed from the included FEPs, and the scenarios can then be evaluated numerically in a safety assessment model, propagating uncertainty. Model results and sensitivity analyses can be used to identify key processes/parameters that control dose estimates. This information can be used to guide R&D. Numerous references for these topics are provided in the slides.

The complexity of safety assessment models can vary, depending on programme needs. Simplified models offer fast solutions, but have limited ability to incorporate multi-physics couplings. More complex models can provide highly integrated coupled multi-physics but may result in excessive run-times, even in a high-performance computing environment. Whatever model complexity and computational approach is used, it must conserve masses of radionuclides throughout the system while implementing radioactive decay and ingrowth. The model should also be capable of discerning where the released radionuclides are in the engineered and natural barrier systems as a function of time.

A survey of meeting participants indicated that only a few of the countries considering disposal in a mined crystalline repository (e.g., Czech Republic, Korea, Spain, Switzerland, USA) have performed a FEP analysis or FEP screening. It was emphasized that a preliminary FEP analysis

[1] Reference list can be found on slides 28 through 32 of the presentation in Appendix C.

can be done in a matter of days by any of the participants using available FEP databases regardless of whether a specific site has been identified. The results could then be used to help identify R&D priorities. FEP evaluations communicate relative importance of technical issues to all disciplines. Initially, generic FEP evaluations do not require site specific data, but can be supported by literature data, geologic surveys, and expert elicitation.

3.3.5 Performance Assessments and R&D Prioritization

"Insights from Safety Assessments for Mined Repositories in Crystalline Rock"
presented by P. Swift, SNL

This presentation provided a summary of safety assessment results for simulated crystalline rock repositories and identified components and processes observed to be potentially important for the crystalline rock repository concept. Current DOE analyses indicate that I-129 drives the dose in systems with slow moving water, but the peak dose remains low (below 0.01 mSv/yr) as long as the buffer remains intact. Buffer failure causes the peak dose to increase, and an increased fracture flow rate significantly hastens the arrival of the peak dose. The Canadian Fourth Case Study shows similar results (peak dose below 0.001 mSv/yr dominated by I-129). The peak dose is approximately 3 orders of magnitude below ICRP 81 criteria. Calculations for the Swedish Forsmark SR-site show Ra-226 as the dominant dose contributor at 1 Ma, but the peak dose (~ 0.0001 mSv/yr) is still orders of magnitude below the risk limit. In the Swedish analysis, failed waste packages, resulting from failed buffer as ice retreats after the next glacial period, are assumed to be intersected by highly transmissive fractures. Ra-226 is the dominant contributor because the flow to the biosphere is rapid within these fractures. The total estimated dose varies linearly with the number of failed waste packages. The uncertainty in fuel dissolution rate is also an important contributor to overall uncertainty. These safety assessment results indicate that crystalline repositories have the potential to provide excellent long-term isolation for SNF and HLW. Thermal load management issues are likely to favor relatively smaller waste packages in crystalline repositories.

The second half of this presentation focused on prioritization of R&D activities. The results of safety assessments can be used to iteratively integrate R&D. Several examples were presented in some detail and included topics such as how to take the existing state of knowledge into account. Important information includes cost and time required to complete the R&D. Evaluation results for the UFD Campaign R&D Roadmap were compiled and organized using the structure of the FEP catalog. A brief summary of the prioritization of engineered system R&D was presented.

One idea mentioned during the presentation is that the KBS-3 approach, with its expensive copper canisters, might be the best alternative if it takes as much or more money to develop an alternative approach.

3.4 Site Selection and Site Characterization

This section summarizes the presentations of participants with specific experiences in site selection and site characterization in their home countries. Some of these experiences were presented at a high level in the status reports on Day 1 (Section 3.2). Here, additional presentations on site selection and site characterization from Day 2 and Day 3 are discussed in the order listed in the agenda (Appendix B). For the details of these presentations, the slides in Appendix C should be consulted.

Swiss siting process - experience from the Swiss radioactive waste management programme (S. Vomvoris, NAGRA)

Mr. Vomvoris described the Swiss programme moving away from crystalline rock to sediments. This is in part because prospective crystalline rock formations in Switzerland tend to be overlain by sediments which make them difficult to characterize with surface investigations only. The original crystalline project investigated two large regions using surface and borehole methods. A second phase, involving more detailed surface investigations in one area, with cross-hole testing, shafts, and underground tests, was never implemented.

Switzerland has approximately 8 million inhabitants and 40,000 km^2 land area, but only 8% of the land area is inhabitable (not mountains). Hence investigations should minimize impacts to the surface in the inhabited regions. Sedimentary formations have been characterized thus far using deep boreholes and surface geophysical investigations. In one of the areas, focused investigations with one deep borehole and a 3-D geophysical survey were performed.

A new siting process has commenced in Switzerland for LLW/ILW and HLW/SNF repositories (see the status report from Day 1). Separate sites are possible, or the facilities may be co-located. The idea of the new process is to get the government authorities (regulators and representatives) at all levels (Federal, Canton, Community) involved early in the process starting with site selection and characterization. Indicator criteria have been developed for safety and engineering aspects, to select sites for further characterization. Six regions have been selected and compared using a multi-attribute utility analysis (MUA). These regions have been approved and form the basis for proceeding to the second stage. The second stage was initiated by Nagra with the proposal of 20 sites as the basis for the discussions with the regions and for the selection of at least 2 sites at the end of Stage 2 for further detailed investigations. The approach followed is "normative," i.e., the implementer proposes sites. The Federal Office of Energy "owns" the entire process. Safety criteria are controlled at the Federal level.

In discussion, technical expertise was identified as a key requirement for implementing and regulating organizations.

Funding is being provided to Cantons and Communities to support review and their active participation. Eventually, impact funds will be distributed when two sites are selected for characterization. Impact funds are common for similar projects in Switzerland and will be based on an evaluation of the effects of the geological repositories at the local and regional level from studies of socio-economic and environmental aspects. The form in which these contributions will be provided is open. In a previous similar project in Switzerland the community proposed that part of the funds should be held in escrow for many years for sustained long-term benefit to communities.

Focus on geological aspects - geology, hydrology, geochemistry, geophysics, environmental isotopes (F. Woller, Consultant to RAWRA)

The first milestone of a deep geological repository is "to select sites with proper geological conditions taking into account local developments at proposed sites. After evaluation of relevant results, include two sites into land use plans (main and reserve ones) for a deep geological repository."

The Czech Geological Survey in collaboration with other investigators is characterizing potential site areas using remote sensing, surface geology, and geophysics. These methods are used to locate boreholes (300, 500 and 1000 m depth; 47.5 mm diameter) for model testing and further investigations. The work complies with the Czech Mining Law, and areas designated for study have been entered as "special interventions affecting Earth's crust" in the territorial plans.

Public acceptance is problematic even for characterization activities. The goal for October 2012 is to sign agreements with affected localities (8 municipalities). Information is needed by "all sides" of the siting debate to inform decisions.

Focus on conflicts of interest (legacy, urban plans, protective areas, natural hazards etc.) (J. Mikšová, RAWRA)

This presentation summarized the characterization approach and stakeholder interactions. Conflicts of interest are defined here as opposing positions on decisions with multiple stakeholders. Characterization will proceed in stages: surface, borehole, and underground investigations. Stakeholders include land owners, municipalities, and state administrations. Constraints include a "long list" of legislation in the Czech Republic as an example. Also, the process is constrained by treaties and international conventions. Conflicting positions are associated with legislated exclusion areas, environmental concerns (e.g., forests), and anthropogenic factors (dams, historical sites, etc.).

The Czech Republic has approximately 10.5 million inhabitants, at a density of 130/km^2. There are 6,248 municipalities and several military reservations. These statistics complicate siting related activities. Benefits from characterization activities, in addition to the information value (e.g., groundwater resources), include employment in the localities, etc.

Focus on construction aspects -repository design, geotechnical properties of rock (M. Dvořáková, RAWRA)

The current schedule for developing a deep geologic respository (DGR) in the Czech Republic was presented in detail. Planned siting activities would culminate in site selection by 2025, with URL construction several years later and repository operations by 2065. As of 2011 the reference disposal concept is similar to the KBS-3H, with prefabricated packages (with clay buffer), ramp access, and separate panels for waste types, covering an area of approximately 4.4 km^2.

The programme is currently focused on siting activities with data collection and underground investigations where access is available. The URL would be constructed at relatively shallow depth (e.g., 250 m) and the repository at a greater depth (550 m) if favorable characteristics are found. Other important areas of concern and R&D plans in the programme include technology development, waste minimization, methods of transport, encapsulation (packaging) methods, and system optimization. The design is currently being modified for a better Czech fit (less adherence to the KBS-3 concept, and parallel emplacement and construction).

Two different disposal zones for two different waste types were identified in the design, prompting a comment that two different safety cases might need to be developed for this design. There was also discussion on whether a ramp was needed.

Focus on the decision-making process including potential schedule/when to start, defining of geological criteria (exclusion criteria, conditional criteria) (J. Slovák, RAWRA)

Past and future steps for siting two facilities were described: a repository for LLW/ILW and for SNF/HLW. The Czech Geological Survey identified 27 candidate areas (selections are not required to be taken from these). In 2012 the goal is to identify 6 or more sites for possible characterization from choices that include both public and private lands. Approximately 4 or more of these would be characterized, supporting a down-selection of two sites in 2018. Agreement from municipalities is needed for these selections.

Sedimentary geology was eliminated from consideration early in the process, mainly due to concerns with drinking water supplies and possible impacts on military sites.

Modeling hydrogeology and hydrochemistry in support of safety assessment for radwaste repositories in fractured rocks - Case studies and lessons learned from Sweden and Finland (J. Molinero, Amphos21)

The focus of this presentation was on the general status of hydrologic and hydrochemical modeling for the Swedish and Finnish repository programmes. Paleoclimate studies for the Baltic region shows that glacial characteristics will prevail during the repository performance period. There presently are "old" brines (at least 1.5 Ma) observed at depths of approximately 1 km. A younger imprint of brine from the Littorina Sea, a brackish phase of the Baltic during the early-mid Holocene (age up to 13 ka), has affected the upper kilometer. This has been perturbed by mixing with freshwater, and by recent groundwater pumping.

Hydrologic simulation presents scale-dependent structure associated with faults and fractures. The discrete fracture network approach is suited for scales up to approximately 100 m, while more extensive models used to understand glacial processes (20 km) are equivalent continuum models and require upscaling of properties.

A key question for the Swedish and Finnish programmes is what groundwater flux and host rock permeability is acceptable? This question can only be addressed in the context of integrated hydrologic simulation and safety analysis.

Hydrochemical modeling is being addressed using a specialized modeling framework. The conceptual model for transport of chemical species represents an integration of site data, expert judgment, and interpretations (e.g., mixing calculations). The appropriate integration of these is a model that combines all of the important data.

The mathematical implementation is being done with stream tubes and channel networks representing flow, matrix diffusion, and reactive transport on multiple, 1-D channel networks developed from stochastic realization. Typical FEM solution strategies have 10^6 nodes and 5×10^6 elements. The approach has used particle tracking, and back-tracking to 4,000 waste packages in order to sort potential radionuclide transport pathways. Travel times from zero to 10 ka have been generated. Back-tracking of particles is useful to link model boundary conditions with waste emplacement locations. PFLOTRAN has been used for flow and some hydrochemistry modeling at Aspo and the SFR site near Forsmark.

A question was raised about model validation. The response was that for this type of model, validation is not really possible, but the various components of the model can be verified to work correctly.

Simulating flow and transport in fractured media (A. Pueschel, GRS)

A 1D model was used to simulate radionuclide release, mobility, and transport from HLW glass through a bentonite buffer and then through a fracture for a generic repository in granite. This model is useful for assessing the various features of the system and the effects of uncertainties. 2D and 3D models are useful in the far field to evaluate flow fields and density driven flow.

A 2D model using d^3f/r^3t was developed to simulate colloidal transport observed in experiments at the Grimsel Test Site. Tracer data were used to calibrate the flow parameters, and colloid transport data were used to fit and calibrate the colloid interaction parameters. It was found that desorption was stronger for trivalent radionuclides than for tetravalent radionuclides.

In another example, a simple vertical 2D discrete fracture network model was used to simulate a complicated fracture network for flow and heat transport calculations. Good agreement between results was found.

Additional, multi-lab collaboration is needed to build confidence in these approaches. Software tools available at the GRS facilitate model-data comparisons.

Geologic mapping and structure geology (J. Pertoldová/K. Verner, CGS)

The presenters described the progress of mapping the Czech Republic geologically, at 1:200,000 (1960's and 1970's), 1:50,000 (2000), and 1:25,000 (ongoing). Digitized maps are available on the CGS website, and English language maps are available. Radioactive waste disposal prospects are expected to be mapped at 1:25,000 by 2014.

Important geological features identified during geological mapping are summarized in the explanation text (including geology, geophysics, geochemistry, mineral resources, hydrogeology, engineering-geological pattern, and environmental geofactors). The structural geology focus is on discerning the stress regime and integrated strain from anistropy of magnetic susceptibility, also measurements of residual strain. Economic benefits include data relevant to new mineral resources, re-evaluation and protection of energy sources like coal and geothermal energy, and information relevant to siting storage and disposal of hazardous waste.

Geophysical airborne and surface exploration and interpretation (M. Karous, Geonika)

A range of surface geophysical surveys are being undertaken, including: gravity, seismic, resistivity, induced polarization, gamma spectrometry, and magnetic susceptibility. A gravity cross-section can determine the angle of contact between formations, subject to interpretation. Single measurement versus distance can identify very deep faults (lower densities at faults). Magnetic surveys from the air can show where crystalline rocks are, in relatively unweathered condition. Airborne methods can also be used to distinguish element ratios in rocks (e.g., potassium, uranium, thorium). Joint interpretation of geophysical methods can give detailed interpreted cross sections. Examples of seismic sections and 3-D seismics were presented. This presentation was completed with an abstract, see Appendix C.

Borehole investigation methods (J. Lukes/M. Prochazka, Aquatest)

Well logging can provide in situ measurements of physical and mechanical properties of rocks, the stage of tectonic deformation of rocks, fractures and fissures, open fractures, fracture orientation, groundwater movement (detection of yields and intensity of water flow), well orientation-dip and azimuth, cavities, and other information that can be obtained from downhole cameras. Measurements are continuous and usually collected in intervals of 5 cm. Methods include fluid resistivity, photometry, gamma log, resistivity log, magnetic susceptibility, acoustic, caliper, gamma-gamma log, neutron-neutron log, sonic log, temperature log, etc. Examples of well logging for fissure connectivity between boreholes using tracer tests were also presented.

The presentation described the history of the Aquatest borehole geophysics company in the Czech Republic and its involvement in repository siting activities. One major point was that temperature and pH logs are used instead of flowmeter logs to speed up logging while producing the same level of understanding of flow features.

Hydrogeology and hydrogeochemistry (T. Pačes, CGS)

The flow and hydrochemical behavior of groundwater in granites in the Bohemian massif were studied for more than five years at a research site in the Czech Republic. Three boreholes, 10 to 14 m apart and drilled to depths of 300 to 350 m, were used to measure hydraulic conductivity (cross-borehole flow tests) and water composition as a function of depth. Hydraulic conductivity decreased from the 10^{-9} to 10^{-6} m/s range in the upper 100 m, to10^{-11} to10^{-10} m/s below 200 m. Sub-horizontal permeable fractures in the upper zone are probably a result of physical changes in rocks due to permafrost during the last glacial period. In a mineralogically homogenous granite, ground water composition varies with depth and with time. No composition was reached after drilling and hydraulic tests in granite with very low permeability after 1800 days of sampling. Temporal trends in the chemical changes were different at individual depth sections of the drill holes. Individual dissolved elements behaved differently too. Therefore, a leveling of the steady state chemical composition of groundwater in host rocks will need a prolonged time of even several years. We found very high steady-state concentrations of total organic carbon (TOC) at depth below 100 m in granite. The source and composition of the TOC is as yet unknown. According to isotopic and chemical data for carbon, the source is not anthropogenic pollution or shallow water rich in humic acids.

Because the rate of uplift and corresponding erosion of the Bohemian massif has been measured to 1 to 2 mm/yr, Pačes questioned the long-term safety of a repository located at a depth of 500 m. At this rate, the repository would be much closer to the surface in 100,000 years. His observations from borehole data, which are similar to observations around the world, indicate higher permeability, more open fractures, and different water chemistry at shallower depths. At the depths, permafrost can become important in a repository performance assessment. Pačes contends that the Czech Republic should strongly consider deep borehole disposal, in which wastes would be disposed at depths from 3 to 5 km in sealed boreholes. Other aspects of deep borehole disposal he likes are the likely lower costs, the low probability that dense water at great depth will migrate to the surface, the reducing chemical conditions, the ability to use steel instead of copper, and the reduced hazards of drilling operations compared to mining operations.

Data management (J. Mikšová, RAWRA)

The Czech "Cadastre" was presented: consisting of geodesy, GIS, gravity control, and other maps. The slides include an example for map indexing. The following topics were discussed: geographic data management (map sheets), geological data management, Czech Geological Survey databases, data and information structure, spatial data structure, metadata, data properties and workflow, data storage, GIS data, and GIS spatial analyses. GIS capability to support siting activities has advanced to 40 raster and 180 vector layers for each of six sites being evaluated.

Why is data management important? It helps us in the decision making process, and it is an essential part of knowledge management, but long term preservation of data and information is necessary.

Communication (L. Steinerová, RAWRA)

The Atomic Act of 1997 created SURAO. In 2002, a deep geological repository was deemed the only feasible option for spent fuel; other options were seen as unrealistic. Public protests and disagreements put a stop to geological research, especially the airborne geophysical surveys, in 2004. The ARGONA project (2006-2009) was created to support the transparency of the decision-making process and to increase communication of risk with stakeholders.

A "RISCOM" risk communication model similar to the Swedish programme has been adopted and will be used in stakeholder interactions. An important challenge is communication of uncertainty, how it is quantified and included in safety assessments. The IPPA project (Implementing Public Participation Approaches) began in 2011 to further enhance communication and decision-making. There is a possibility of direct payments to cooperating localities. A reference stakeholder group is being formed, focusing on technical expertise.

A comment from one of the participants was that stakeholders want to be 100% certain before granting approval, and that is difficult to achieve.

KURT (KAERI Underground Research Tunnel) activities and prospects (Y.K. Koh, KAERI)

KURT, consisting of a 180-m ramp (10% grade) accessing 75 m of crossing drifts, is located in medium to coarse-grained two-mica granite at a maximum depth of 90 m. It includes a borehole drilled to a depth of 500 m below one of the drifts. The first stage was completed in 2006 and an extension through a fracture zone (called MWCF) will be built in the next two years. The purpose of the extension is to demonstrate in situ long-term EBS performance and to characterize the MWCF. KURT has been used to conduct numerous tests and monitoring activities, including a small-scale heater test, EDZ characterization, and migration tests for solutes and colloids. An EBS testing dubbed "DEBS-KURT" is in the planning stages. The KURT programme has focused on streaming potential methods for identifying flowing fractures.

GTS (Grimsel test site) main activities and strategies (I. Blechschmidt, Nagra)

The Grimsel Test Site is a system of tunnels (3.5 m diameter, 1.1 km long) built at the site of a pumped storage project, offering underground access for testing since 1984. Currently it is the only in situ test site in the world that allows use of radionuclides. Many tests have been performed there. Current activities include the long-term cement test, long-term diffusion test, colloid formation and migration test, grout injection experiments, and the gas permeable seal test. FEBEX, one of the projects, is the longest thermal-hydrologic-mechanical (T-H-M) experiment running, with the heater (simulated HLW canister) in the bentonite block filled tunnel running continuously since 1997. One of the advantages of the GTS is the favorable boundary conditions (practically non-existent excavation disturbed zone, rocks with high-compressive strength, etc.).

The GTS offers a platform for cooperation with international partners, training, technical public relations, and interaction with interested stakeholders. Twelve countries and the European Union are partners at the Grimsel site currently.

4.0 FINALE

Lead: A. Orrell, SNL

Following the last presentation, the participants discussed what they learned, their observations, and thoughts about whether the scientific visit achieved its objectives, and the prospects for future interactions. The principal objectives of the scientific visit were

1. Establish personal contacts for future collaboration
2. Identify common issues
3. Evaluate the potential benefit of a "Crystalline Club" emphasizing "early stage" programmes

There was broad agreement that this exchange achieved the objectives. Numerous participants expressed appreciation for establishing new personal contacts and their intent to share information in the coming weeks and months. Some also discovered one or two other countries with issues, plans, geology, or programmes very similar to their own that could be good examples, lessons, or models for their own countries. The common issues discussed as a group included (see Finale working slides in Appendix C):

- Public acceptance issues
- Defining the regulatory or government frameworks, decision-making process
- Site selection
    - Methods and approaches, schedule
- Disposal concepts
    - Open vs. closed, horizontal vs. vertical emplacement, repository/storage, linking storage and disposal through cask size, interim storage concepts, conveyance and handling, shaft vs. ramp
- Data management
    - Data acquisition, data collection, data storage, data flow
    - Raw data, natural analogues, material properties
- Planning R&D programmes
    - Laboratory and field testing
- Lessons learned
- Flow and transport
- Design and performance of engineered components
- Discrete fracture network (DFN) characterization
- Integration of data and modeling
- Knowledge management

- Safety case/safety assessment/FEP screening

Further interactions were discussed, with suggestions for

- Future technical meetings focused on topical areas (including deep borehole disposal)
- Special session at the annual International High-Level Radioactive Waste Management Conference (Albuquerque, NM, USA)
- Collaboration with other groups: GSA, AWRA, Migration, NAWG, etc.
- Include LLW and ILW disposal concepts in crystalline host rock
- More discussion of knowledge management
- More discussion of lab and field work to understand processes, properties, natural analogues, etc.
- Cost strategies: optimization, estimation, funding mechanisms, decommissioning
- Coupling of long-term storage to disposal concepts

The IAEA funded participants agreed that this scientific visit was useful and educational and that the interactions were beneficial. Participants from most of the countries were enthusiastic about participating in future exchanges. The following "volunteers" were enlisted for follow-on actions to push forward an agenda for a future scientific visit:

- Romania A. Sorescu
- Spain J. Molinero
- Czech Republic J. Slovak
- USA G. Freeze
- UK R. Whittleston
- IAEA P. Degnan (not present but a key source of input and possibly funding)

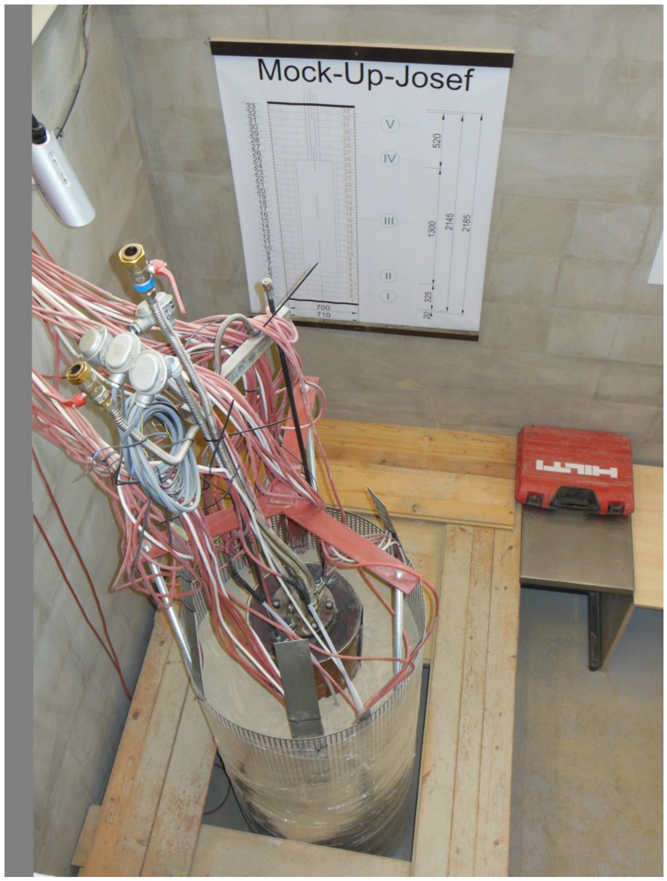
The idea of this group founding a "Crystalline Club" at some point in the future was unanimously considered a logical and beneficial future step. The proposed goals of the "club" are to enhance cooperation, collaboration, and sharing of information among its members. Also, it would promote flow of information and other resources from the more advanced programmes to emergent ones.

IAEA participants were requested in their reports to evaluate and recommend future interactions but not to call this group a "club" because "club" implies formalities that this group has not undertaken at this point.

5.0 SESSION PHOTOS

6.0 JOSEF GALLERY TOUR

The fourth day of the scientific visit consisted of a tour of the Josef Regional Underground Research Centre, run by the Centre for Experimental Geotechnics (CEG) of the Czech Technical University in Prague.



Small-scale supercontainer mock-up.

Emplacement boreholes for small-scale supercontainer test.

Underground discussions.

Final words.

7.0 REFERENCES

References cited in the proceedings can be found in the presentations in Appendix C.

APPENDIX A: PROGRAMME FOR THE SCIENTIFIC VISIT ON CRYSTALLINE ROCK REPOSITORY DEVELOPMENT

PROGRAMME FOR THE SCIENTIFIC VISIT ON CRYSTALLINE ROCK REPOSITORY DEVELOPMENT

Prague, Czech Republic
24-27 September 2012

DAY 1 – MONDAY 24 SEPTEMBER 2012

7:30 – 8:30 REGISTRATION

8:30 – 10:00 INTRODUCTION AND WELCOME

Introduction and welcome by Acting Managing Director of RAWRA (J. Prachař)

PRESENTATION OF STATUS REPORTS (CHAIR: RAWRA - J. SLOVÁK/J. MIKŠOVÁ)

Status Report - recent history, accomplishments, site characterization working plans, new directions, lessons learned, policies, funding, regulatory requirements etc.

1. Status Report – Czech Republic (J. Slovák, RAWRA)
2. Status Report – USA (P. Swift, SNL)
3. Status Report – Germany (W. Steininger, KIT)

10:00 – 10:30 BREAK

10:30 – 12:00 PRESENTATION OF STATUS REPORTS (CONT.) (CHAIR RAWRA - J. SLOVÁK/J. MIKŠOVÁ)

4. Status Report – Switzerland (S. Vomvoris, Nagra)
5. Status Report – Great Britain (R. Whittleston, NDA)
6. Status Report – Korea (I.Y. Kim, KAERI)

12:00 – 13:15 LUNCH

13:15 – 15:15 PRESENTATION OF STATUS REPORTS (CONT.) (CHAIR: SNL - P. SWIFT)

7. Status Report – Slovakia (M. Kováčik, EN-GEO Consult)
8. Status reports – IAEA group
    a. Poland – M. Banach
    b. Lithuania – A. Sirvydas
    c. Romania – D. Dogaru /A. Sorescu
    d. Mexico – R. Vázquez Ponciano
    e. Pakistan – Z.H. Shah

15:00 – 15:20 BREAK

15:20 – 17:00 STATUS REPORT SUMMARY (CHAIR: RAWRA- J. SLOVÁK / SNL - A. ORRELL)

Discussion – all participants
Summary of participating countries' approaches, joint statement, potential action, evaluation provided by organizing committee

DAY 2 – TUESDAY 25 SEPTEMBER 2012

8:00 – 10:00 REPOSITORY PROGRAMME DEVELOPMENT METHODOLOGY (CHAIR: SNL - P. MARINER)

1. Repository Programme Development - from concept to licensing (A. Orrell, SNL)
   - Stages in the development process
   - Infrastructure, legal and regulatory framework, funding, organizational responsibilities
2. Technical Bases for Repository Construction in Crystalline Rock (P. Mariner, SNL)
   - Identification of important site attributes to be evaluated during the site screening and site characterization stages
3. Disposal Concepts in Crystalline Rock (E. Hardin, SNL)

10:00 – 10:20 BREAK

10:20 – 12:00 PROGRESS IN SITE SCREENING AND SELECTION (CHAIR: SNL - E. HARDIN)

1. Status Report – Spain (J. Molinero, Amphos21)
2. Swiss process - Experience from the Swiss Radioactive Waste Management Programme (S. Vomvoris, NAGRA)
3. Group Discussion
   - Open discussion of site screening and selection based on lessons learned, perspectives, and needs from all participants

12:00 – 13:15 LUNCH

13:15 – 15:00 SITE CHARACTERIZATION METHODS (CHAIR: RAWRA - J. SLOVÁK)

1. Technical Advances in Site Characterization
   a. Focus on geological aspects -geology, hydrology, geochemistry, geophysics, environmental isotopes etc. (F. Woller, RAWRA's consultant)
   b. Focus on conflicts of interest (legacy, urban plans, protective areas, natural hazards etc.) (J. Mikšová, RAWRA)

c. Focus on construction aspects -repository design, geotechnical properties of rock (M.Dvořáková, RAWRA)

d. Focus on the decision-making process including potential schedule/when to start, defining of geological criteria (exclusion criteria, conditional criteria) (J. Slovák, RAWRA)

2. Group Discussion
   - Open discussion of site characterization methods based on lessons learned, perspectives, and needs from all participants

15:00 – 15:20 BREAK

15:20 – 17:30 POST-CLOSURE SAFETY ASSESSMENT (CHAIR: SNL - G. FREEZE)

1. Application of the Safety Assessment Methodology (G. Freeze, SNL)
   - Features, events and processes (FEPs) and scenarios for crystalline host media
   - Safety assessment modelling
2. Insights from Safety Assessments for Mined Repositories in Crystalline Rock (P. Swift, SNL)
   - Integration with research and development programmes
3. Group Discussion
   - Open discussion of safety assessment needs from all participants

19:00 – 22:00 DINNER IN THE HISTORICAL CENTRE OF PRAGUE (HOSTED BY RAWRA)

DAY 3 – WEDNESDAY 26 SEPTEMBER 2012

8:00 – 10:30 SITE SCREENING AND SITE CHARACTERIZATION – TOPICS OF INTEREST I (RAWRA - J. MIKŠOVÁ(CGS - T. PAČES)

1. Modelling Hydrogeology and Hydrochemistry in Support of Safety Assessment for Radwaste Repositories in Fractured Rocks - Case Studies and Lessons Learnt From Sweden and Finland (J. Molinero, Amphos21)
2. Simulating Flow and Transport in Fractured Media (A. Pueschel, GRS)
3. Topics related to site screening and characterization focused on field work

   a. Geological mapping and structural research: implication for High Level Waste Disposal

   (J. Pertoldová/K. Verner,CGS)

   b. Application of geophysical airborne and surface methods for HLW disposal (M. Karous, Geonika)

   c. Application of well logging for study of granitoid massif for storage of radioactive waste-

   (J. Lukeš/M. Procházka/M Pitrák, Aquatest)

d. Uncertainties in hydrodynamics and hydrochemistry in granites considered as a host rock for spent nuclear fuel in the Czech Republic (T. Pačes/L. Rukavičková, CGS)
e. Data management (J. Mikšová, RAWRA)
f. Linking communication theories into the Czech reality (L. Steinerová, RAWRA)

10:30 – 10:50 BREAK

10:50 – 12:15 SITE SCREENING AND SITE CHARACTERIZATION – TOPICS OF INTEREST II (RAWRA - J. MIKŠOVÁ/CGS - T. PAČES)

4. KURT (KAERI Underground Research Tunnel) Activities and Prospects (Y.K. Koh, KAERI)
5. Grimsel Test Site - Nagra's competence center for studies in fractured rock Formations (I. Blechschmidt, Nagra)
6. Group Discussion
   - Open discussion of site screening and characterization topics based on lessons learned, perspectives, and needs from all participants
   - Identification of opportunities for collaboration

12:15 – 13:30 LUNCH

13:30 – 15:30 FINALE (SNL – A. ORRELL /RAWRA - J. SLOVÁK)

1. Feedback and Lessons Learned
   - Peer review/group discussion regarding approaches to crystalline rock repository programme development in participating countries
2. Summary
   - Cooperation, joint statements, action
3. Close of Prague part of SV.

15:30 – 16:30 BREAK

16:30 TRANSFER TO THE JOSEF REGIONAL UNDERGROUND RESEARCH CENTRE

- Transfer by bus from Prague to a village located near to the Josef Facility, accommodation.

19:00 – 22:30 DINNER

- Informal dinner at a local pub.

- Discussion on a potential "Crystalline Host Rock Club" (CHRC) – mapping of interest of the establishment of a working group or platform made up of countries in which crystalline rock is being considered as the host rock for eventual radioactive waste disposal.

DAY 4 – THURSDAY 27 SEPTEMBER 2012

8:00 – 14:00 JOSEF REGIONAL UNDERGROUND RESEARCH CENTRE

- 8:00 Departure from the hotel
- 8:30 Welcome – Josef URC
- 9:00 Josef URC Presentation – Main Activities and Strategies (J. Pacovský, CEG)
- 9:30 - 12:00 Josef URC visit
- 12:00 - 14:00 Refreshment
- 14:00 Departure from Josef URC

15:00 TO 16:00 ARRIVAL BACK IN PRAGUE

CLOSE OF SCIENTIFIC VISIT

APPENDIX B: PARTICIPANTS

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APPENDIX C: PRESENTATION SLIDES

Introduction and Welcome
by Jan Prachař
Acting Managing Director of RAWRA

Ladies and gentlemen,

I would like to warmly welcome you to the scientific exchange meeting here in Prague. The meeting was designed to promote technical information exchange between participants from those countries engaged in the investigation and exploration of crystalline rock massifs for the eventual construction of nuclear waste repositories.

I am very happy that this meeting has attracted so many respected experts from a total of 13 countries.

This event provides an ideal opportunity for specialists to meet and exchange their knowledge on the future development of radioactive waste disposal.
It also provides an opportunity for the establishment of potentially fruitful relationships between the various agencies involved which, it might be hoped in the future, will lead to mutually beneficial cooperation not only in terms of the conducting of research projects, but also with regard to the exchange of staff and the establishment of personal relationships between the experts involved which can only be for the good of all concerned.
In particular, we can learn from the mistakes that have been made in the past in terms of DGR siting and perhaps decide that this meeting will not merely be a “one-off”, but that it becomes a regular exchange of ideas.
This event represents a unique meeting of countries which are working on the development of DGRs in granitic environments however, most importantly, it is not just about presentations, but also about gathering information and the exchange of views on the value of the workshop itself.
I dare to hope that one of the outcomes of the exchange visit will consist of the establishment of a “CLUB”, the missions of which will be to identify and subsequently address the various technical challenges that confront the disposal of radioactive waste in crystalline rock environments and to constantly map progress on this issue among countries that are focused on granite rock disposal.
I would like to thank Sandia National Laboratories, and Mr. Andrew Orrell in particular, for their contribution to this event and, of course, the IAEA for their financial support.

Finally I would like to wish everyone here a fruitful and enjoyable exchange meeting and a pleasant few days' stay here in Prague.

Thank you

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Radioactive Waste Management in the Czech Republic

Radioactive Waste Repository Authority

Jan Prachař

Managing Director

2012

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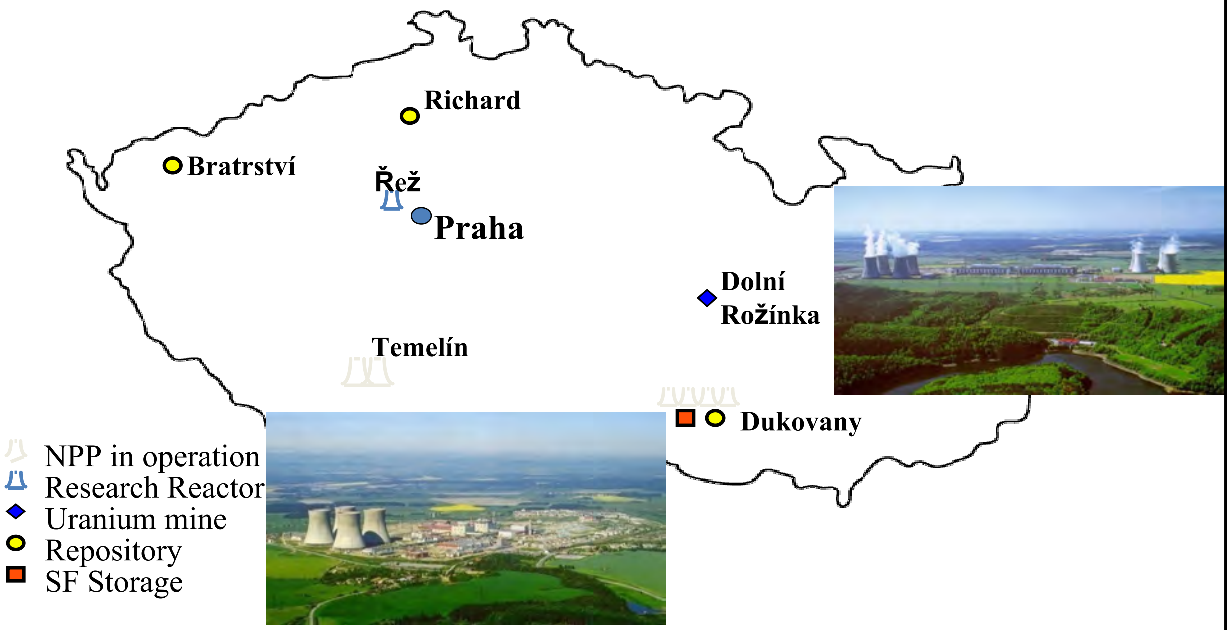
Nuclear sites in the Czech Republic



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Radioactive Waste Management Principles

The state guarantees safe disposal of all radioactive waste

•Framed by the Atomic Act No. 18/1997

Policy for Radioactive Waste Management and Spent Fuel Management (approved by the Czech government on 15 May 2002, resolution No. 487)

- Waste producers are responsible for safe management
- RAWRA is responsible for disposal
- Nuclear account established to collect financial means for disposal
- NPP operator is responsible for NPP decommissioning and processing of RW before its final disposal
- NPP operators shall create financial provisions to cover the cost of future NPP decommissioning
- Import of RW is forbidden

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Low and Intermediate Level Waste

- Amount - 41400 m^3 up to 2100
- Collection, sorting, treatment, conditioning, transport, storage - RW generators´ responsibilities
- RW disposal – RAWRA´s responsibility
- 3 Repositories in operation : Dukovany, Richard, Bratrství
- Closed repository Hostim - monitoring
- Supervision State Ofice for Nuclear Safety - regulator

Repository Dukovany

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Disposal of LLW/ILW
Capacity 55 000 m^3
Operation since 1995
Until 2100

Repository Richard

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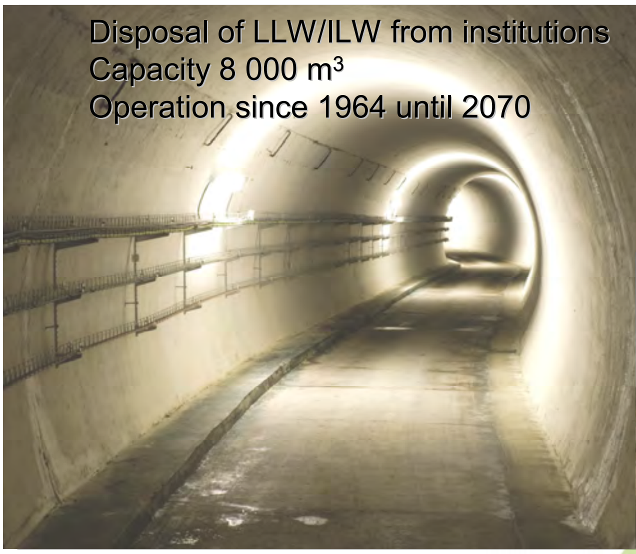
Disposal of LLW/ILW from institutions
Capacity 8 000 m^3
Operation since 1964 until 2070



Repository Bratrství

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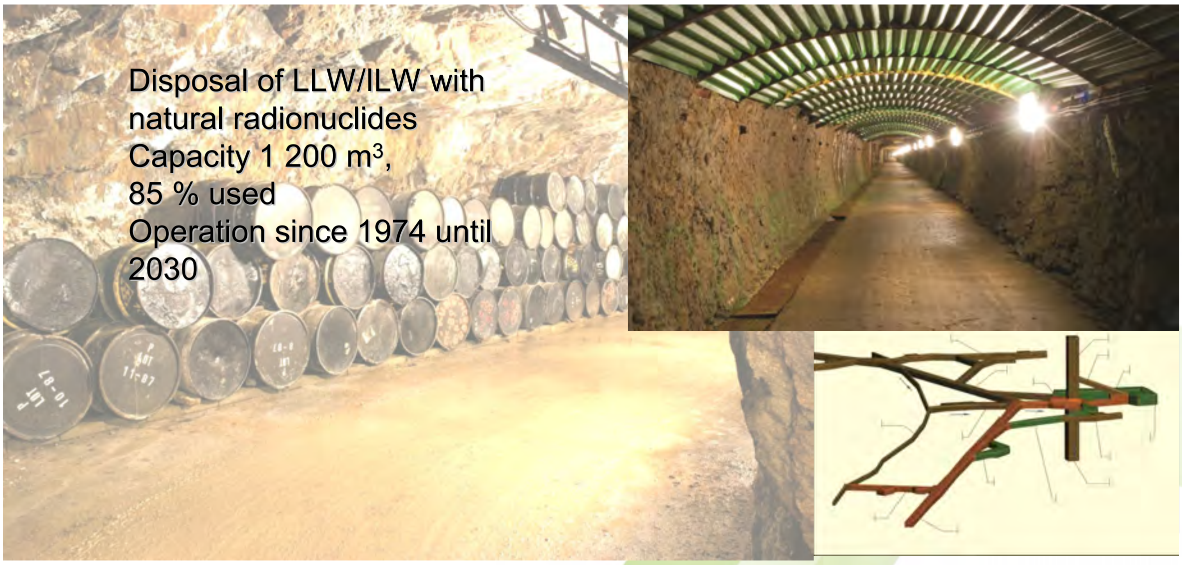

High Level Waste Management

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Supposed waste amount for the geological repository

6 reactors in operation and 3 intended

- HLW - NPPs Dukovany and Temelin 3000 m^3
- HLW - new units 2000 m^3

- SNF - EDU 1 (4 reactors) 1940 t (40 years operation)
- SNF - ETE 1 (2 reactors) 1790 t (40 years operation)
- SNF - new 3 reactors (TE 2+DU 1) up to 5000 t (60 years operation)

Required space for 5 862 disposal containers

2 047 disposal containers (440 type)
1 124 disposal containers (1 000 type)
2 691 disposal containers (new type)

NSF storage

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2 storage facilities

•NPP Dukovany
•NPP Temelín

•SNF is a property of NPP´s operator ČEZ

•Castor casks

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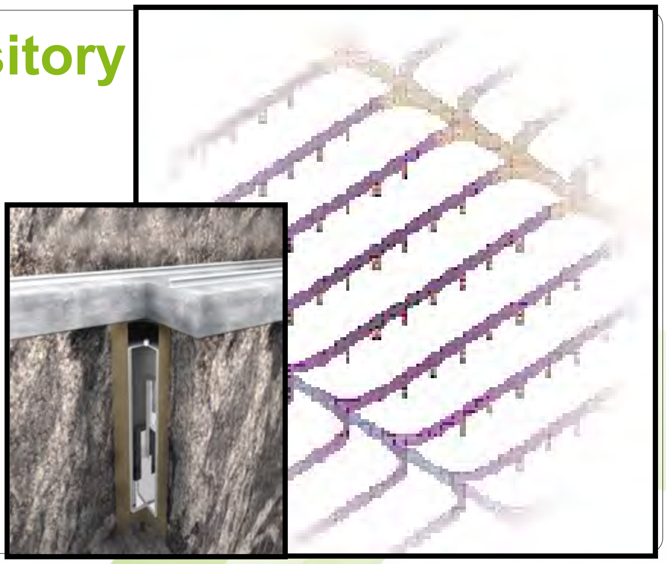
HLW / SNF Disposal Concept Reference Design 1999

Geological Repository

Scandinavian disposal concept
adopted for Czech condition

Capacity:
4000 t of SF
3000 m^3 of HLW

Operation in 2065



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Timing

Reference option - direct disposal of SNF in GR

2015/ 2018 – Two suitable sites – main and alternative
2025 – Safety approvement of the main site
2030 – Construction of Underground Research Laboratory
2065 – Commissioning of the GR

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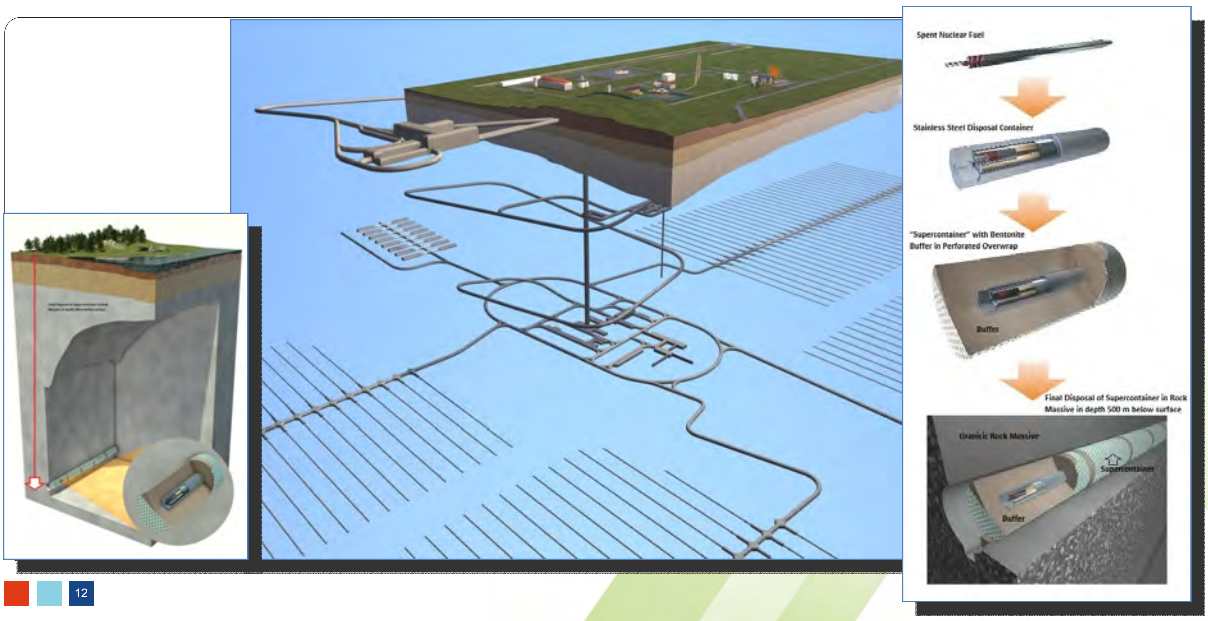
Reference design 2011



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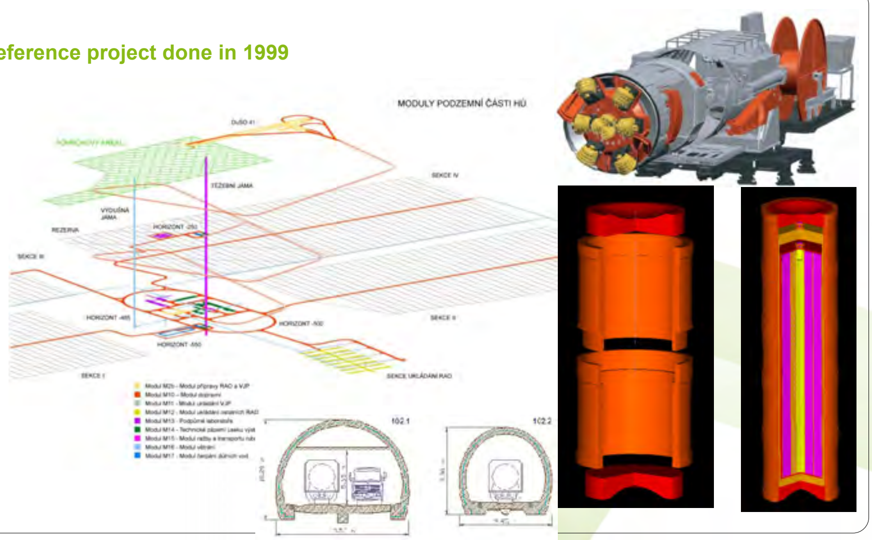
Optimalisation of the Refence projet 2012

Finishing this year, last Reference project done in 1999

Actualisation of :

- Technologies
- Amount of waste
- Transport system
- Safety
- Inviromental impact
- Costs
- Design



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Legislation

2012 The State Energetic Concept Actualisation

Encouraging nuclear energy

NPP Temelin 2 new units
NPP Dukovany 1 new unit

→ Actualisation of the RWM Concept

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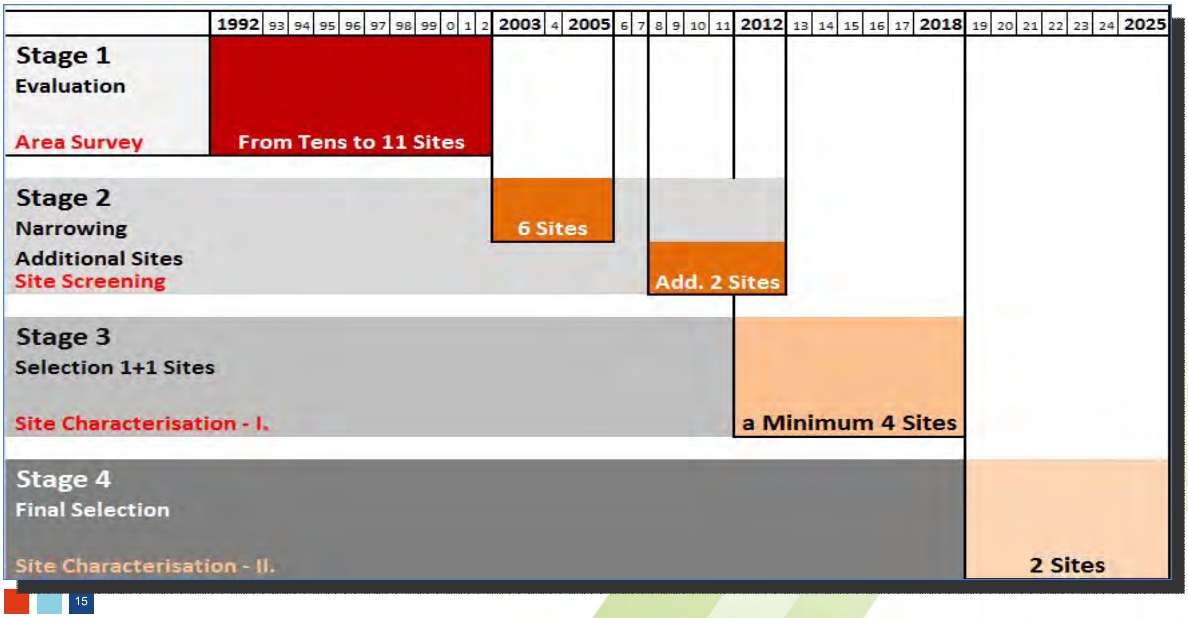
Site selection phases



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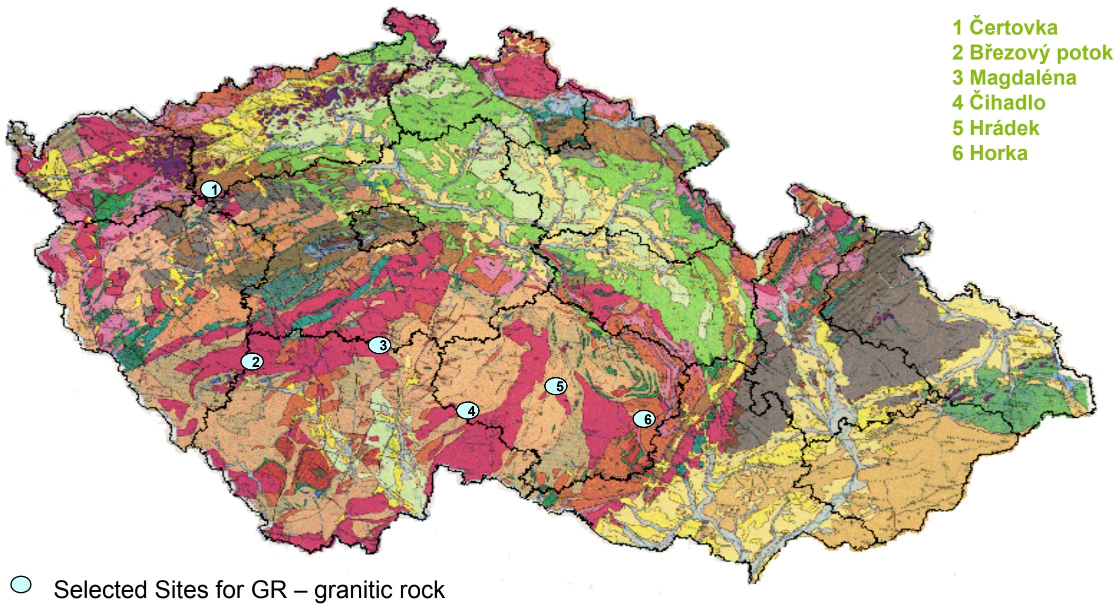
Preliminary site selection



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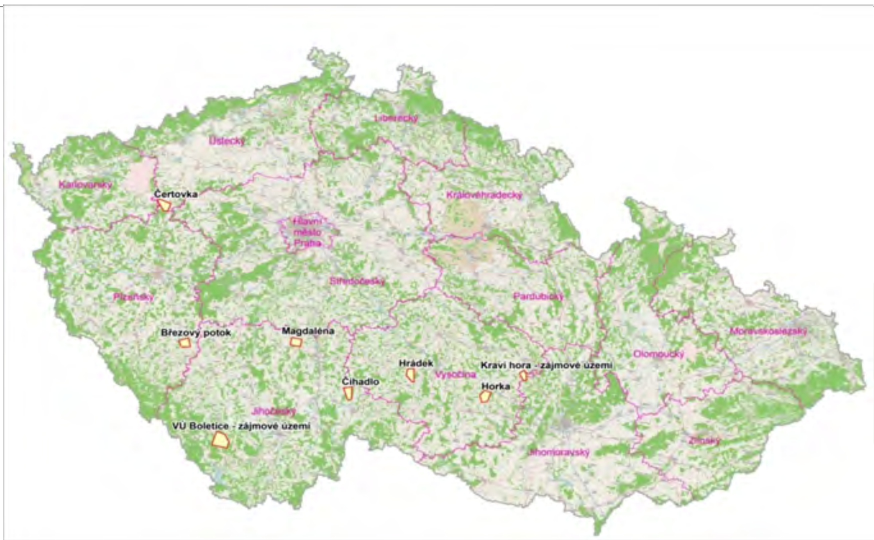
2 additional sites in consideration



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Supposed Site selection proccess 2012 – 2018

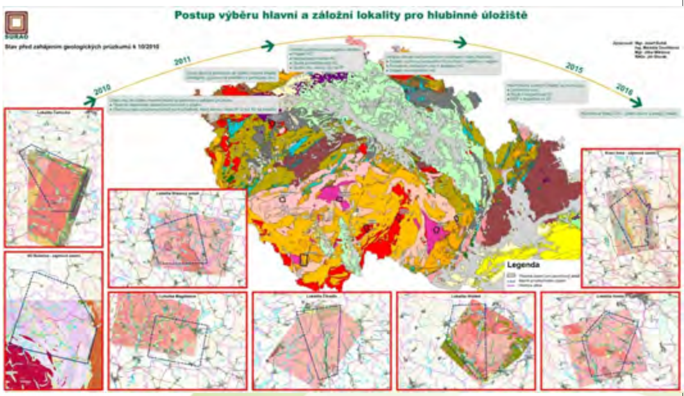
Geological survey on site at the 4 sites

Parallel geophysical and geochemical landscape survey
Drilling of boreholes (5 – 500 m, 2 (3) 1000 m)
Rock characterization – in situ measurements laboratory research

Environmental site specific studies

At the each sites with suitable geology:

Design of the GR
Feasibility Study
Preliminary Safety Case
Environmental impacts study



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Public involvement

By the ARGONA project - first public hearing in May 2009

- November 2009 – National conference – „**Deliberation - Way to the Deep Geological Repository**“
  - under the auspices of the minister of industry and trade
  - First „round table“ discussion across all stakeholders
- June 2010 – **„round table“** discussion how to establish transparency and open dialogue with all stakeholders
  - First discussion about establishing „Working group for Dialogue“ independent discussion forum for set up transparency site selection with involving public
- **November 25th, 2010 – first meeting of**
  Working Group for Dialogue

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Public involvement principles

Voluntarism as a primary principle

Call to local municipalities to participate on the site selection process

Geological survey start **only on the site where municipalities want to participate**

Benefits for local municipalities

Direct annul payment to municipality only on the site where RAWRA will have licence for geological survey

9/2011 – update Atomic act.
Annually maximum 4 M CZK (160 T €) per municipality
Fixed 600 T CZK + 0,30 CZK per m^2 of exploratory area

20

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Thank you for your attantion

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21

Exceptional service in the national interest

Sandia National Laboratories

Current Status of the United States Radioactive Waste Disposal Program

Peter Swift
National Technical Director
U.S. Department of Energy Used Nuclear Fuel Disposition Campaign

Presented to the Scientific Visit on Crystalline Rock Repository Development, Prague, Czech Republic

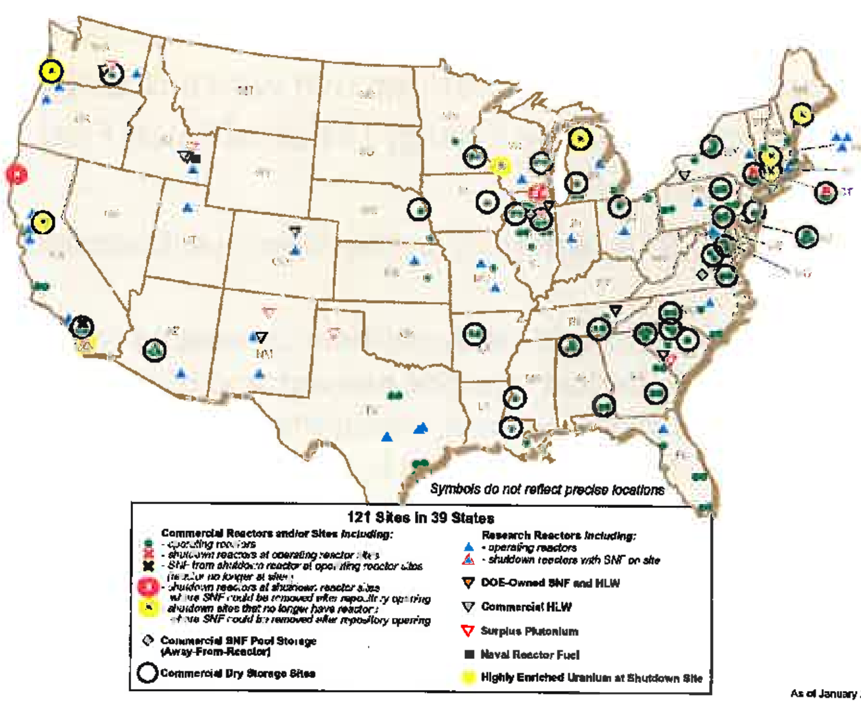
24 September 2012

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2012-7486P

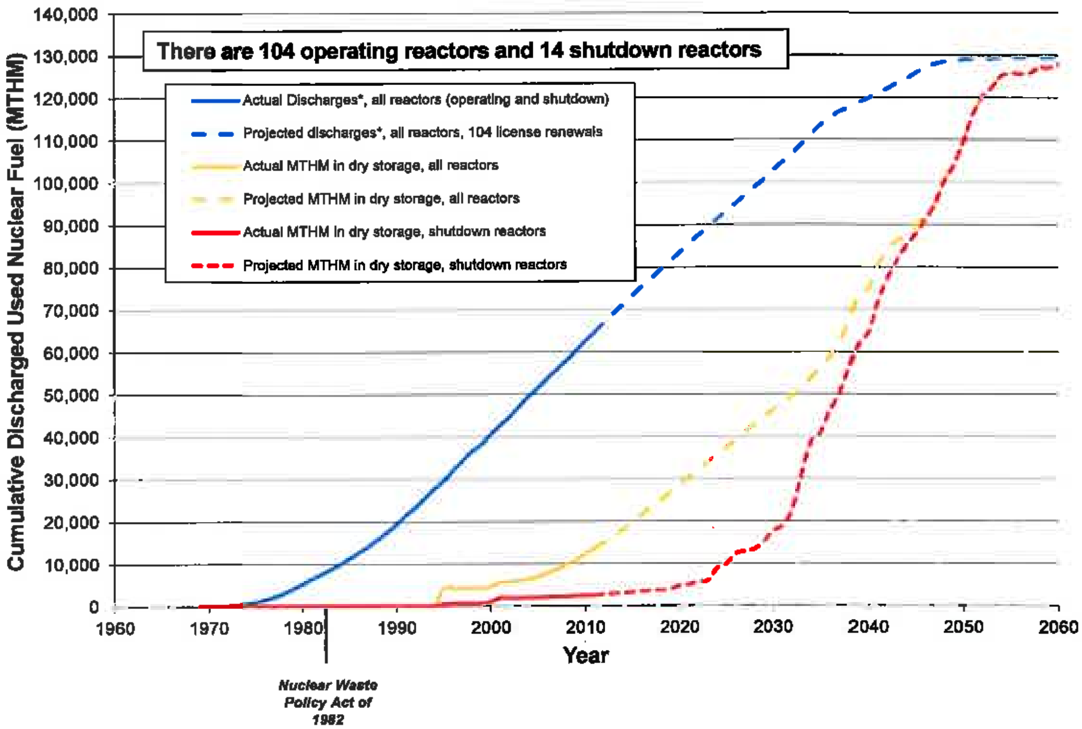
Spent Nuclear Fuel and High-Level Radioactive Waste in the United States

Sandia National Laboratories



As of January 2008

Historical and Projected Commercial Spent Nuclear Fuel Discharges in the United States



Source: Based on actual discharge data as reported through 12/31/02, and projected discharges, in this case for 104 license renewals

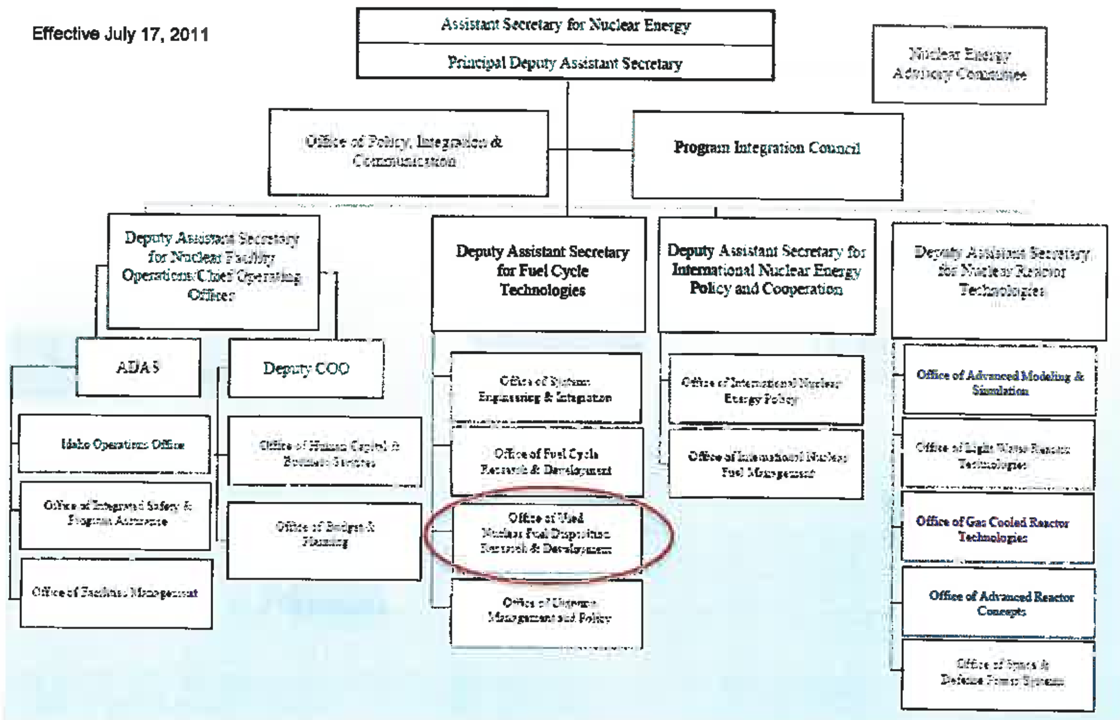
3

The US Repository Program

- The national mission for management and disposal of used nuclear fuel and high-level radioactive waste is assigned to the DOE Office of Nuclear Energy Office of Used Fuel Disposition (NE-53)
  - R&D within NE-53 is performed by the "Used Fuel Disposition Campaign"
  - The mission of the Used Fuel Disposition Campaign is to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

4

DOE NE Organizational Chart



UFD Campaign 2009-Present

- FY09 Planning meeting at Argonne National Laboratory, June 2009
- FY10 R&D
  - Disposal R&D, modest level of effort on Storage R&D, no Transportation R&D
- FY11 R&D
  - Nine national laboratories participating in UFD
  - Significant R&D program in Storage, including Transportation
  - Disposal R&D not site specific
- FY12 R&D
  - Increase in work scope following Congressional appropriations in December 2012, some elements of FY12 work scope not established until fourth quarter
  - Programmatic uncertainties remain regarding national policy and litigation
- FY13 R&D work scope planning in progress

UFD Campaign R&D Participants… 9 US National Laboratories

SRNL

Pacific Northwest National Laboratory

Los Alamos National Laboratory

Sandia National Laboratories

Argonne National Laboratory

Lawrence Livermore National Laboratory

ornl Oak Ridge National Laboratory

INL Idaho National Laboratory

Berkeley Lab

7

Organization of R&D in the Used Fuel Disposition Campaign

UFD Campaign
Peter Swift
National Technical Director (NTD)
Mark Nutt
Deputy NTD

Management Groups	**Campaign Crosscut** **Mark Nutt Deputy NTD** **Group Manager**	**Disposal Research** **Kevin McMahon** **Group Manager**	**Storage & Transportation** **Ken Sorenson** **Group Manager**
R&D Work Activities	Perspectives on NW Mgt.	Engineered Barrier Natural Systems Thermal Load Mgt. & Design Disposal System Modeling Salt Disposal Investigations Advanced Modeling	Test & Evaluation Capability Engineered Materials Exp. Transportation Security R&D Investigations Engineering Analysis
Support Activities	Management & Integration International	Features, Events & Processes Low Level Waste Disposition Inventory Projections Regional Geology & Tectonic Hazards	

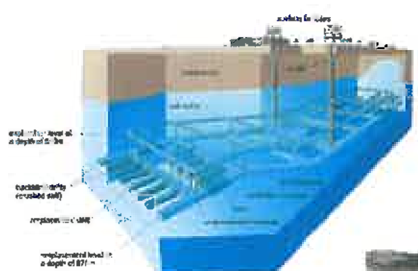
8

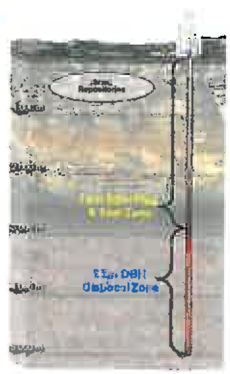
Generic Disposal R&D

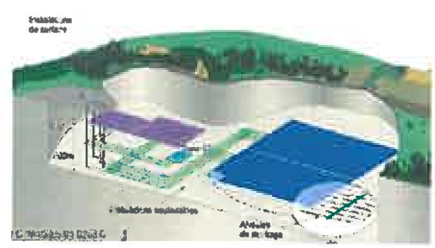
- The Nuclear Waste Policy Act and Congressional Appropriations preclude site-specific repository investigations
- All disposal research must be generic at this stage
- What can generic R&D accomplish?
  - Provide a sound technical basis for the assertion that the US has multiple viable disposal options that will be available when national policy is ready
  - Identify and research the generic sources of uncertainty that will challenge the viability of disposal concepts
  - Increase confidence in the robustness of generic disposal concepts to reduce the impact of unavoidable site-specific complexity
  - Develop the science and engineering tools required to address the goals above, through collaborations within NE and DOE, and with universities, industry, and international programs

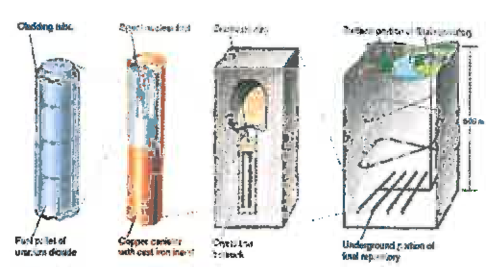
U.S. Disposal R&D Focuses on Four Options

- Three mined repository options (granitic rocks, clay/shale, and salt)
- One geologic disposal alternative: deep boreholes in crystalline rocks









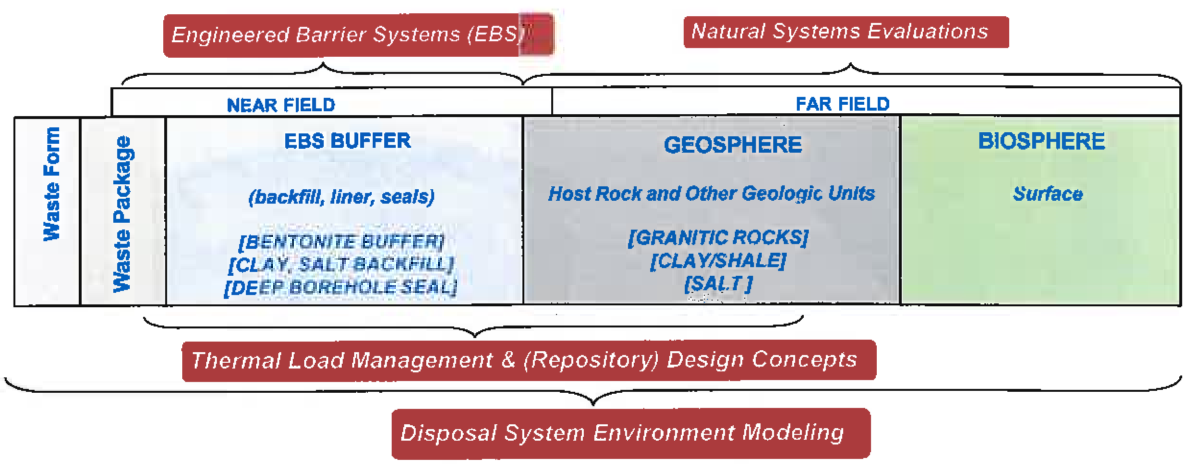
How Did the UFD Identify Disposal R&D Needs?

- *Used Fuel Disposition Campaign Disposal Research and Development Roadmap*
  - "an initial evaluation of prioritization of R&D opportunities that could be pursued by the campaign"
  - Completed March 2011
  - Used to inform prioritization decisions for disposal research in 2012 and beyond
- Update in progress

http://www.ne.doe.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

11

UFD Disposal Research Activities



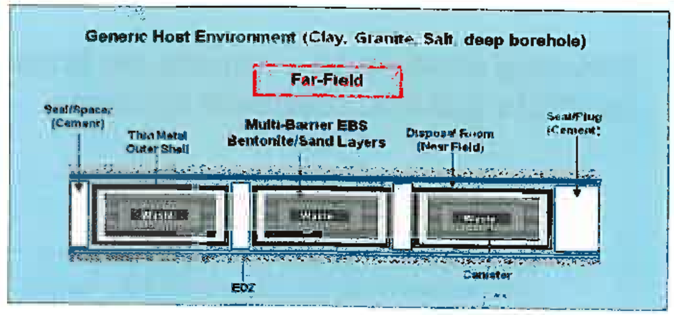
SUPPORT, ANALYSIS & EXPERIMENTAL ACTIVITIES

Engineered Materials Performance	*(corrosion, degradation studies)*
Features, Events & Processes	*(how R&D is organized and prioritized)*
Low Level Waste Disposition Issues	*(part of total nuclear waste consideration)*
Inventory Projections	*(LLW/HLW, used fuel, open → closed fuel cycles)*

12

Generic Engineered Barrier Systems R&D

EBS and materials evaluation for multiple disposal environments (clay/shale, granitic rocks, salt, deep borehole)



Representative activities

- Evaluation of EBS configurations and material properties: backfill and sealing material (clay and cement)
- Evaluation of clay / metal interactions at elevated temperatures and pressures: literature review, clay phase characterization, and experiments
- Expand THM constitutive and reactive diffusive transport modeling in bentonite
- Laboratory-scale crushed-salt consolidation experiments and modeling

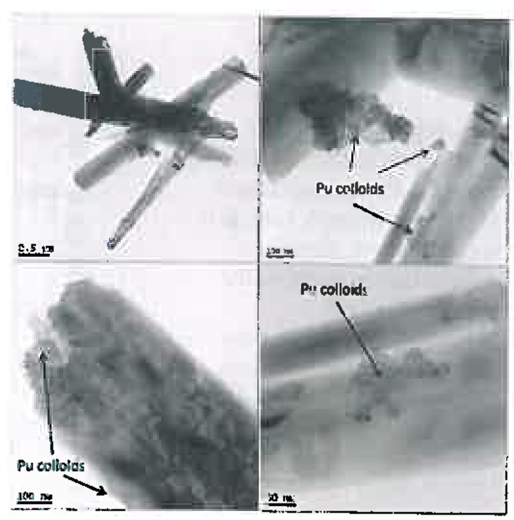
13

Generic Natural Systems Evaluation R&D

Evaluation of key natural system attributes of multiple disposal system concepts to evaluate impacts on waste immobilization and isolation

Representative activities

- Regional geologic characterization
- Discrete fracture network simulation
- Effects of spatial heterogeneity in Kd on radionuclide transport
- Experimental work on Pu colloid behavior in the presence of goethite
- Geomechanical modeling of excavation damage zone in clay/shale and salt
- Experimental work on saturated and unsaturated flow through clay
- Experimental work related to direct disposal of e-chem salt in a salt repository



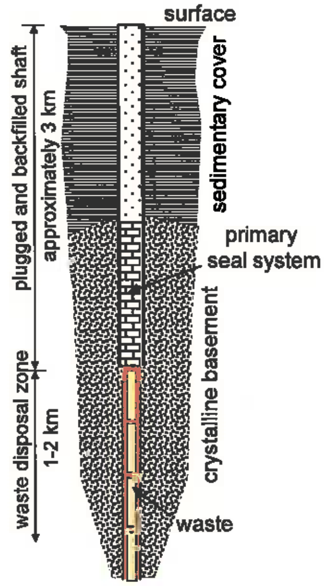
•TEM of Intrinsic Pu(IV) nano-colloids sorbed to goethite at 25° C for 103 days

14

Generic Disposal System-Level Modeling R&D

Develop models to evaluate performance of multiple generic disposal systems

Representative activities
- Implement configuration management for the generic performance assessment (PA) models
- Document technical basis for treatment of Features, Events, and Processes for each generic PA model
- Develop preliminary generic PA models for repositories in clay/shale, granitic rock, salt, and deep borehole settings
  - Highly simplified geometries
  - Isothermal behavior except for deep borehole



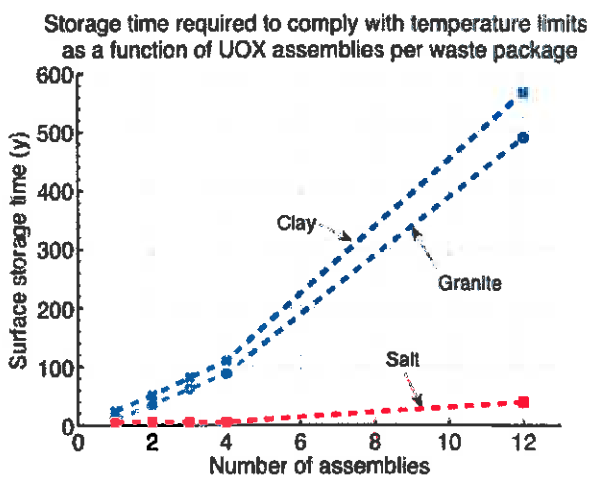
Source: modified from Brady et al., 2009, Deep Borehole Disposal of High-Level Radioactive Waste, SAND2009-4401

15

Thermal Load Management & Design Concepts R&D

Thermal modeling and testing to evaluate thermal loading options for multiple disposal concepts and alternative waste forms

Representative activities
- Develop representative design concepts for repositories in clay/shale, granite, salt, and deep borehole settings.
- Identify waste streams for thermal analysis
- Complete thermal loading analyses in representative design concepts for selected waste streams



Minimum decay storage durations to limit peak PWR waste package surface temperature to 100° C (granite, clay) or 200° C (salt). (Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143)

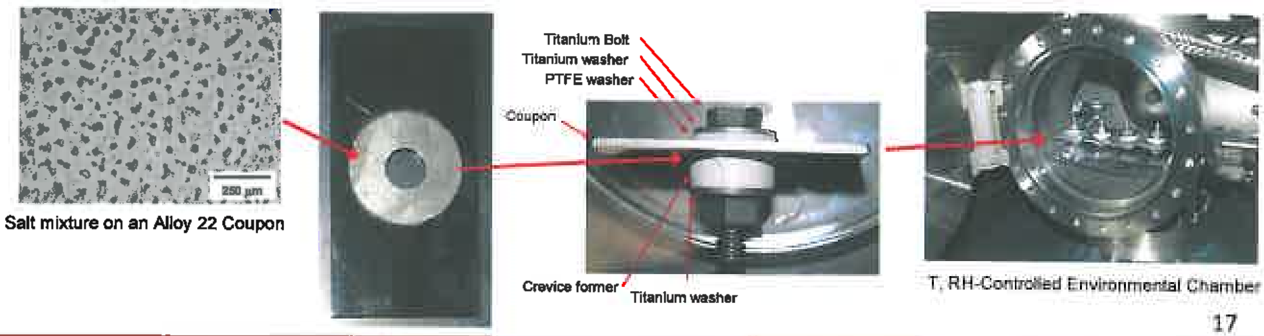
16

Engineered Materials Performance R&D

Experiments and model development for long-term performance of engineered materials in storage and repository environments

<u>Representative activities (limited to repository environments in 2011, expanded to include storage in 2012)</u>

- Ongoing experiments (some initiated as part of Yucca Mountain project):
    - Immersion: Sampled after 9 months of exposure. Analysis of samples underway
    - Deliquescence: Corrosion initiation experiments with 2-,3-, and 4-salt assemblages completed
    - Dependence of extent of corrosion on quantity of salt present is now being investigated
- Literature survey/gap analysis for material performance in repository environments has been initiated



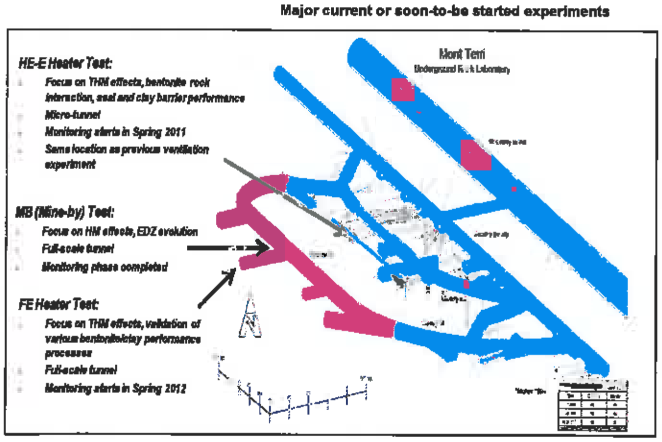
17

UFD Campaign International Activities

Primary new goal for Disposal R&D in FY12: Establish formal collaborative R&D arrangements ongoing international programs

Ongoing collaborations continue in multiple areas, including storage, transportation, and disposal

Major current or soon-to-be started experiments



Mont Terri: International underground research laboratory (URL) in clay in Switzerland

Joining the URL will give DOE access to data from all Mont Terri R&D, also the opportunity to conduct new experiments

Colloid Formation and Migration Project

Colloid research at Grimsel granite URL in Switzerland

DECOVALEX: (Development of Coupled Models and their Validation against Experiments)

DOE has participated in the past, new phase of project began Spring 2012

KAERI Underground Research Tunnel (KURT)

R&D plan for experiments beginning in 2013

18

Sandia National Laboratories

Questions?

19

Recommendations from the Blue Ribbon Commission on America's Nuclear Future

Sandia National Laboratories

- BRC's Report to the Secretary of Energy published January 2012
  - A new, consent-based approach to siting future nuclear waste management facilities.
  - A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.
  - Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.
  - Prompt efforts to develop one or more geologic disposal facilities.
  - Prompt efforts to develop one or more consolidated storage facilities.
  - Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available.
  - Support for continued U.S. innovation in nuclear energy technology and for workforce development.
  - Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.
- The DOE is working to address these recommendations

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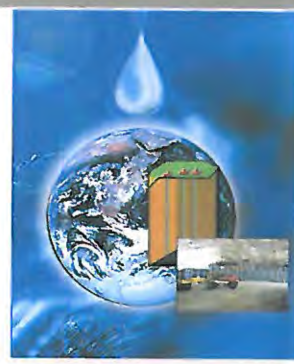
Karlsruhe Institute of Technology

SCIENTIFIC VISIT ON CRYSTALLINE ROCK REPOSITORY DEVELOPMENT
PRAGUE, SEPTEMBER 24 -27, 2012

PROJEKT MANAGEMENT AGENCY KARLSRUHE
WATER TECHNOLOGY AND WASTE MANAGEMENT (PTKA-WTE)

PTKA
Project Management Agency Karlsruhe
within Karlsruhe Institute of Technology



Federal Ministry
of Economics
and Technology

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Karlsruhe Institute of Technology

Current situation

R&D issues

International cooperation

Lessons learned?

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Kernenergie in Deutschland

Source: Deutsches Atomforum

- 8 nuclear power plants, 9 reactors (8 off-line in 2011 after Fukushima)
- nominal output 2010/11: 21 GW /13 GW
- gross power generation in 2010/2011 140/108 TWh/yr
- about 23 % / 17 % of total electricity production
- 3 research reactors operational
- 4 decentralized interim storage facilities
- 12 storage facilities at NPP sites
- 2 nuclear facilities in operation (fuel element production, U-enrichment)

CURRENT SITUATION

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

3 Phases

In 2000:
- Decision to phase-out nuclear till 2032 by the Federal Government
- Agreement between the Federal Government and the utilities
- every reactor has its own rest lifetime and final power production
- Replacement by renewables or natural gs
- Stop of exploration, moratorium on Gorleben (3 to 10 yrs)
- no further decision by the following Government

In 2010:
New Federal Government (CDU-FDP)
Energy Concept 2050 (stepwise reduction of CO to 80%, 1990, 80% renewables for electricity prod., reduction of primary engergy by 50% (2008), financial subsidies
Agreement on prolongation of NPP – lifetimes, NPP are safe
however, phase-out in principle, nuclear energy is a bridge technology
Further exploration of the Gorleben site

In 2011: FUKUSHIMA
- political decision (moratorium), shut down 8 NPPs, so called stress test (no safety relevant results)
- Decision to phase-out nuclear step by step till 2022
- Energy supply by renewables (mainly wind and solar), transition time natural gas and fossile PP
- New laws to govern these challenges

- HOWEVER:
  - Baseload supply, grid extension, legal consequences, technological consequences, power lines, economic consequences, increasing prices, supply security, european consequences (european power grid), etc. etc.
- Gorleben exploration ongoing, but a new law under discussion (Repository siting law)

CURRENT SITUATION

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Main elements/obligations for Member States:

Member states must draw up national programs (by 2015 at the latest), covering:

- national policy on rad waste management from generation to disposal
- milestones and clear time frames for implementation
- inventory of all spent fuel and rad waste
- assessment of costs and financing schemes
- transparency policy
- Clear statement of "polluter pays principle"
- Periodical peer reviews of the national framework, competent regulatory authority and/or national programmes (exchange experience, identify best practices)
- Transparency: Information on nuclear waste policy to be made available to the public; opportunity to participate effectively in decision-making

Disposal Facilities

- Directive mentions near-surface disposal as typical concept for low and intermediate level waste
- For high-active waste, deep geological disposal as safest and most suitable option
- General rule: Rad waste to be disposed of in the Member State where it was generated, however:

  Two or more EU Member States can agree to use a disposal facility in one of them ("regional approach").

  Exports to countries outside EU are only admissible under certain conditions
  Shipment of spent fuel of research reactors to other countries (repatriation of spent fuel) is still possible (taking into account international agreements)

Germany: New Laws (AtG), Endlagersuchgesetz (Repository siting law) – new siting procedure

CURRENT SITUATION

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Morsleben: Repository in closure phase

1970	Bartensleben mine selected as repository
1971	Start of trial disposal (LLW)
1974	Approval of repository construction
1981/1986	1st and 2nd permanent operation licenses
10/1990	Morsleben repository a Federal Facility under BfS, operated by DBE
1991	Disposal stop, refurbishment
1994	Disposal restarted
09/1998	Waste acceptance interrupted
09/1999	Waste disposal terminated Licensing procedure only for closure
11/2000	Advanced backfilling - repository closure to follow
2011	Public hearing
2014	License for closure expected

DBE TEC

Konrad: Repository under construction

1965 – 1976	Iron ore production approx. 7 mil. t. Deposit ~ 1.4 billion t
1975	Preliminary survey as candidate site
1982	Site Suitability statement and License Application submitted
09/92 - 03/93	Public hearing (75 hearing days)
14.06.00/ 17.07.01	Consensus Agreement - *Finishing licensing procedure* - *Withdrawal immediate enforcement*
01.08.01	Radiation Protection Ordinance amendment License application amendment
05.06.02	LICENSE GRANTED
2002-2008	Litigation
2008-2010	Start of Repository Construction
2019	Currently Likely Disposal Start

DBE TEC

Gorleben: Site Characterization Facility

22.02.1977	Site designation Gorleben (Nukleares Entsorgungszentrum/NEZ)
April 1979	Start of surface site characterization
1980/1981	Four deep boreholes (1002/1003/1004/1005)
Mai 1983	Comprehensive suitability statement (PTB)
Sept. 1986	Ground-breaking for Shaft 1
Oct. 1996	Communication between Shaft Gorleben 1 and Gorleben 2 (840-m-Sohle) established: Thereafter excavation of infrastructure area and characterization of Exploration Area 1
01.10.2000	Site characterization interrupted. Thereafter stand-by operation only
03.03.2010	Germany announces to the IAEA Board of Governors that site exploration will continue
01.10.2010	Politically motivated Moratorium to the exploration of the Gorleben site ends
01.07.2010	Start of a preliminary safety case study
01.11.2010	Restart of underground site characterization
2012	????

DBE TEC

! New siting law may have influence on Gorleben

Source: DBE TECHNOLOGY GmbH

CURRENT SITUATION

Project Management Agency Karlsruhe
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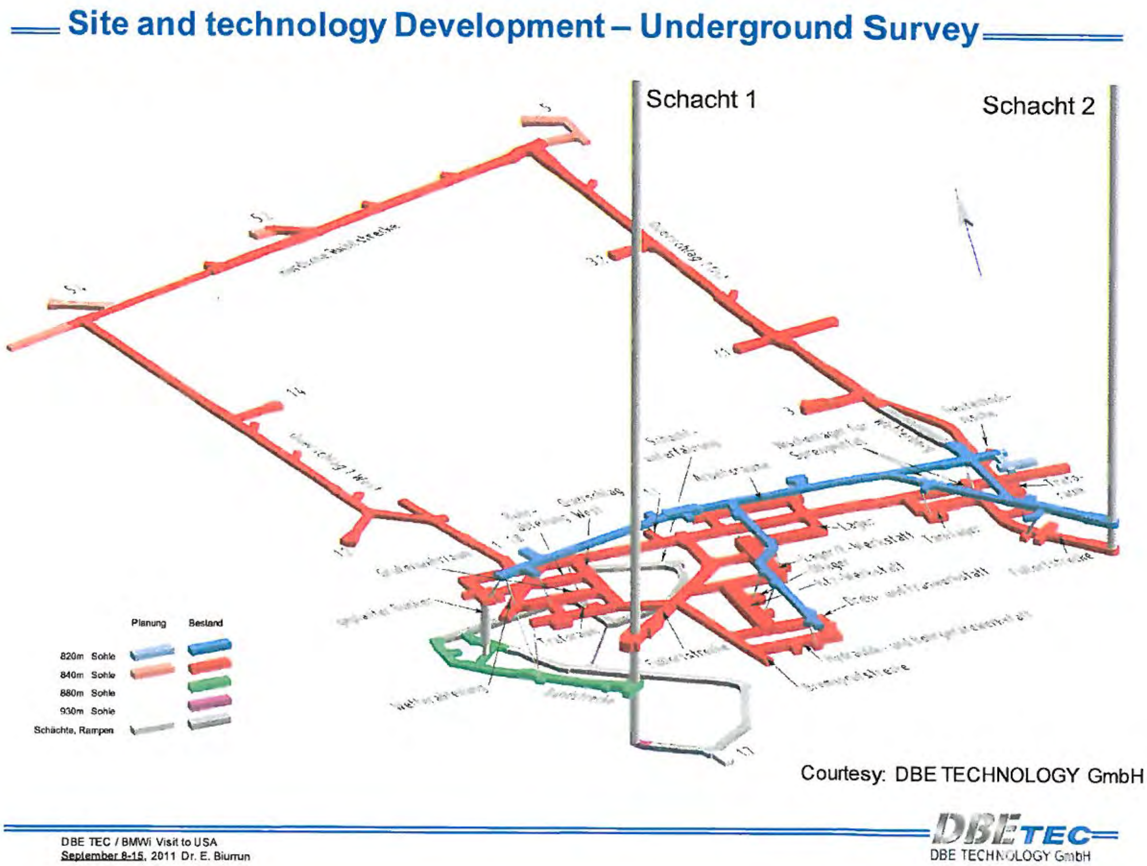
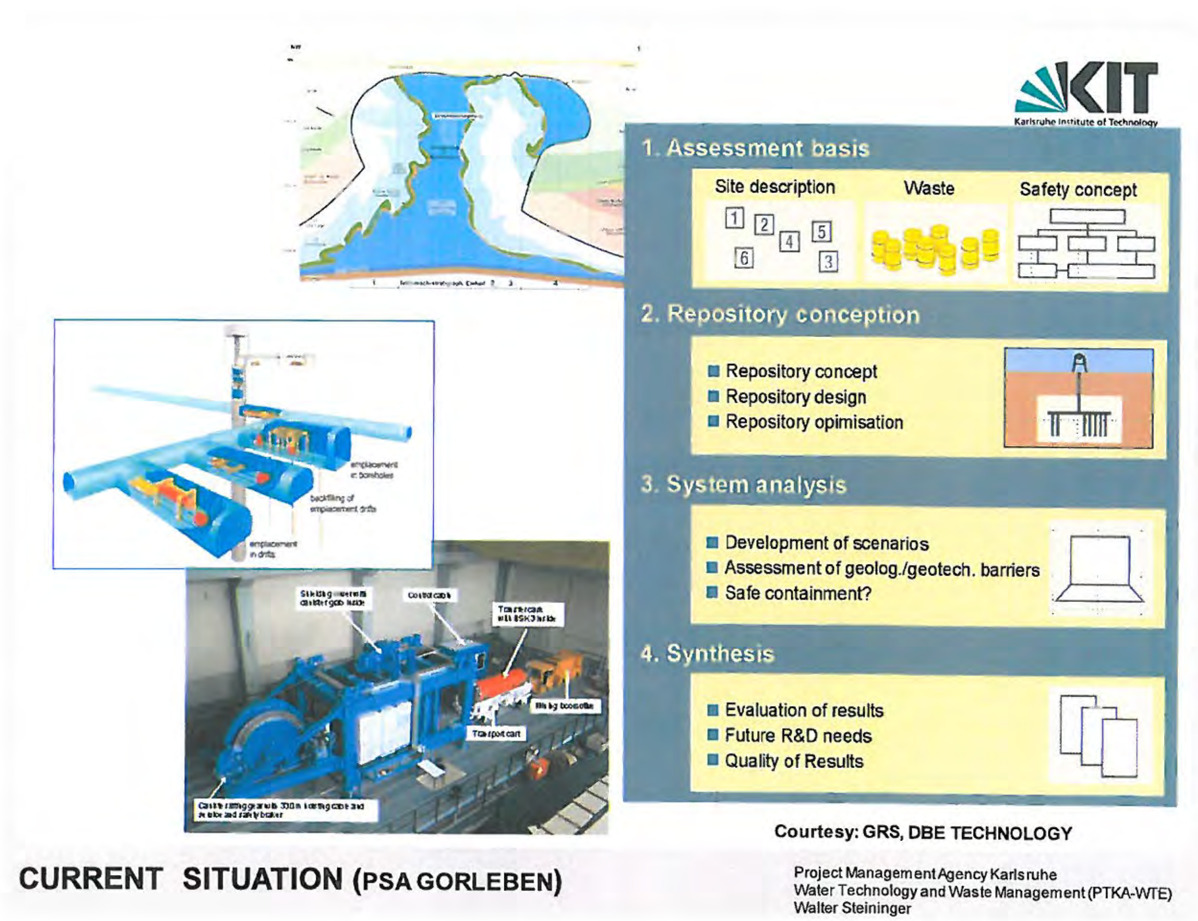
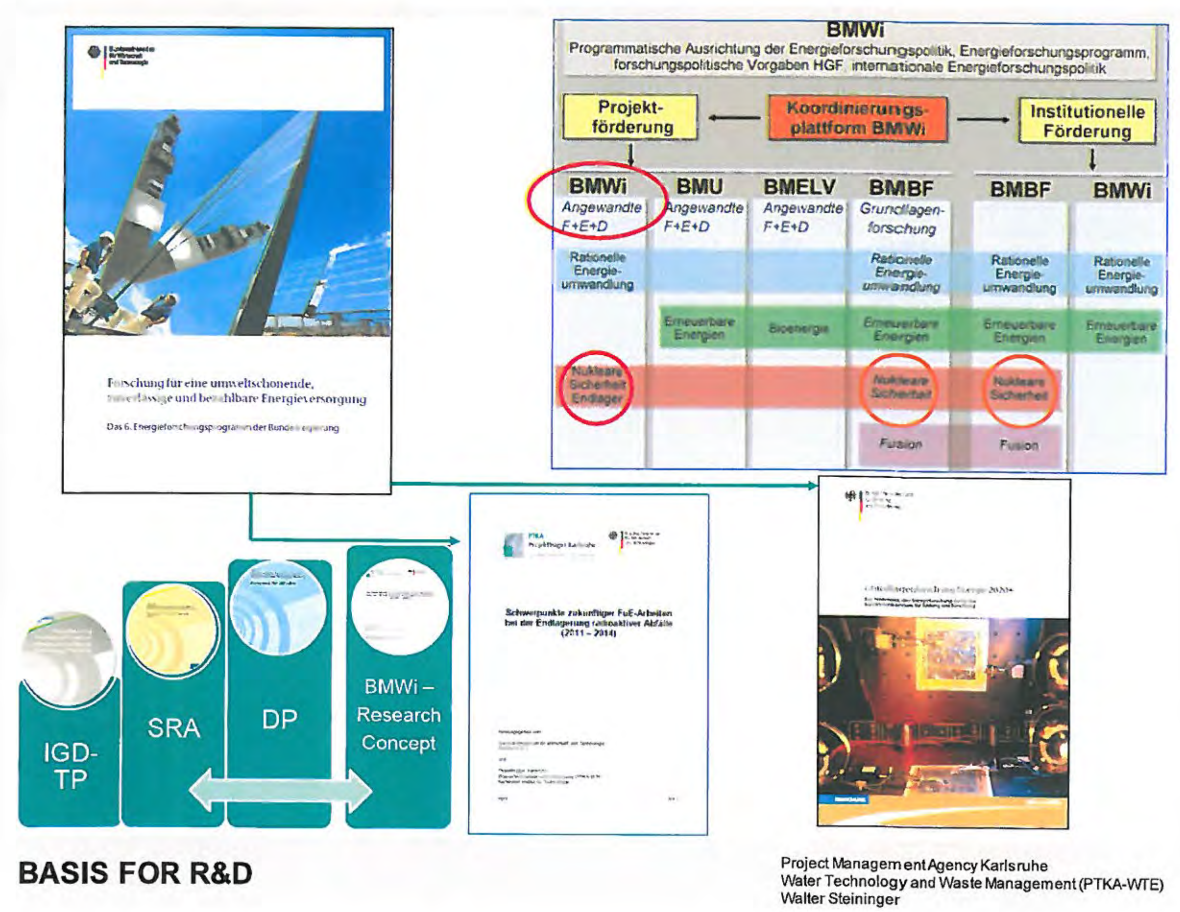


Site and technology Development – Underground Survey
Schacht 1
Schacht 2
Planung
Bestand
820m Sohle
840m Sohle
880m Sohle
930m Sohle
Schächte, Rampen
Courtesy: DBE TECHNOLOGY GmbH
DBE TEC / BMWi Visit to USA
September 8-15, 2011 Dr. E. Biurrun
DBE TEC
DBE TECHNOLOGY GmbH



KIT
Karlsruhe Institute of Technology
1. Assessment basis
Site description
Waste
Safety concept
2. Repository conception
Repository concept
Repository design
Repository opimisation
3. System analysis
Development of scenarios
Assessment of geolog./geotech. barriers
Safe containment?
4. Synthesis
Evaluation of results
Future R&D needs
Quality of Results
Courtesy: GRS, DBE TECHNOLOGY
CURRENT SITUATION (PSA GORLEBEN)
Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger



BMWi
Programmatische Ausrichtung der Energieforschungspolitik, Energieforschungsprogramm, forschungspolitische Vorgaben HGF, internationale Energieforschungspolitik
Projekt-förderung
Koordinierungs-plattform BMWi
Institutionelle Förderung
BMWi
Angewandte F+E+D
BMU
Angewandte F+E+D
BMELV
Angewandte F+E+D
BMBF
Grundlagen-forschung
BMBF
BMWi
Rationelle Energie-umwandlung
Erneuerbare Energien
Bioenergie
Nukleare Sicherheit Endlager
Nukleare Sicherheit
Fusion
Forschung für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung
Das 6. Energieforschungsprogramm der Bundesregierung
IGD-TP
SRA
DP
BMWi – Research Concept
Schwerpunkte zukünftiger FuE-Arbeiten bei der Endlagerung radioaktiver Abfälle (2011 – 2014)
BASIS FOR R&D
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Water Technology and Waste Management (PTKA-WTE)
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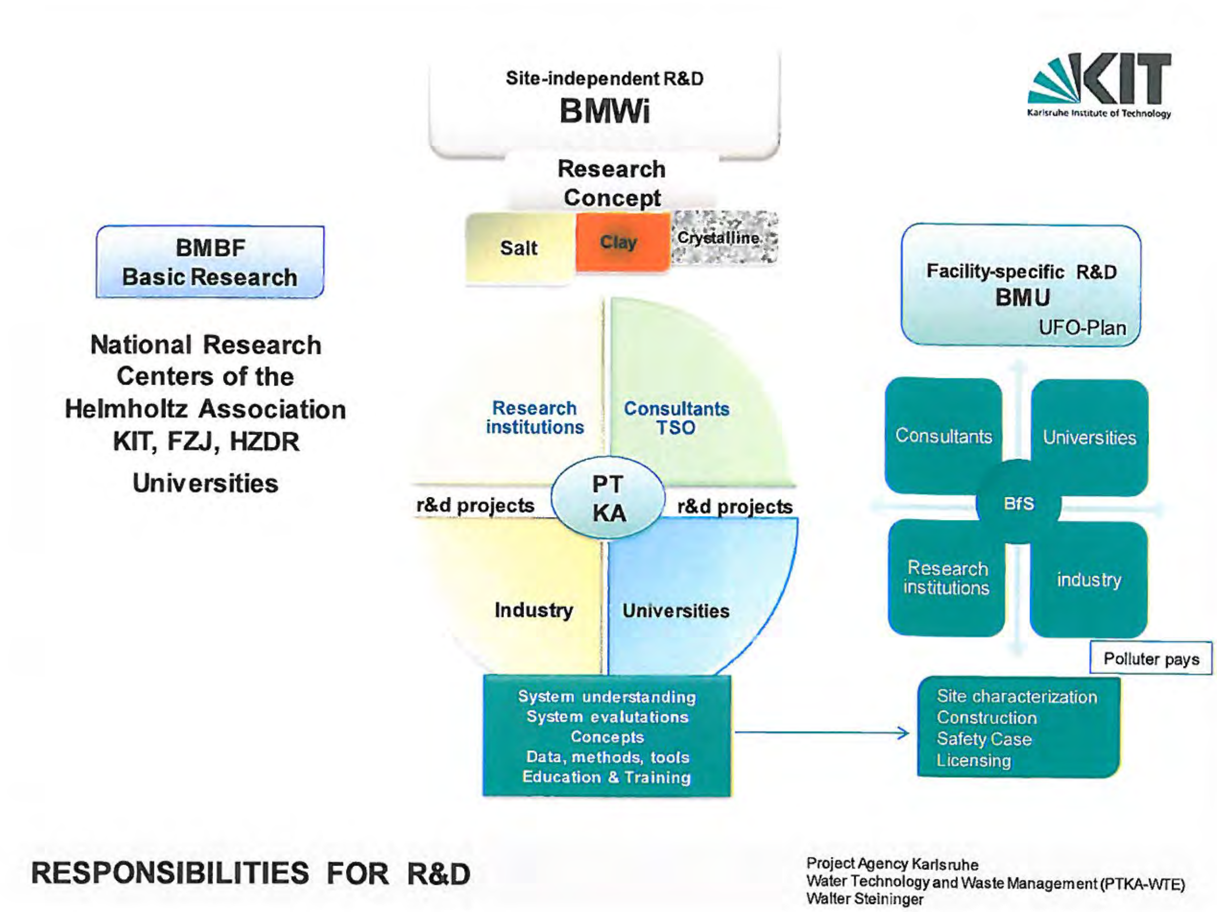

Site-independent R&D
BMWi
Research Concept
Salt
Clay
Crystalline
BMBF
Basic Research
National Research Centers of the Helmholtz Association
KIT, FZJ, HZDR
Universities
Research institutions
Consultants TSO
PT KA
r&d projects
r&d projects
Industry
Universities
System understanding
System evalutations
Concepts
Data, methods, tools
Education & Training
Facility-specific R&D
BMU
UFO-Plan
Consultants
Universities
BfS
Research institutions
industry
Polluter pays
Site characterization
Construction
Safety Case
Licensing
KIT
Karlsruhe Institute of Technology
RESPONSIBILITIES FOR R&D
Project Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

1. Safety Case
2. Waste forms and their behavior
3. Technical feasibility & long-term behavior of repository components
4. Development strategy of the repository
5. Safety of construction & operations
6. Monitoring
7. Governance & stakeholder involvement

X-cutting activities

Dialogue with the regulator
Competence maintenance, E&T
Knowledge Management
Communication

WM program specific activities

Site characterization issues
Transportation
Requirement management systems
Waste acceptance

Repository System

Concepts, Technologies & Demonstration
Host rock properties
Waste & containers
Geotechnical barriers

System behavior and system description

Host rock
Near field geochemistry
Behavior of the technical and geotechnical barriers
Scenarios
Methods, models and numerical simulation
Model qualification & reduction of uncertainties
System analyses

X-cutting topics

Conceptual options (consequences of P&T scenarios, retrievability,
Knowledge Management and memory keeping, data management, governance)

Safeguards

IGDTP - SRA Key Topics → BMWi Research Concept

R&D TOPICS

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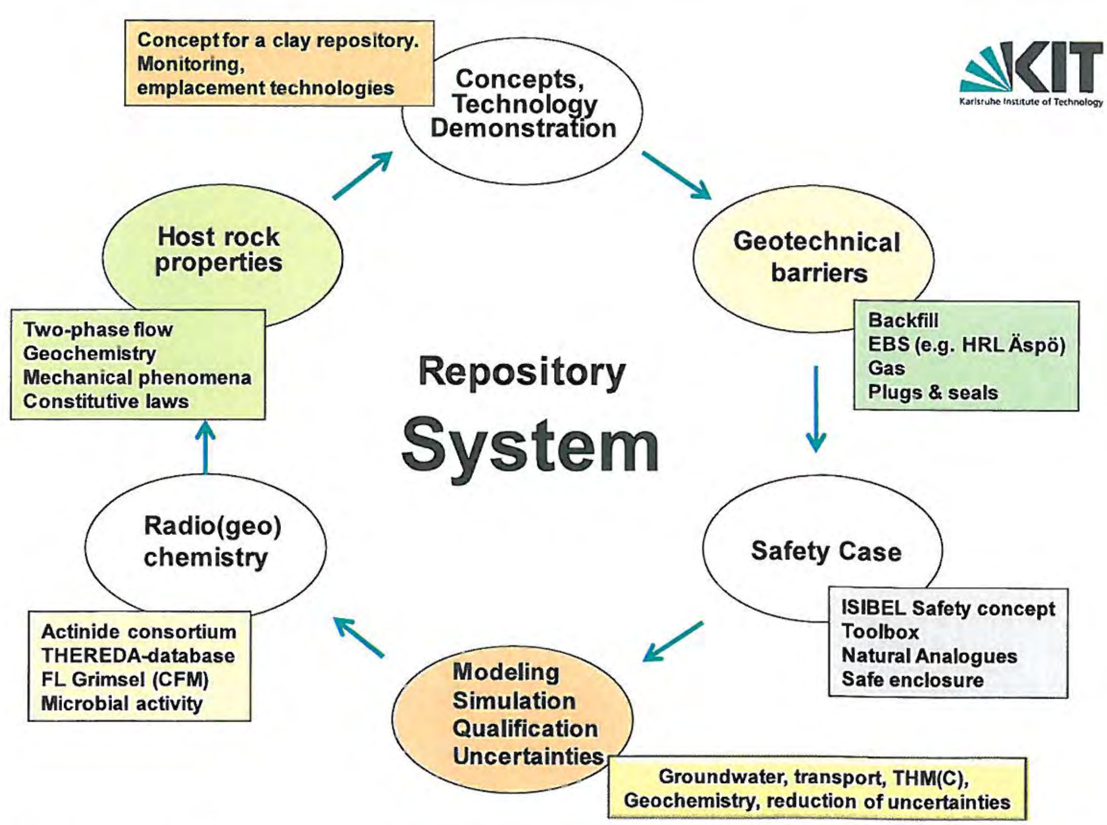
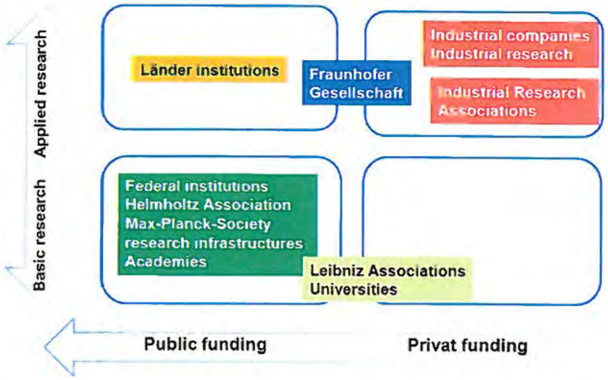
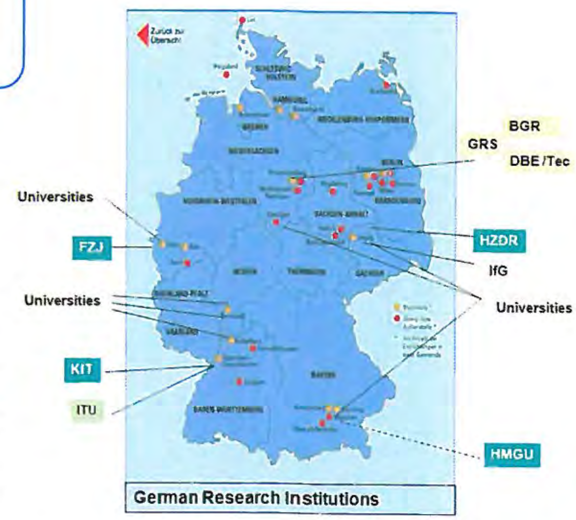


R&D TOPICS & PROJECTS

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger





PROJECT MANAGEMENT AGENCIES

- act on behalf of Federal and Länder Ministries
- support the implementation of federal R&D programs
- administrative support and expert advice to potential project proposers, project supervision and evaluation.
- support of ministerial departments, conceptual support in preparing R&D programs
- organizing conferences, workshops, and support in international cooperation activities.
- are a sort of service provider in R&D and knowledge transfer (broker between the Federal Ministries as contracting and financing authority and the customers, scientific institutions and industry)

RESEARCH LANDSCAPE

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Water Technology and Waste Management (PTKA-WTE)
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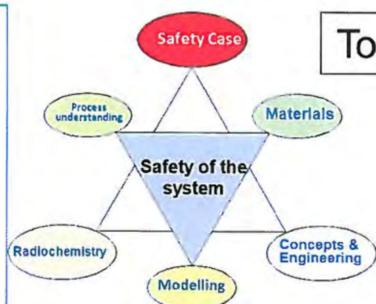


Topics

transfer

Cooperation

INTERNATIONAL COOPERATION

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Objectives

- to identify parameters of potential host rocks in addition to rock salt
- to develop and to test investigation methods and models to demonstrate their applicability and transferability
- to exchange experiences and know-how
- to acquire the essential expertise and knowledge to make science-based recommendations on the pros and cons of different host rocks
- to maintain flexibility with different host rock options

KIT Karlsruhe Institute of Technology

- **Bilateral Agreements**
- **WTZ-Agreements**
- **Financial support of consortium members**
- **Contractual agreements**

OECD/NEA
Salt Club & Clay Club

INTERNATIONAL COOPERATION

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

- Collaboration hibernated for more than 10yrs
- Decision to halt the Yucca Mountain Project, discussion on the future of nuclear in US

- Re-start of collaboration in 2010 with the a common US-German Workshop in Mississippi (organized by PTKA, Sandia NL, DBE TEC)

- 2011 signature of a MoU between BMWi and US-DOE (EM, EN)
- 2011 common workshops between US (SNL, LANL) and German research organizations (radio/actinide chemistry, geomechanics)
- Common project /undertakings between German and US (SNL, LANL) scientists
- 2012 3rd US-German WS in ABQ & project meeting "joint project on salt benchmark"

- Founding of a co-operative project of the IGSC, so-called SALT CLUB (Germany, US, The Netherlands, Poland), 1st NA Workshop

COOPERATION – UNITED STATES

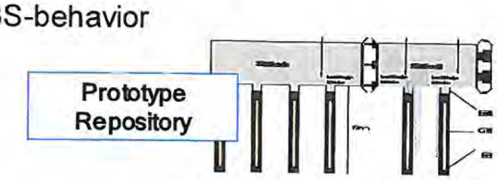
Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

- 2001 agreement between BMWi and MINATOM (now ROSATOM)
- 2002 agreement to collaborate (14 project ideas, focusing on HLW disposal)
- Bi-annual expert meetings to evaluate the progress and/or to define projects of mutual interest
- Very successful cooperation since between German and Russian organizations
- Main activity: Russian project to dispose of HLW and long-live radioactive waste near Krasnojarsk, now one of the 15 high priority nuclear projects in Russia
- Joint use of geological, safety assessment and engineering expertise basis for success and acceptability by Russian partners and authorities
- Since 2002 in total 18 projects defined (8 finished, two postponed, 8 running or in the preparation / discussion phase)

COOPERATION – RUSSIA (CRYSTALLINE & CLAY)

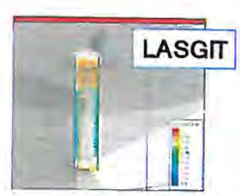
Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

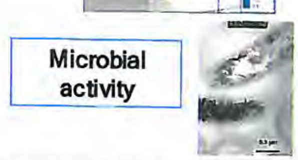
- Cooperation in R&D in the HRL Äspö on the basis of the Swedish-German Agreement between SKB and BMWi since 1995 (construction of the Äspö HRL)
- R&D activities comprised groundwater modeling, RN migration, microbial influence, EBS behavior, gas transport phenomena, monitoring)
- NOW: R&D activities focus mainly on EBS-behavior (THM(C), modeling, monitoring, etc.)



Projects

- Prototype Repository Decommissioning
- LASGIT (Large-scale gas injection test) (BGR)
- Alternative Buffer Materials (BGR)
- Temperature Buffer Test modeling (DBE Tec)
- MICROBE (microbial influence) (HZDR)
- Task Forces (EBS and Groundwater modeling) (BGR, GRS)





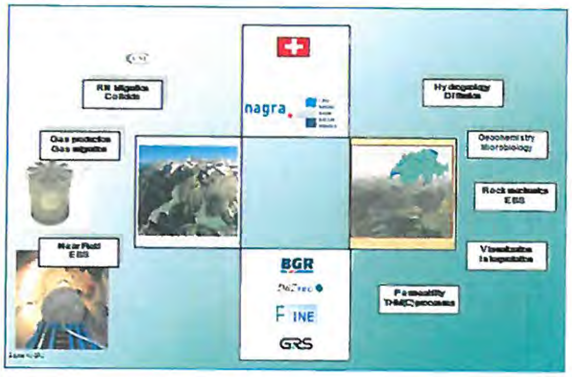
COOPERATION – SWEDEN (CRYSTALLINE)

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

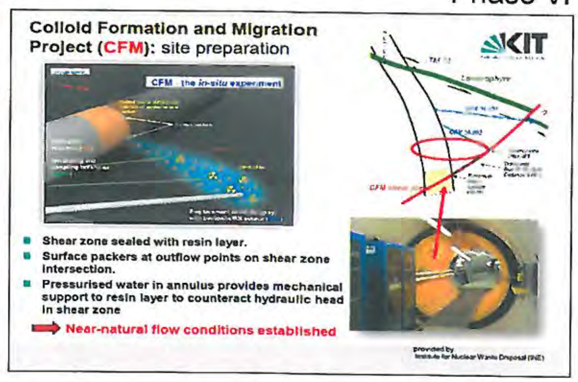
Grimsel Test Site

- Start of cooperation in 1983
- Since then participation in projects in all the R&D phases
- Basis: BMWi – NAGRA agreement
- Participation of several German research organizations (presently KIT/INE, GRS)
- Currently phase VI
- Project CFM (colloid formation and migration – in situ project)

Phase V



Phase VI



COOPERATION – SWITZERLAND (CRYSTALLINE)

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Framework Programs of the European Commission (EURATOM)

for most of the projects contributions to German research organizationsc as co-funding body

Implementation-oriented R&D on all remaining key aspects to establish a sound scientific and technical basis for **demonstrating** the technologies and safety of geological disposal to underpin the development of a common European view on the main issues

Studies on relevant near field processes, understanding of the repository environment, bedrock and pathways to biosphere, developments of robust PA/SA methodologies (modelling tools), engineering studies and demonstration of repository designs, In situ characterisation of host rocks in generic & site specific URLs, investigation of governance and societal issues related to public acceptance.

COOPERATION – EUROPEAN COMMISSION

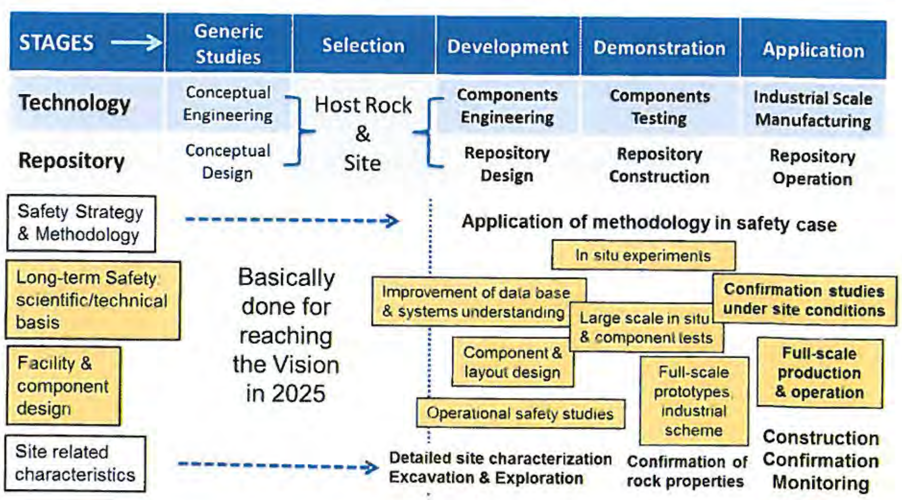
Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

- RD&D for implementing a DGR
  - sound scientific-technical program
  - long term aspects, E&T, knowledge management
  - multidisciplinary project, cooperation aspects (national & international)
- Implementing Geological Disposal of Radioactive Waste - Technology Platform (www.igdtp.eu) as an example
- System approach, i.e. the repository and its surroundings
- Take mistakes as chances & possibilities (even the most advanced programs had their drawbacks)
- Holistic appraoach: U-mining – NPP – Decomissioning – Repositories (DGR and subsurface)
- International cooperation is an important and indispensable part of any program

LESSONS learned? (1)

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

- Staged approach for implementation ((take into account the long time frames and the consequences)
- Sound conceptual basis (however adaptive)



Courtesy: Wernt Brewitz

LESSONS learned? (2)

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

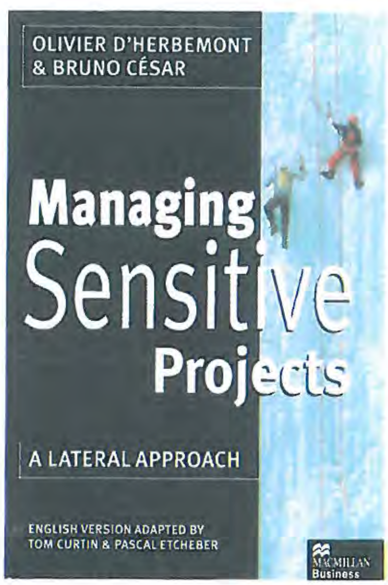
Basic tasks in repository development and implementation

	Generic studies and concept development	Selection of host rock & site selection	Technology development and repository design	Technology demonstration and repository construction	Industrial-scale manufacturing and repository operation
Safety strategy and methodology	Development of safety assessment methodology	Application of methodology in safety case and improvement of methods	Application of methodology in safety case & improvement of methods	Application of methodology in safety case	Application of methodology in safety case
Long-term safety: scientific and technical basis	Broad-based research	Research narrowed to deal with host rock-specific aspects and specific aspects associated with the selected EBS	In situ experiments and improvement of data bases and understanding	Scientific work focused on small number of residual issues; large-scale in situ experiments & component tests	Confirmation studies on components under site conditions incl. monitoring
Facility and component design	Concept variant studies	Repository design concepts adapted to specific rock type	Component design and layout design; operational safety studies	Full-scale prototypes constructed, industrial scheme developed	Full-scale production and operation
Site-related characteristics	Surveys of potential host rocks and their characteristics based on available information	Host rock characterization and site-specific studies	Detailed site characterization; excavation	Construction of main underground facilities; confirmation of rock properties for final design	Construction, confirmation, monitoring

Courtesy: Wernt Brewitz

LESSONS learned? (2)

Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger



- Clear legal basis
  - financial provisions
  - decision making
  - national program
  - responsibilities
  - funding
  - safety requirements by a regulatory body
- Stakeholder involvement from the very beginning
  - siting (criteria, requirements)
  - responsibilities, transparancy, tracability
- Governance issues (social, economic, etc.)
- Program Management by a responsible WMO
- avoid political influence if possible

LESSONS learned? (3)

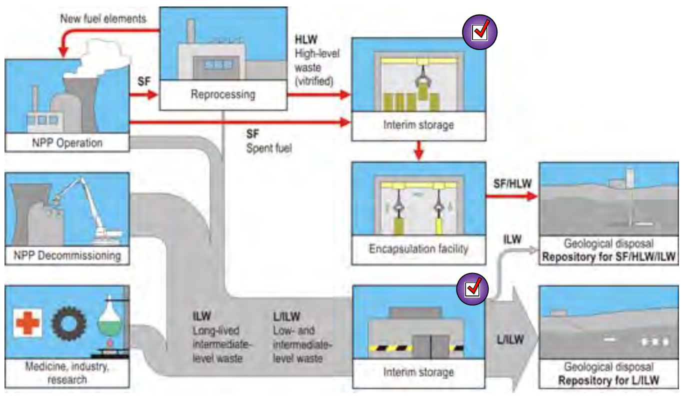
Project Management Agency Karlsruhe
Water Technology and Waste Management (PTKA-WTE)
Walter Steininger

Radioactive Waste Management in Switzerland – Recent Advances and Outlook

Crystalline Rock Repository Development
24-27 September 2012, Prague

Dr. Stratis Vomvoris

Swiss waste management concept



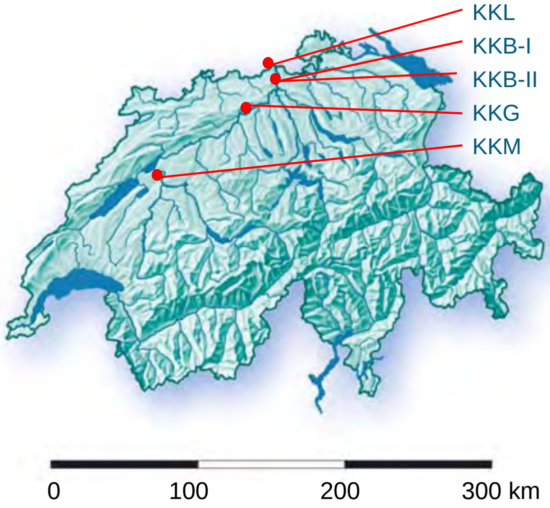
Two geological repositories (legal requirement):

- Spent fuel and vitrified high level waste → HLW repository
- Long-lived intermediate waste → HLW repository (co-disposal)
- Low and intermediate waste (L/ILW) → L/ILW repository

Nuclear energy in Switzerland

5 Nuclear Power Plants (3253 MW_e)

KKL	Leibstadt	(1984)	1165 MW_e
KKB-I	Beznau	(1969)	365 MW_e
KKB-II	Beznau	(1971)	365 MW_e
KKG	Goesgen	(1979)	985 MW_e
KKM	Muehleberg	(1971)	373 MW_e



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Nuclear energy in Switzerland

- 2011: Decision of the Federal Government on a revised energy policy, confirmed by both Chambers of Parliament
  - Staged phase-out until approx. 2034
  - No new nuclear plants of generation 3 or older will be built
- As a consequence, a revised Law on Nuclear Energy will be presented by the Federal Government later this year
  → A national referendum on the revised law is expected in 2 - 3 years
- April 2012: Presentation of "Energy Strategy 2050" by Federal Government
  - Focus on increased energy efficiency and the expansion of hydropower and renewable energies
  - "If necessary": fossil fuel-based electricity production (gas-fired combined-cycle power plants)

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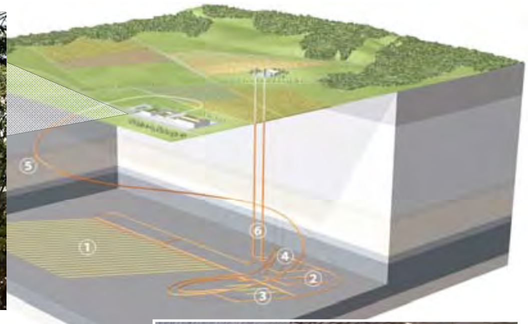
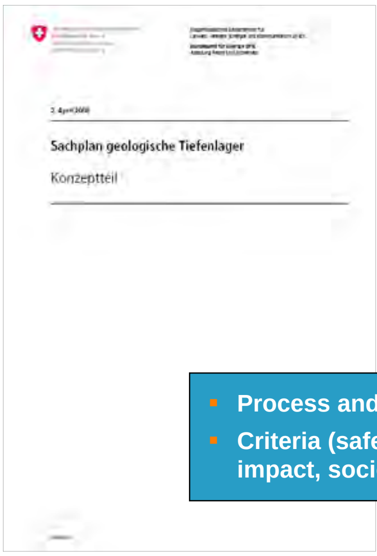
Swiss concept for HLW/SF[1] and LL-ILW[2] repository

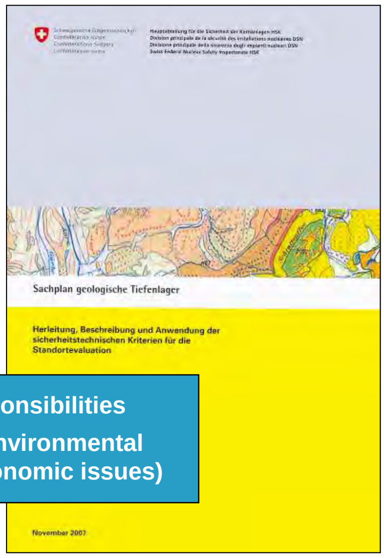
[1] High-level radioactive waste and spent fuel
[2] Long-lived intermediate level radioactive waste



❶ HLW/SF repository
❷ LL-ILW repository
❸ Pilot repository
❹ Test area (rock laboratory)
❺ Access tunnel
❻ Ventilation and construction shafts

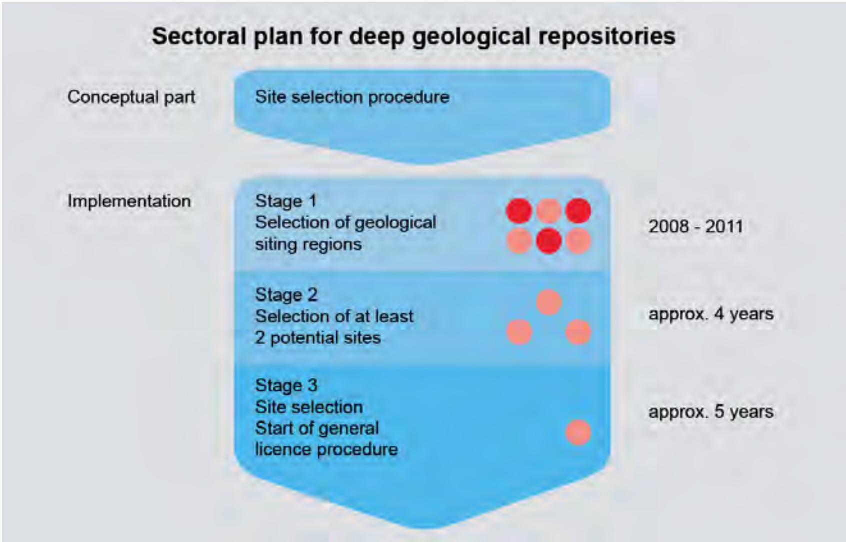
Sectoral Plan 'Deep Geological Repositories'





- Process and responsibilities
- Criteria (safety, environmental impact, socio-economic issues)

Sectoral Plan – Site Selection Process



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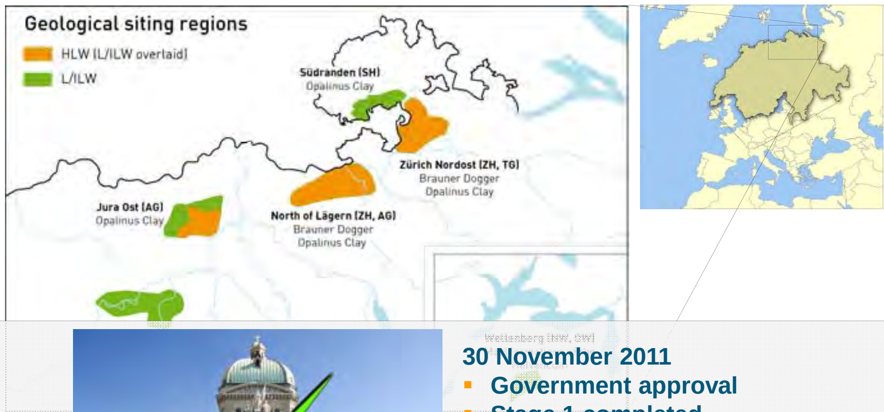
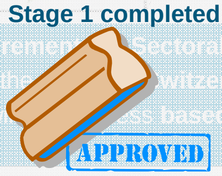
Proposed siting regions – October 2008



30 November 2011
- Government approval
- Stage 1 completed



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Sectoral Plan Process: Stage 2 (2012 –)

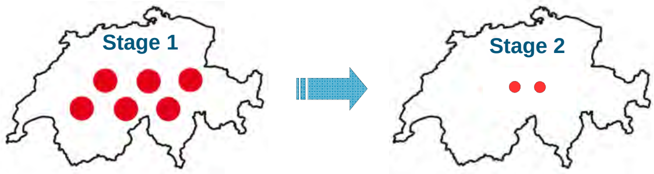
Selection of at least 2 sites based on criteria that include:

1. Preliminary safety analysis
2. Engineering pre-studies including surface infrastructure
3. Socio-economic-ecological studies

Site-specific evaluation and comparison – proposals by Nagra

Led by the Swiss Federal Office of Energy

Strong regional and local participation component



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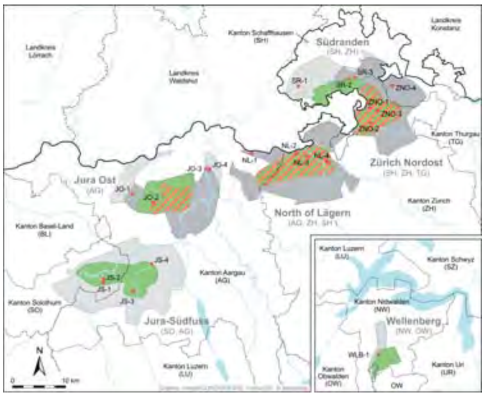
Stage 2: Selection of sites for the surface facilities

- Nagra proposed **20 areas** for siting of surface facilities on January 20, 2012
- Selection criteria
  - Safety and engineering feasibility
  - Environmental protection and land use planning
  - Integration of facilities in the siting region



- Step-by-step process
  - Presentation to the local population in February and March 2012, under the lead of SFOE (15 events, incl. 2 in Southern Germany)
  - Discussion of proposals within "regional conferences" (a region may propose alternative siting areas)

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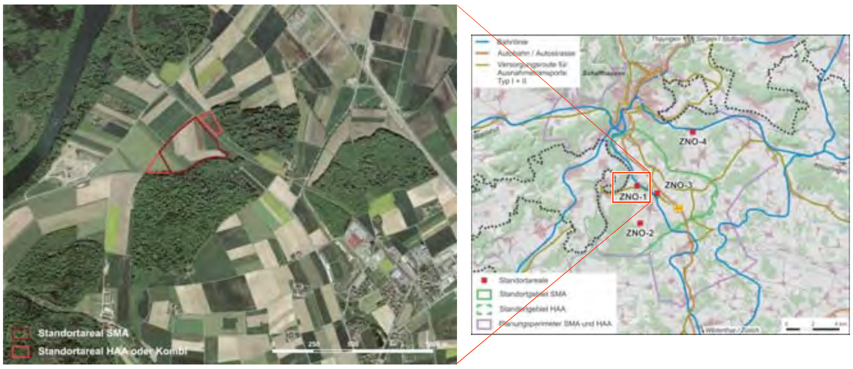
Example of proposed site



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Participation in Stage 2 – Regional Conferences

Activities:

- Discussion of surface facilities
- Studies related to land use and socio-economic aspects
- Projects for the sustainable development of the region

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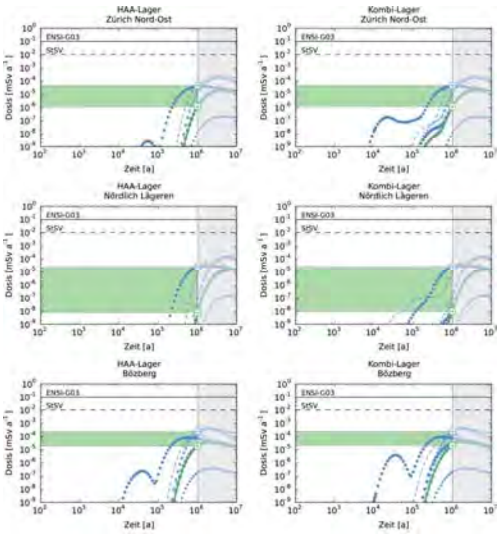
nagra

Highlights of scientific and engineering activities 1/2

Nagra performed and submitted to the authorities (ENSI) provisional analyses in order to:

- verify that the state of knowledge of the geological conditions at the sites is sufficient to perform the safety-based comparison of the siting regions
- confirm that the planned investigations will be sufficient for Stage 1 and Stage 2

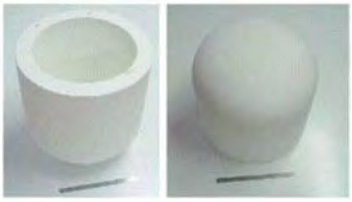


The authorities approved Nagra's conclusions.

Highlights of scientific and engineering activities 2/2

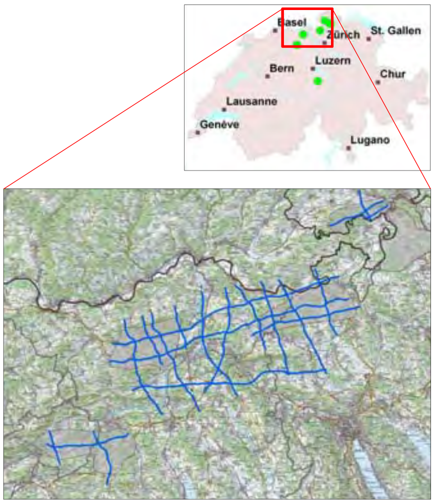
Alternative canister materials for SF/HLW

- Copper-shell (~ available)
- Ceramics (concepts available, developments needed → inherent material properties)
- Possibility for copper coating is being investigated



Stage 2: Field investigations

- 2D-seismic campaign between October 2011 and March 2012
  - HLW siting regions “Jura Ost” and “Nördlich Lägeren”
  - LLW siting regions “Südranden” and “Jura Südfuss”
  - > 300 km 2-D lines
  - Interpretation ongoing

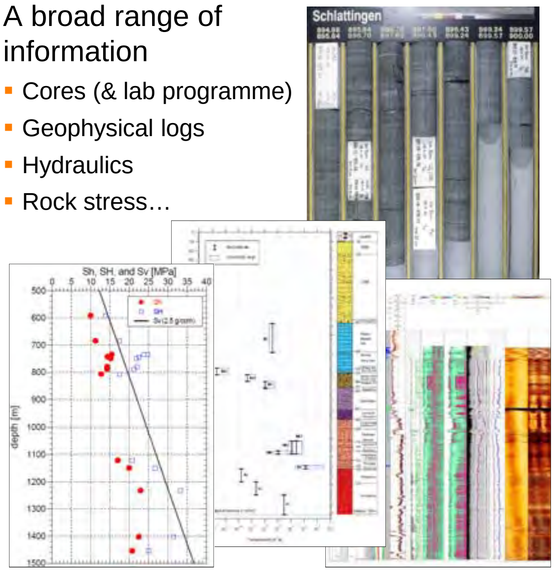


15 04.07.2012 Waste management in Switzerland / Ett nagra

Participation in investigations of 3rd parties

A broad range of information

- Cores (& lab programme)
- Geophysical logs
- Hydraulics
- Rock stress…



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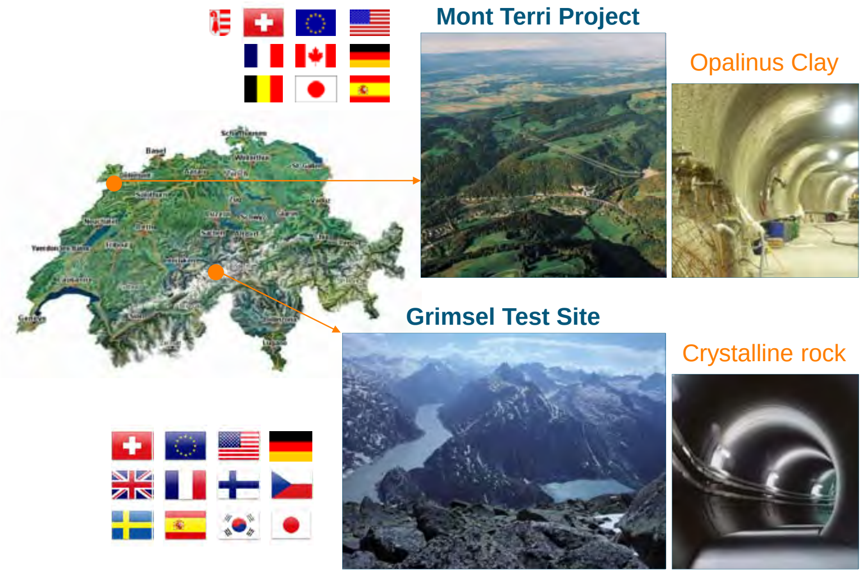
Research at underground rock laboratories



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Next steps in the site selection process

Stage 2: Selection of at least two sites for each repository

- Evaluation of the sites proposed in January 2012 by the authorities and regional conferences (includes any additional sites proposed by the regional conferences)
- Narrowing-down the number of sites and proposal of at least 2 sites for L/ILW and 2 sites for HLW/SF repository
- Evaluation of the specific proposals by the authorities and commissions
- Recommendations (Federal Office of Energy) to the Federal Government
- Evaluation by the Federal Government and final decision (2015/2016)

Current activities at Nagra:

- Support the site selection process
- Safety assessments and engineering designs
- Preparation of site exploration programmes

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Next steps in the site selection process

Stage 3: Selection of one site for each repository

- Field investigations, including seismic and deep boreholes, at the sites selected in Stage 2
- Analyses of results and selection of 1 site for each repository based on:
  - Safety case
  - Comprehensive socio-economic analysis
  - Environmental impact analysis
  - Overall evaluation
- General license application

Decision of the Federal Government → Site permit

Facultative national referendum

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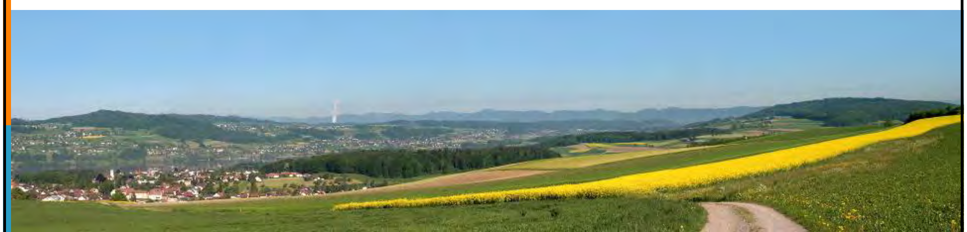
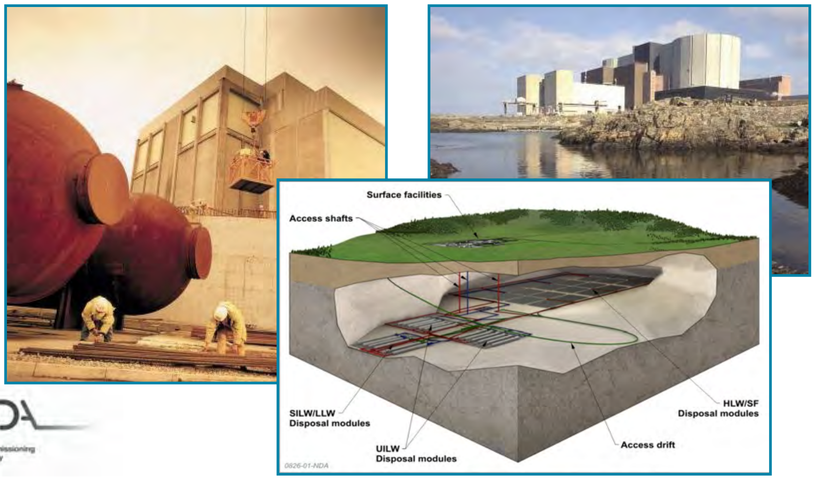


thank you
for your attention

nagra.

NDA status update – UK waste disposal programme



NDA
Nuclear Decommissioning Authority

Responsibilities

- Non-departmental Public Body established in April 2005
- Remit to clean up the civil public sector nuclear wastes
- Sites and facilities built from 1940s onwards
- Annual funding of ~£2.8Bn
- Based in West Cumbria with regional offices
- Responsible for 19 former UKAEA and BNFL sites & integrated waste strategy

"To deliver safe, sustainable and publicly acceptable solutions to the challenge of nuclear clean-up and waste management."

NDA

2

Legacy wastes

3

Higher activity wastes

4

Defence wastes

5

UK waste inventory

Materials	Packaged volume		Radioactivity (At 1 April 2040)	
	Cubic Metres	%	**Terabequerels**	%
HLW	1,400	0.3%	36,000,000	41.3%
ILW	364,000	76.3%	2,200,000	2.5%
LLW (not for LLWR)	17,000	3.6%	<100	0.0%
Spent nuclear fuel	11,200	2.3%	45,000,000	51.6%
Plutonium	3,300	0.7%	4,000,000	4.6%
Uranium	80,000	16.8%	3,000	0.0%
Total	**476,900**	**100**	**87,200,000**	**100**

0643-01

6

Managing Radioactive Waste Safely

- White paper published 12 June 2008
- Government's framework for managing higher activity radioactive waste through geological disposal
- Communities invited to open discussions with Government about possible future hosting facility – without commitment
- Community benefit package

NDA as implementing body committed to:

- Programme of R&D
- Development of RWMD into delivery organisation
- Preparation and planning for geological disposal

NDA

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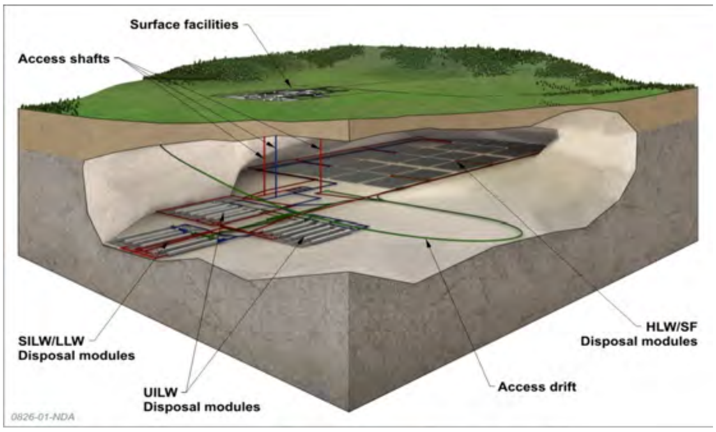
Conceptual Geological Disposal Facility



NDA

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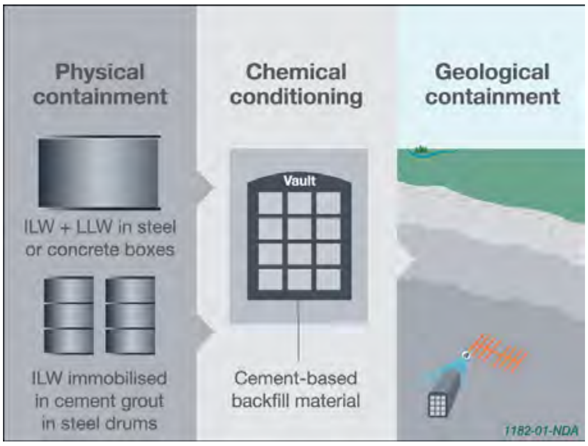
ILW multi barrier concept



NDA

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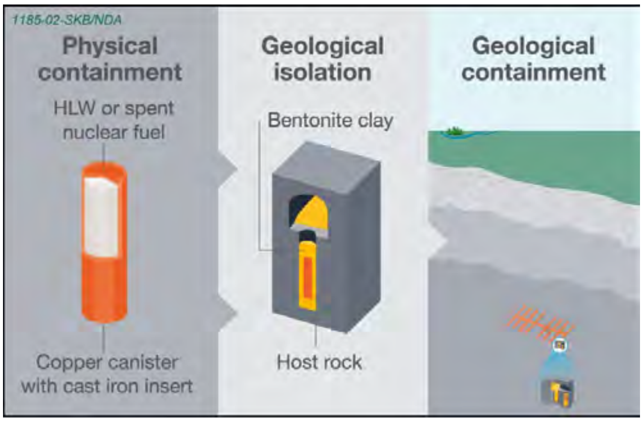
HLW and SF reference concept (SKB)



NDA

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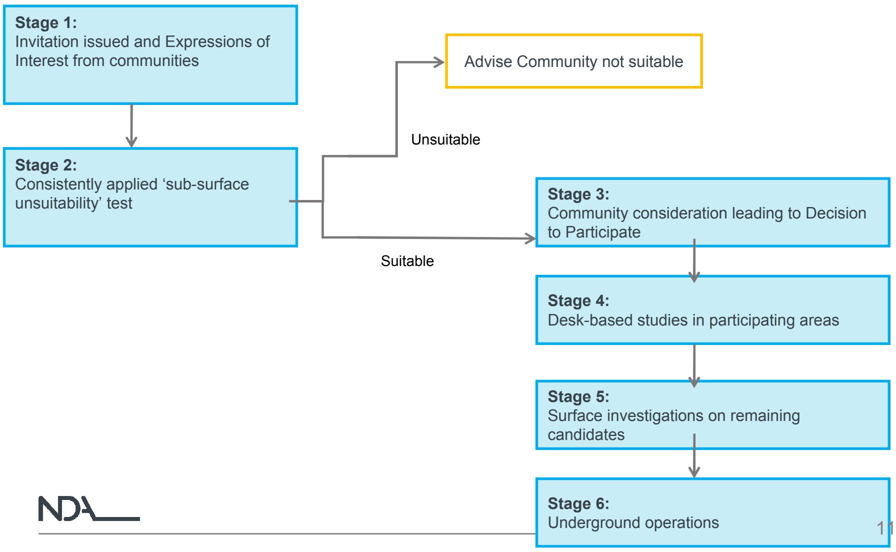
MRWS site selection process



NDA

11

Interest

In 2008 UK communities invited to express interest:

2008/9 West Cumbria MRWS Partnership established from 2 communities who expressed interest - (Stage 1)

Hard rock overlain by sedimentary succession

British Geological Survey (BGS) screening reported in 2010 (Stage 2)

Indicative programme suggests a decision on whether to participate due late 2012 (Stage 3)

NDA

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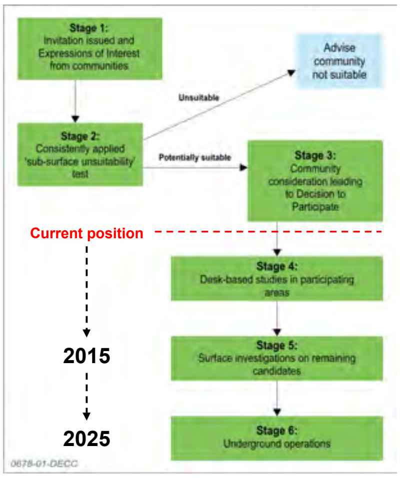
Going forward

Key milestones in the program:

- Late 2012 – Decision whether to participate expected from West Cumbria County Councils
- Progression to Stage 4 Desk Studies
- 2015 – Surface investigations, Stage 5
- 2025 – Underground operations, Stage 6
- 2040 – First waste emplacement



NDA

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Other developments

Programme Acceleration:

- Government proposed program acceleration, enabling emplacement 2029
- Subject to ongoing reviews
- Planning for S5 investigations during S4
- Running investigations in parallel at the start of S5

Research step change:

- Progression to larger scale experiments, concept optimisation
- Increase participation in international programmes, e.g. URLs
- Demonstration experiments

NDA

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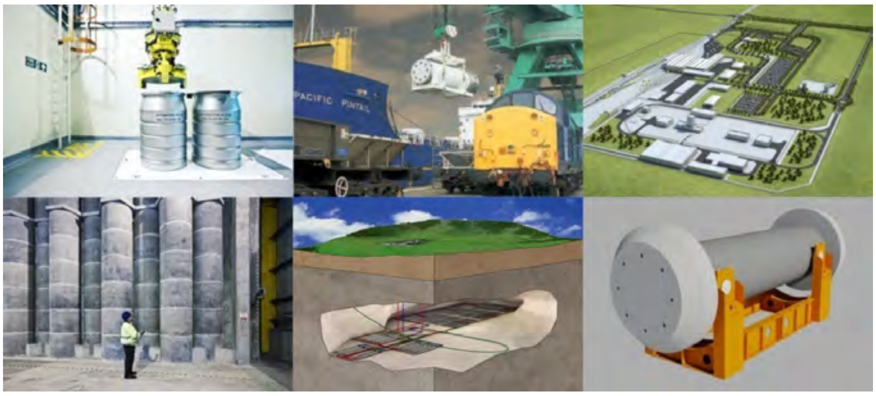
Questions?



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The Scientific Visit on Crystalline Rock Repository Development
September 24-27, Prague, Czech Republic

KAERI Korea Atomic Energy Research Institute

Current Status of Radioactive Waste Management in Korea

Sep. 24, 2012

Inyoung KIM & Yongkwon KOH

Korea Atomic Energy Research Institute

0

KAERI Korea Atomic Energy Research Institute

Contents

1 Nuclear Energy Program and SF Generation

2 National Framework for Radioactive Waste Management

3 LILW Management

4 R&D Activities for HLW Disposal

1

KAERI Korea Atomic Energy Research Institute

1 Nuclear Energy Program and SF Generation

2

KAERI Korea Atomic Energy Research Institute

Nuclear Energy Program

- 21 NPPs are in operation, 30.3% of total electricity in 2011
- Nuclear Energy ~46% by 2020 and 59% by 2030 (MKE)

In operation
21 units
(18,716 MW)

Under construction
7 units
(8,600 MW)

Under Planning(W,K)
4 units
(5,600 MW)

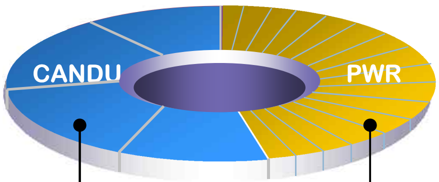
3

Spent Fuel Generation

KAERI Korea Atomic Energy Research Institute

- All SFs are storing at ARs of which storage capacities could be saturated from 2016 ; KHNP are trying to expand until the mid. 2020's.
- Further long-term SF management: interim storage and continuous R&D to reduce SF inventory

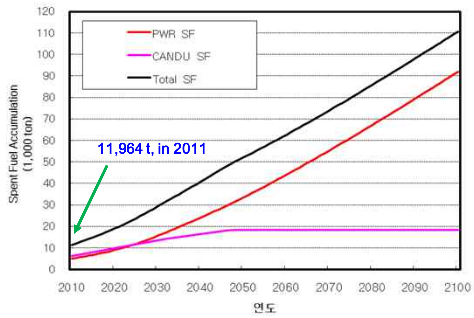
Annual Spent Fuel Generation 720t/yr



CANDU:
- 95 t/yr,unit
- 4 units
- 380 t/yr

PWR:
- 20 t/yr, unit
- 17 units
- 340 t/yr

Projection of Spent Fuel Generation



Spent Fuel Storage at NPPs

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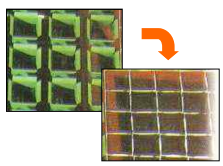
* As of Dec. 2011 (Unit : Assemblies)

Site	Capacity	Saturation	Accum.
Kori	5,971	2016	4,701
Yong-gwang	7,154	2016	4,671
Uljin	5,550	2017	3,906
Wolsong	499,632	2018	344,456
Total	518,307		357,734

- To secure the on-site storage capacity
  - PWR's storgae facility has been expanded by re-racking and transshipment.
  - CANDU SFs have been transferred to the dry storage facility (concrete silo) since 1991

- **Kori**
  - **Unit 1 : Transshipment to Units 3&4**
  - **Unit 3&4 : Addition of high density racks**
- **Ul chin**
  - **Unit 1&2 : Full re-racking of AR pool**
- **Young kwang**
  - **Unit 1 : Transshipment to Units 3&4**



- **Wol song**
  - **Unit 1 : 300 Concrete silos for 162,000 bundles**

5

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Research Institute

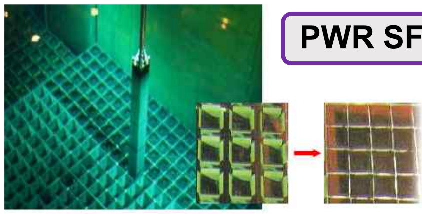
Expansion of SF Storage Capacity

PHWR(CANDU) SF

① **Concrete Silo**

② **MACSTOR/KN-400**

PWR SF



High Density Reracking

Transshipment between NPPs

6

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2 National Framework for Radioactive Waste Management

7

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National Policy for RWM

253rd AEC's Decision (Dec. 2004)

- **Final repository for LILW should be constructed by 2009.** → **Delayed until 2014 for safety reason**
- **Spent Fuel Management**
  - **All SF will be stored at sites until the middle of 2020s.**
  - **Future national policy for SF management will be decided through public participation taking into consideration of nat'l and int'l trends on policy and technology development.**

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Act for RWM

- **This Act has been effective since January 1st, 2009.**
- **Key contents are:**

  ① **Establishment of a new Org. as a implementer for RWMA**

  → **Korea Radioactive Waste Management Corp (KRMC)**

  ② **Establishment of the RW Management Fund which is paid by the Radioactive Waste generator(s).**

  → **KRMC is responsible for managing the RWM Fund**

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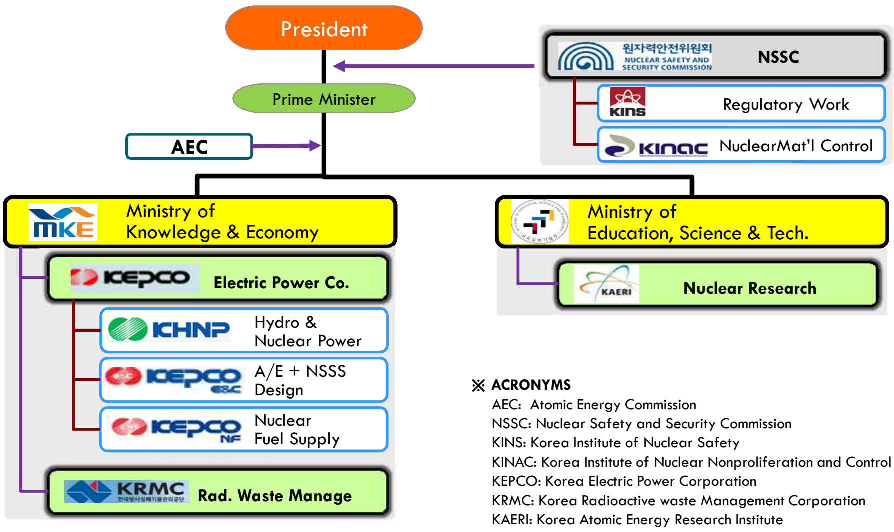
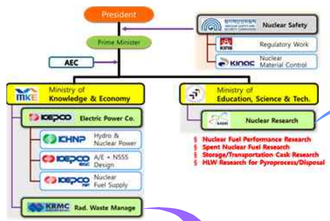
Organization for Nuclear Energy



※ ACRONYMS
AEC: Atomic Energy Commission
NSSC: Nuclear Safety and Security Commission
KINS: Korea Institute of Nuclear Safety
KINAC: Korea Institute of Nuclear Nonproliferation and Control
KEPCO: Korea Electric Power Corporation
KRMC: Korea Radioactive waste Management Corporation
KAERI: Korea Atomic Energy Research Institute

KAERI
Korea Atomic Energy Research Institute

Mission of KAERI vs. KRMC



Nuclear Research

✓ Basic and fundamental technologies development for management of HLW from AFC and other future reactor system

* MEST/KAERI is focusing on the development of AFC.

KRMC Rad. Waste Manage

✓ Final management of all kinds of radioactive waste produced in Korea

✓ KRMC is responsible for implementing radioactive waste management projects like transportation, storage and disposal.

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Mission & Organization of KRMC

- **Mission**
  - Transport & Disposal of Low- and Intermediate-Level Wastes
  - Interim Storage & Disposal of Spent Fuels
  - Siting, Construction & Operation of RWM Facilities
  - R&D on Radioactive Waste Disposal and SF Management
  - Administration of RWM Fund for the Government
- **Organization**
  - HQ : 3 Divisions, RWM Fund Management Center, Wolsong LILW Disposal Center
- **Employees : 250**

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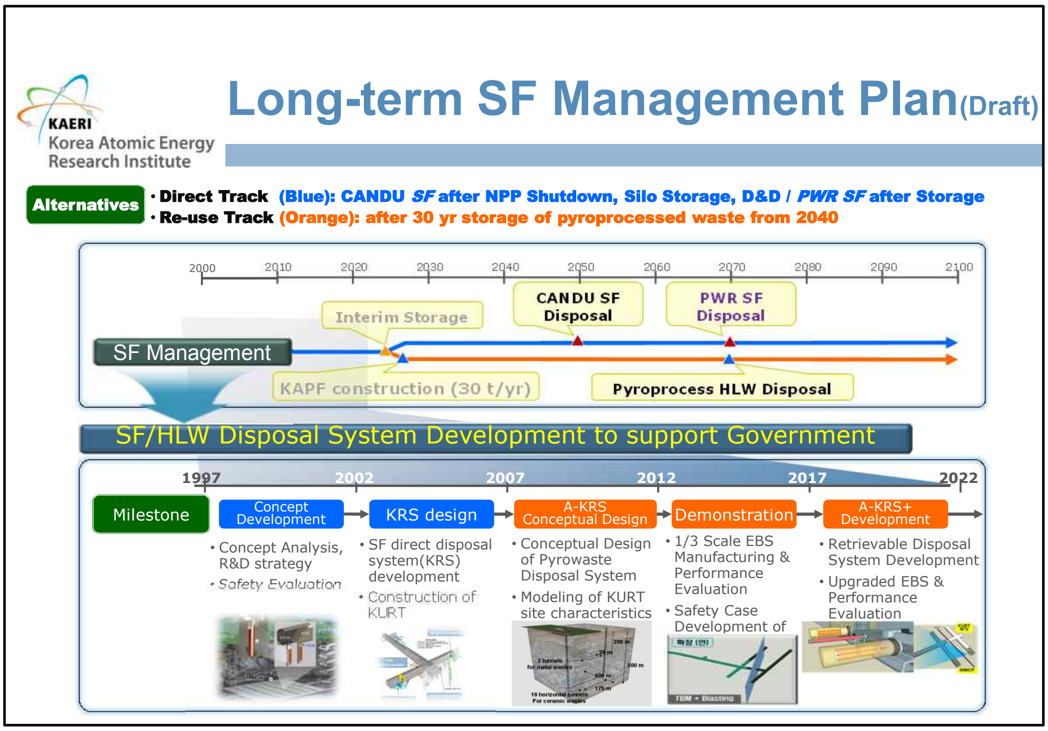
Progress in National Plan for Long-term SF Management

Long-term Management Policy of Spent Fuel

- KRMC has proposed strategies for SF management through an internal consensus of domestic nuclear community.
- Consequently, SF stored at the plant sites will remain for more some time until the national long-term management plan of SF will be finalized in near future through public involvement (MKE).



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3 LILW Management

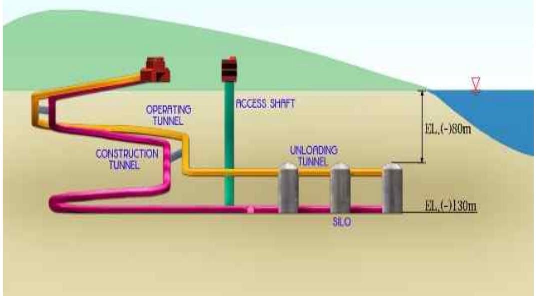
15

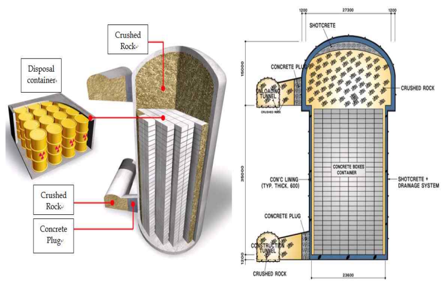
LILW Disposal Site(Gyeong-Ju)

- Altitude : ≥ 30 m from sea level
- Disposal capacity : total 800,000 WP (100,000 packages for the 1st stage)

Disposal Method

- Silo type (underground)
- 80~130m below ground (1st stage)
- D24m x H50m (internal)





17

Bird's-eye View of LILW Disposal Facility

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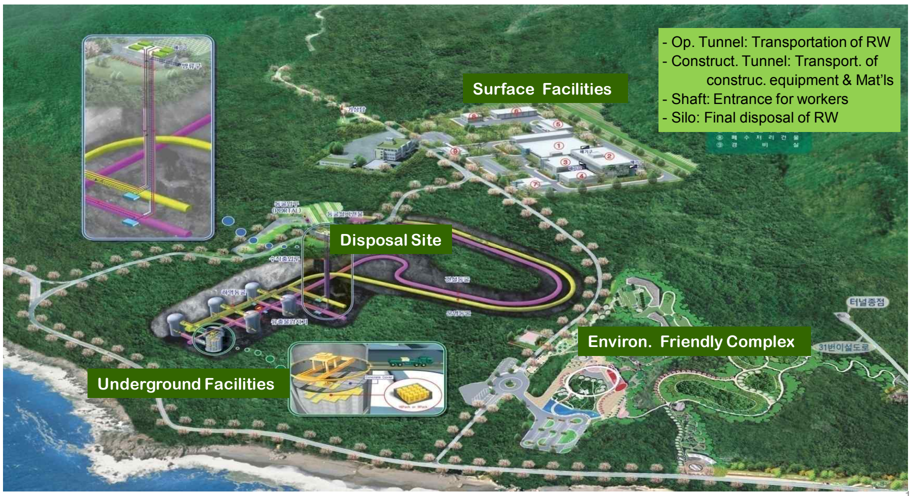

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LILW Disposal Facility Construction

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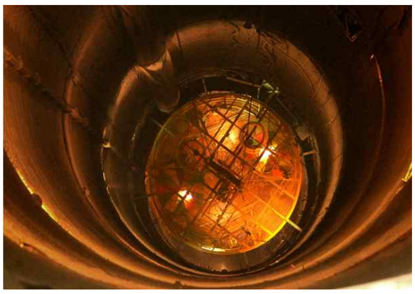
- Project Approval by MKE(2007.7)
- Const. & Op. License of MEST (2008.7)
- Operation (2014.6)


[Portal]


[Shaft Entrance]

19

LILW Disposal Facility Construction

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- **Overall Progress Rate : 87.9% (August, 2012)**

- **Operation Tunnel**

Excavation rate: 100% (1,415m/1,415m)

- **Construction Tunnel**

Excavation rate: 100% (1,950m/1,950m)

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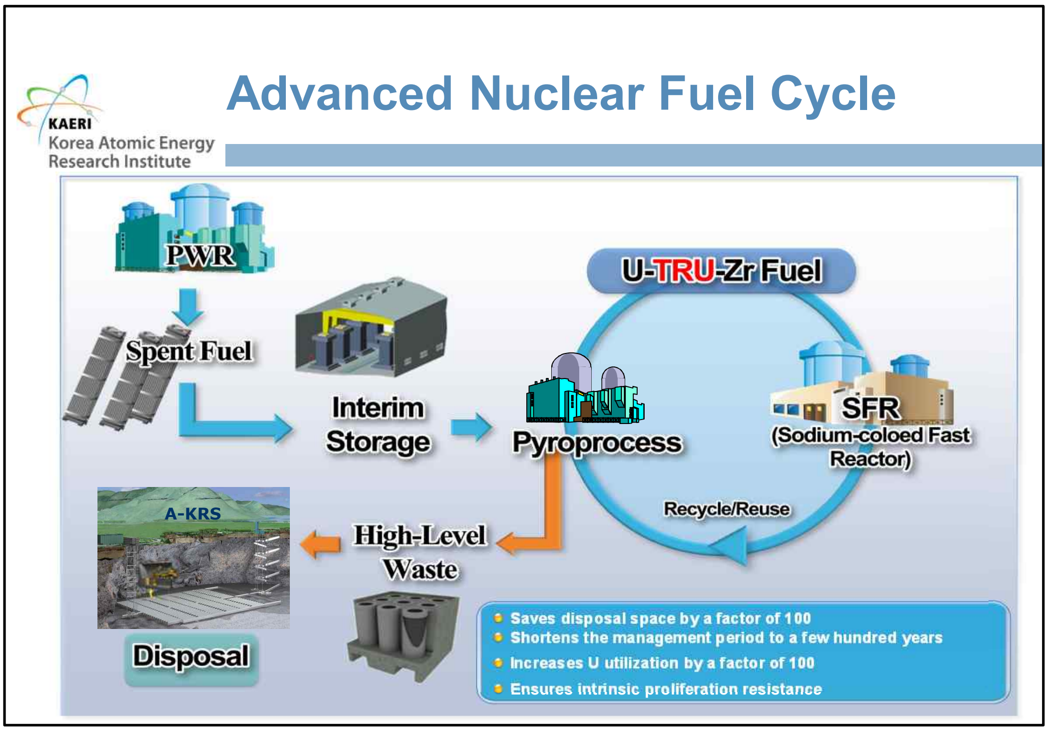
4 R&D Activities for HLW Disposal

21


Advanced Nuclear Fuel Cycle
KAERI
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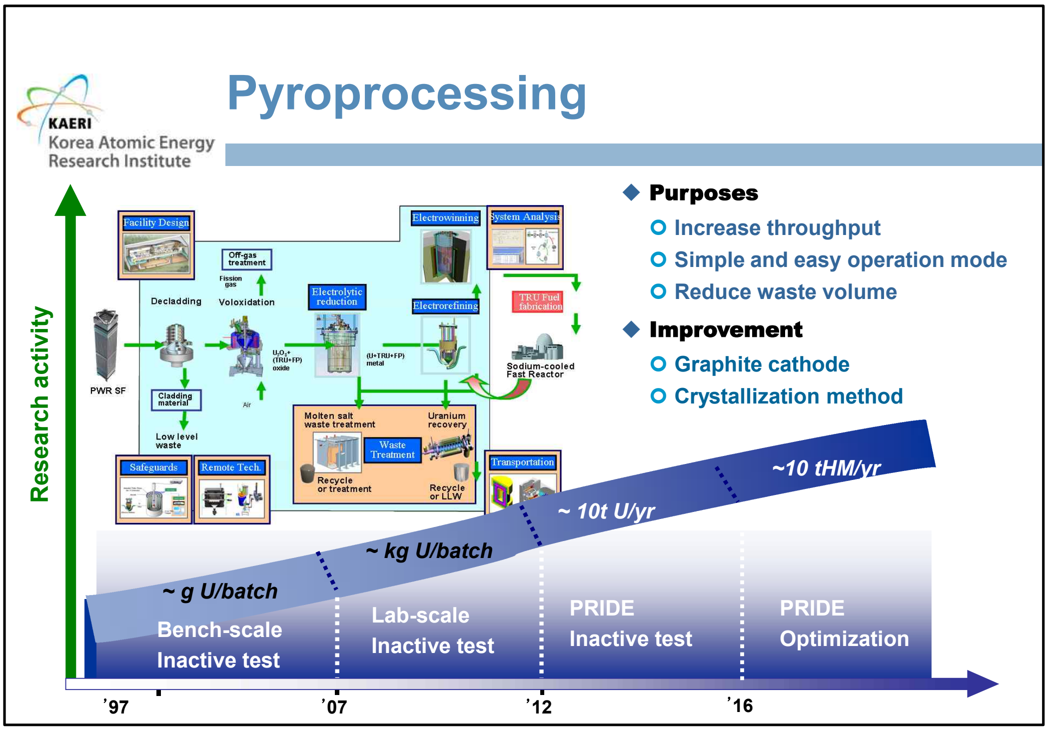
PWR
Spent Fuel
Interim Storage
Pyroprocess
U-TRU-Zr Fuel
SFR
(Sodium-coloed Fast Reactor)
Recycle/Reuse
High-Level Waste
A-KRS
Disposal
Saves disposal space by a factor of 100
Shortens the management period to a few hundred years
Increases U utilization by a factor of 100
Ensures intrinsic proliferation resistance


Pyroprocessing
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Purposes
Increase throughput
Simple and easy operation mode
Reduce waste volume
Improvement
Graphite cathode
Crystallization method
Research activity
Facility Design
Decladding
Voloxidation
Electrolytic reduction
Electrowinning
Electrorefining
System Analysis
TRU Fuel fabrication
Sodium-cooled Fast Reactor
PWR SF
Safeguards
Remote Tech.
Waste Treatment
Transportation
~ g U/batch
~ kg U/batch
~ 10t U/yr
~10 tHM/yr
Bench-scale Inactive test
Lab-scale Inactive test
PRIDE Inactive test
PRIDE Optimization
'97
'07
'12
'16

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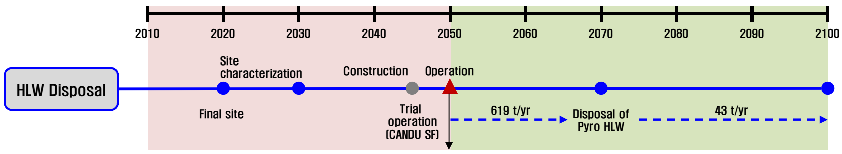
Current Activities for HLW Management Programme

- Formulating **long term management programme** for spent nuclear fuel
  - Strategies for interim storage and final disposal policies including time table, budget, and R&D programme



- Preliminary studies on construction of **deep URL and knowledge management system**
- Korea and the United States started a **10yr feasibility study on pyro-processing technology.**
- For international collaborations, **KAERI and SNL** has carried out the applied study on the **spontaneous potential method** since 2010, which will give an idea to indicate the conducting features in fractured rock mass.

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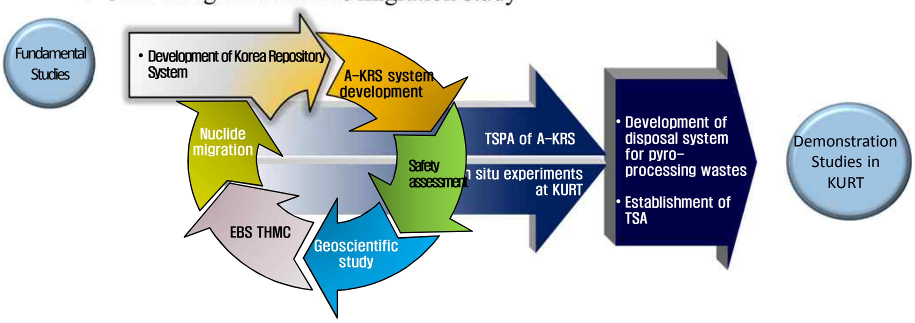
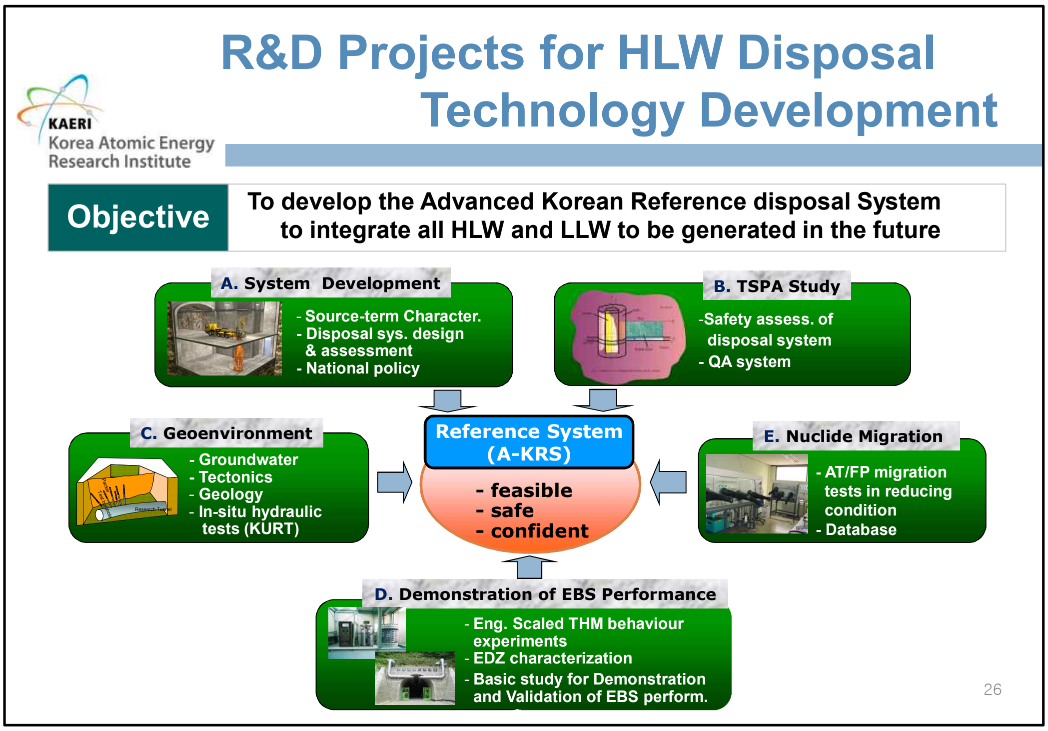
KAERI R&D Program for HLW Disposal Technology Development

1997 — 2007 — 2012 — 2016

- **For developing an appropriate advanced fuel cycle, KAERI is developing a HLW disposal technology as follows:**
  - conceptual design of an advanced geological disposal system
  - development of safety assessment methodologies
  - characterization of a deep geological environment around KURT facility
  - EBS design and nuclide migration study




R&D Projects for HLW Disposal Technology Development
KAERI
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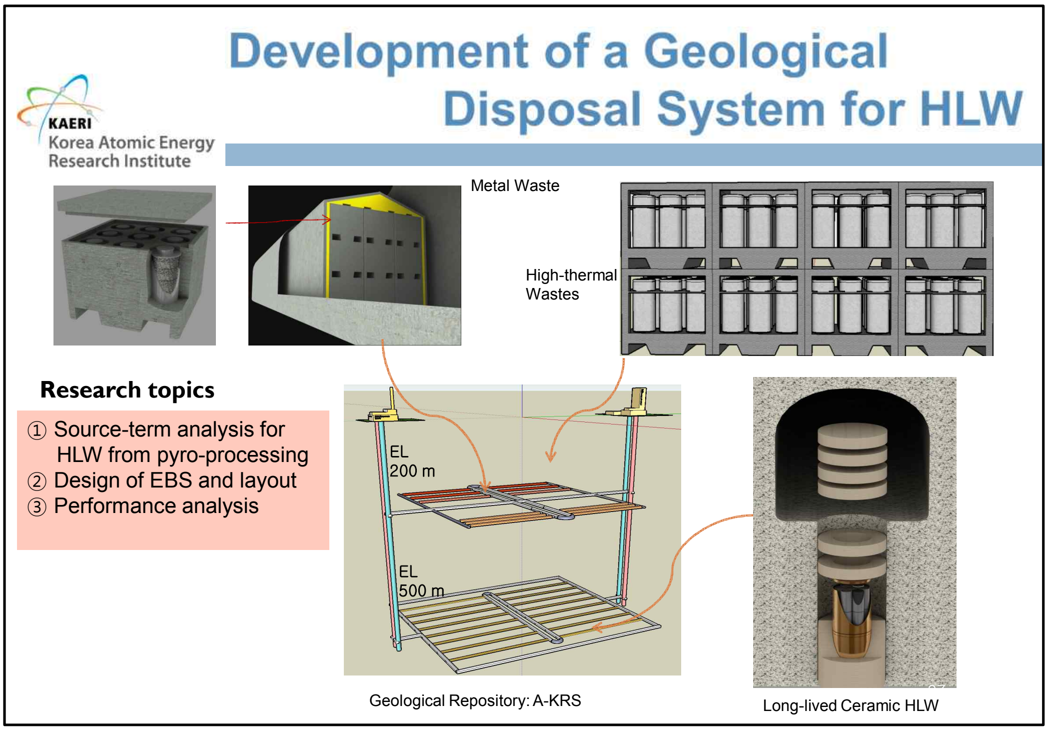
Objective
To develop the Advanced Korean Reference disposal System to integrate all HLW and LLW to be generated in the future
A. System Development
- Source-term Character.
- Disposal sys. design & assessment
- National policy
B. TSPA Study
-Safety assess. of disposal system
- QA system
C. Geoenvironment
- Groundwater
- Tectonics
- Geology
- In-situ hydraulic tests (KURT)
Reference System (A-KRS)
- feasible
- safe
- confident
E. Nuclide Migration
- AT/FP migration tests in reducing condition
- Database
D. Demonstration of EBS Performance
- Eng. Scaled THM behaviour experiments
- EDZ characterization
- Basic study for Demonstration and Validation of EBS perform.
26


Development of a Geological Disposal System for HLW
KAERI
Korea Atomic Energy Research Institute
Metal Waste
High-thermal Wastes
Research topics
① Source-term analysis for HLW from pyro-processing
② Design of EBS and layout
③ Performance analysis
EL 200 m
EL 500 m
Geological Repository: A-KRS
Long-lived Ceramic HLW

Integrated SA of the A-KRS

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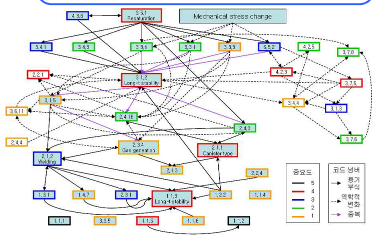
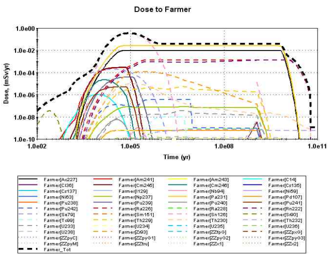
Research topics

① Development of the scenarios for the post-closure safety assessment
② Post-closure safety assessment of the A-KRS
③ Operational safety assessment of the A-KRS using the PSA tools.

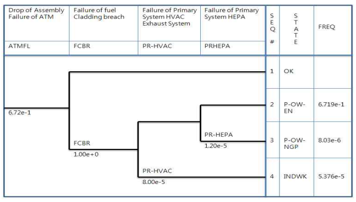
Development of the scenarios



Post-closure safety assessment



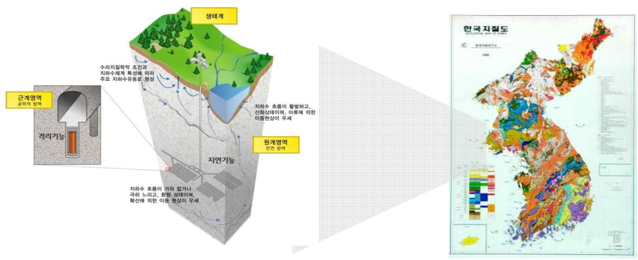
Operational safety assessment



Geological Environment Assessment of Korean peninsular

KAERI Korea Atomic Energy Research Institute

- **Korea Radioactive Waste Management Cooperation started R&Ds related on**
  - Interim storage for spent fuel (from 2009)
  - Siting for deep geological disposal (from 2010)
- **Objectives**
  - To understand long-term stability of geological environment
  - To provide basic data for understanding of deep environment
  - To support the establishment of siting program



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Thank you

30

Miloš KOVÁČIK
EN-GEO Consult, Ltd.

Igor SLANINKA
Geological Survey of Slovak Republic

Jozef PRÍTRSKÝ
DECOM, a.s.

Development of Geological Repository of HLW in Slovakia

(status, year 2012)

Prague, Czech Republic
24-27 September 2012

1

Deep Geological Repository in Slovakia
(original plans)

- Research, development, exploration, design activities
- 1996-1998 Phase I (screening of the whole territory)
- 1998-2001 Phase II (site selection and characterization)
- 2004-2007 Phase III (selection of 2 sites)
- 2008-2012 Phase IV (selection of one preferred site)
- 2012-2030 Phase V (design documentation, site licensing, permit)
- 2030 Beginning of construction (construction permit)
- 2030-2055 Construction
- 2037-2095 Operation
- 2057-2095 Successive partial closure
- 2095-2103 Final closure

Prague, Czech Republic
24-27 September 2012

2

R & D for a Deep Geological Repository in Slovakia

- **Research, development, exploration, design activities** (coordinated by Decom Slovakia, Ltd.,1996-2001, based on initial study of Nuclear Research Institute, Plc. Prague-Rez, 1993)
  - Design and implementation (EGP Invest, Ltd., Uhersky Brod, Czech Republic and Energoprojekty, Plc., Bratislava)
  - Source term (Nuclear Research Institute, Plc., Prague, Czech Republic)
  - Near field (Nuclear Research Institute, Plc., Prague, Czech Republic)
  - Far field (Geological Survey of Slovak Republic, Bratislava)
  - Siting (Geological Survey of Slovak Republic, Bratislava)
  - Safety analyses (Nuclear Power Plants Research Institute, Plc., Trnava, Slovak Republic)
  - Public involvement (AEA Technology, Harwell, U.K. and Decom Slovakia, Ltd., Trnava, Slovak Republic)
  - Legislation (Decom Slovakia, Ltd., Trnava, Slovak Republic)
  - Quality assurance (Decom Slovakia, Ltd., Trnava, Slovak Republic), and
  - Coordination (Decom Slovakia, Ltd., Trnava, Slovak Republic)
- **Geological research of crystalline environs** (Geological Survey of Slovak Republic, 2001-2002)
- **Research of site selection in sedimentary environs** (Geological Survey of Slovak Republic in cooperation with IAEA, SCK-CEN, Tractebel, 2001-2012)
- **Site characterization methodology of sedimentary environs** (Geological Survey of Slovak Republic, 2007-2012)

Design and Implementation (1996-2001)

- **Technical design for two hypothetical sites (sedimentary and crystalline)**
- **Conceptual ideas (transportation, reception of spent fuel and HLW, encapsulation, conditioning, manipulation, transportation, emplacement of containers, control systems, etc.)**
- **Preliminary safety, technical, and economic requirements for implementation, time scale**
- **Analysis of the need for an underground laboratory (generic or confirmation)**
- **Preliminary feasibility study**

Source Term
(1996-2001)

- Study of:
  - physical and chemical properties of spent-fuel assemblies
  - mechanisms of radionuclide release (from spent fuel and vitrified/cemented forms)

Prague, Czech Republic
24-27 September 2012

5

Near Field
(1996-2001)

- **Modelling of engineered-barrier and container**
- **Assessment of physical and chemical properties of sealing materials for closure**
- **Radionuclide migration and retardation in engineered barriers**
- **Transport characteristics of the critical group of radionuclides.**
- **Proposal of a disposal container**

Prague, Czech Republic
24-27 September 2012

6

Far Field
(1996-2001)

- Analysis of groundwater flow mechanism (in saturated and unsaturated environments)
- Modelling of dissolved substances transport
- Coupled processes
- 3-D models of potential sites

Prague, Czech Republic
24-27 September 2012

7

Siting
(1996-2001)

- Screening of the territory of Slovakia
- Site selection
- Site characterization

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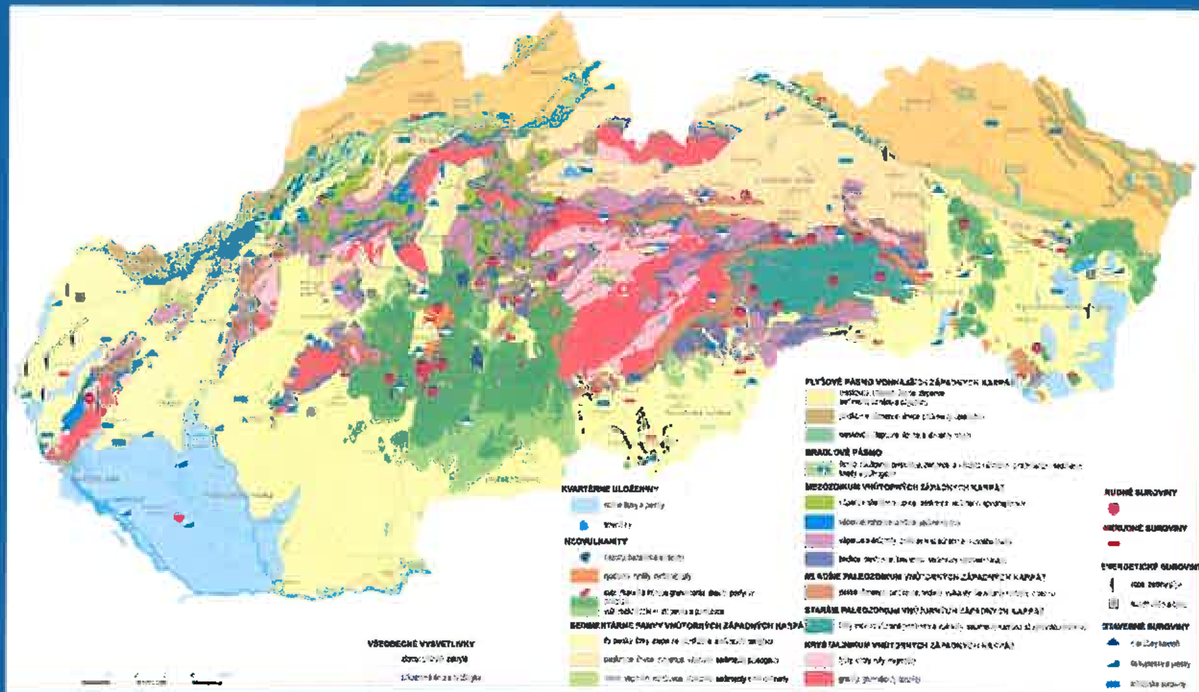
24-27 September 2012

8

Geology of Slovakia



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9

Main litological types of rocks of the Western Carpathians

- **Magmatic and metamorphic rocks** (Paleozoic and older)
- **Carbonate rocks** (Mesozoic)
- **Flysch sequences** (Tertiary - Paleogene)
- **Molase sediments** (Tertiary - Neogene)
- **Volcanics** (Neogene)
- **Quaternary deposits**

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24-27 September 2012

10

Requirements to the host rock

- Long-term safety over the lifetime of the repository
- Favourable hydrogeological conditions
- Lithological a tectonic homogeneity
- Neotectonic stability
- Absence of raw potential raw materials
- „Technical" parameters of rock mass

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24-27 September 2012

11

Prospecive host rocks for a geological repository in Slovakia

- Granitoid rocks: granite, tonalite, granodiorite, etc.
- Argillaceous rocks: siltstone, claystone, mudstone, etc. (Schecen schlier, Ciz Formation)

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12

Hard rocks

(granitoid rocks of Palaeozoic age)

- **Large horizontal and vertical rock bodies**
- **Neotectonic stability**
- **Lack of mineral resources**
- **Lithological and structural homogeneity ???**
- **Hydrogeological conditions (permeability only along discontinuities) ???**
- **Favourable engineering geological, termophysical and technological properties**

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13

Soft rocks

(claystones, siltstones of Neogene age)

- **Large horizontal and vertical extent**
- **Absence of brittle tectonics**
- **Very low permeability ($k_f < 3.10^{-11}$ m.s^{-1})**
- **Absence of mineral resources**
- **Homogeneity of properties**
- **Less suitable engineering geological, termophysical and technological properties**
- **Good sorption propreties**
- **Reduction conditions**
- **„Predictable" rock environment**
- **Low energy of relief**
- **Presence of geodynamic phenomena (landslides, erosion)**
- **Deep groundwaters of Na-Cl type**

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24-27 September 2012

14

Positives and negatives of granitoid rock environs in Slovakia

- Stable rock environs
- Low dynamics of the area
- Favourable mechanical and termophysical properties
- Standard technology of construction
- Proximity to the waste source

- Lithological heterogeneity
- Hydrogeological conditions
- Tectonic deterioration
- No exact data from deeper horizons

Prague, Czech Republic
24-27 September 2012

15

Positives and negatives of argillaceous rock environs in Slovakia

- Hydrogeology
- Homogeneity
- No brittle tectonics
- Good retention properties
- „Predictable" rock environs

- Technological quality of rock
- Geodynamic phenomena (landslides, gully erosion)
- Occurrence of CO_2 emanations and mineral waters not far from site (Ciz spa)
- Closeness to the state border

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24-27 September 2012

16

Prospective areas for a HLW repository within Slovakia

- Central part of the Tribeč Mts. (48,6 km^2)
- Southern part of the Veporské vrchy Mts. (77,7 km^2)
- Soutwestern part of the Stolické vrchy Mts. (24,2 km^2)
- Eastern part of the Cerová vrchovina Uphills (87,0 km^2)
- Western part of the Rimavská kotlina basin (85,2 km^2)

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24-27 September 2012

17

Geological studies performed and data gathered

- **Geology** (mapping, drilling, geophysical measurements, lab testing)
- **Hydrogeology**
- **Geochemistry and hydrogeochemistry**
- **Engineering geology** (properties of rocks, soils)
- **Seismicity and Neotectonics** (GPS field measurements)
- **Geomorphology** (geological processes)

Prague, Czech Republic
24-27 September 2012

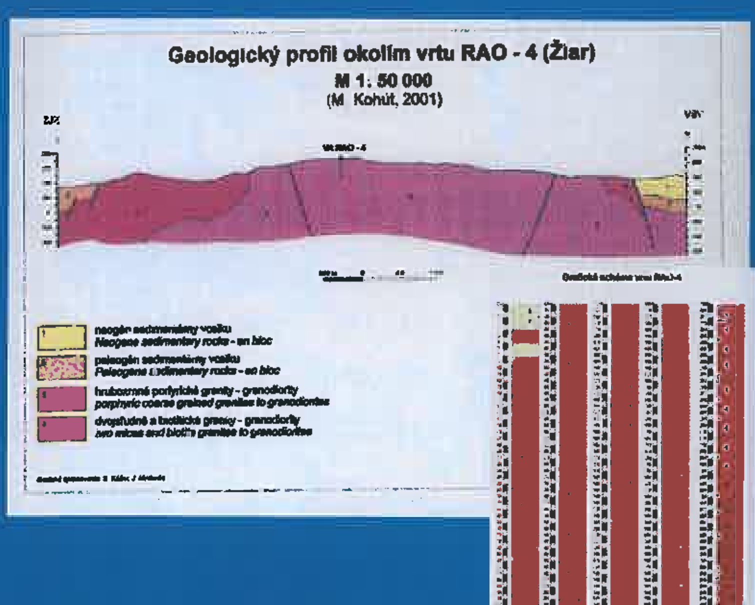
18

Driling and sampling

Prague, Czech Republic
24-27 September 2012

19

Borehole RAO-4 in the Žiar mountains



Prague, Czech Republic
24-27 September 2012

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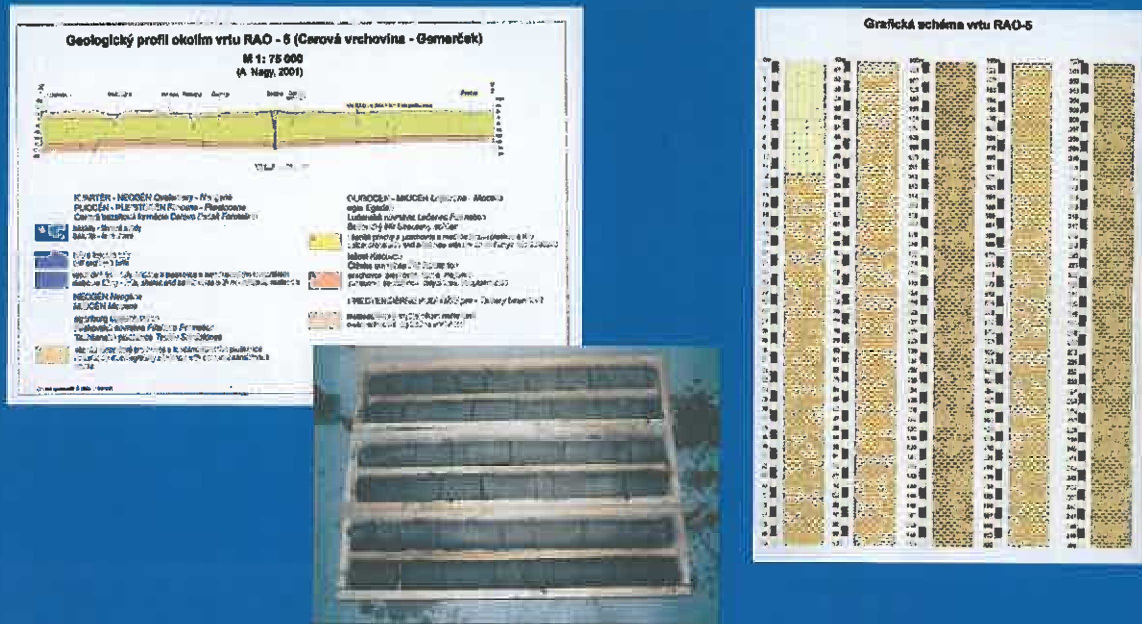
Borehole RAO-5 in the South Slovakian Basin



Conclusions

- Almost nothing has been made since 2001
- The „tip of the day" is to restart the programme
- To decide the rock type is the most urgent task (in respect of PA, SA, etc.)
- To assess intuitively rather than rationally - argillites seem to be more „favourable" (more „predicitive" environment)
- Repository available in year 2037 is an unrealistic plan
- An international solution is not excluded
- The decissive factor - public acceptance

RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

THE STATUS REPORT OF THE SITUATION ON THE POLISH NUCLEAR ENERGY PROGRAM

MARCIN BANACH

„Scientific Visit on Crystalline Rock Repository Development Program……" PRAGUE, Czech Republic: 24-27 September 2012.

RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

Basic documents of the Polish Nuclear Energy Program

- Resolution of the Council of Ministers dated on 13 January 2009, on the measures taken for the development of nuclear energy.
- Council of Ministers dated on 12 May 2009, on the establishment of the Government Plenipotentiary for Polish Nuclear Energy, submitted by the Minister of Economy.
- "General activity schedule for the nuclear energy" dated on 11 August 2009, accepted by the Council of Ministers
- "Energy policies of Poland to 2030", accepted on 10 November 2009 by the Council of Ministers
- „Polish Nuclear Energy Program ", it is supposed to be accepted by the Council of Ministers upon completion of cross-border consultation

„Scientific Visit on Crystalline Rock Repository Development Program……" PRAGUE, Czech Republic: 24-27 September 2012.

RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

Polish Nuclear Energy program (Subcjects)

- Goals and schedule of Polish Nuclear Energy Program
- Nuclear power in the context of long-term energy policy
- Cost analysis and economic justification for the development of nuclear energy
- Organization of the works on the implementation of the PNE Program
- Providing conditions for the safe use of nuclear energy
- The costs of implementation and funding source of the PNE Program
- The choice of location
- Preparation and amendment of the national transmission system
- Environment protection
- Technical support and researches for PNE program
- Security of nuclear fuel supply
- Economy and management of radioactive materials at various stages of the nuclear fuel cycle
- Participation of the domestic industry in the PNE program
- Public consultation and public information process related to preparation and implementation of the PNE program

„Scientific Visit on Crystalline Rock Repository Development Program......" PRAGUE, Czech Republic: 24-27 September 2012.

RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

- The independent administration authority acting as the Polish Nuclear Regulatory Body - PAA (from 2014 Nuclear Regulatory Commission)

- **Department of Nuclear Energy at the Ministry of Economy** subordinate to the minister of the economy, his main task is to assist the Ministry in the creation and coordination of the development strategy of nuclear energy

- **Radioactive Waste Management Plant (ZUOP)** - a leading institution in the field of executive management of radioactive waste. A significant part of the costs of operation with spent fuel and radioactive waste produced by nuclear power plant will be covered by the operator (the investor).

- **Investors**, and after the start of their operation **Operators,** are operators with the experience and knowledge necessary to build and operate such facilities, and adequate financial resources.

„Scientific Visit on Crystalline Rock Repository Development Program......" PRAGUE, Czech Republic: 24-27 September 2012.

RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

The Ministry of Economy is responsible for the implementation of nuclear energy program in Poland.

THE MINISTRY OF ECONOMY

The Minister is responsible for:

- operation of the national energy systems, taking into account the principles of rational economy and energy security needs of the country;

- activities related to the use of atomic energy for socio-economic needs of the country;

-control of the foreign trade in goods, technologies and services of the strategic importance for national security

-maintenance of the international peace and the security in connection with the international agreements and obligations;

-implementation of the administration of foreign trade in goods and services, as well as import and export matters of technology.

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

NATIONAL ATOMIC ENERGY AGENCY

was designated to the role of the Regulatory Body and the nuclear regulatory control in the field of nuclear power plants development in the country.

President of the National Atomic Energy Agency is responsible for:

- preparing projects of documents concerning the politics of the state in ensuring the nuclear safety and the radiological protection, taking into account development program of the nuclear energy production, and internal and external threats;

- exercising regulatory control and supervision over the activities leading to actual or potential ionizing radiation exposure of humans and environment, including the issuance of decisions on licences and authorizations and other decisions, as provided in this Act,

- performing the tasks resulting from the obligations of the Republic of Poland concerning accountancy and control of nuclear materials, physical protection of nuclear materials and facilities, special control measures for foreign trade in nuclear materials and technologies, and from other obligations resulting from international agreements on nuclear safety and radiological protection,

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

RADIOACTIVE WASTE MANAGEMENT PLANT (ZUOP)

ZUOP is the State-owned Public Utility, responsible for the management of the radioactive waste and nuclear material in Poland; ZUOP is the only operator of existing surface radioactive waste repository and will be responsible for new surface radioactive waste repository and a deep geological radioactive waste repository in the future.

The Radioactive Waste Management Plant is the only institution in Poland authorized for management and storage of radioactive waste and spent nuclear fuel.

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

ACTIVITY OF RWMP

- Storage and disposal of radioactive waste, spent nuclear fuel and nuclear materials, radioactive sources and other radioactive substances,

- Seeking new locations and design of the facilities for storage and disposal of radioactive waste, and spent nuclear fuel and nuclear materials, radioactive sources and other radioactive substances,

- Keeping computed inventory – according to international safeguards rules - of collected, processed, stored and disposed radioactive waste, spent nuclear fuel and nuclear materials, spent radioactive sources (SRS) and other radioactive substances,

- Development of radioactive waste processing technology and storage methods of nuclear materials, radioactive sources and other radioactive substances, and testing of prototype devices and experimental installations planned to be implemented in this regard,

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

ACTIVITY OF RWMP

- Development of technologies for preparation of spent nuclear fuel for storage and disposal purpose,
- Decontamination of facilities, contaminated installations and equipment, commissioned by users of radioactive sources and nuclear materials,
- Recovery of the environment and infrastructure after radiation accidents,
- Activity related to decommissioning of nuclear facilities and final closure of radioactive waste repositories,
- Conducting training, information activities concerning issues of management and storage of radioactive waste, spent nuclear fuel, nuclear materials, radioactive sources and other radioactive substances, for the needs of their users and general public.

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

Finance resourses

According to Article 114 of the Atomic Law to ensure proper management of radioactive waste and spent fuel and to secure financing of cost for management and disposal of spent fuel and radioactive waste, including waste from decommissioning, a State-owned public utility named "Radioactive Waste Management Plant" located in Otwock - Świerk, was established for conducting the activities involving radioactive waste management and spent nuclear fuel management, and – above all – for the activities ensuring permanent feasibility of radioactive waste and spent nuclear fuel disposal.

The plant shall receive from national budget an allocated subsidy shall be established in budgetary legislation, on the request from the minister of the Economy.

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

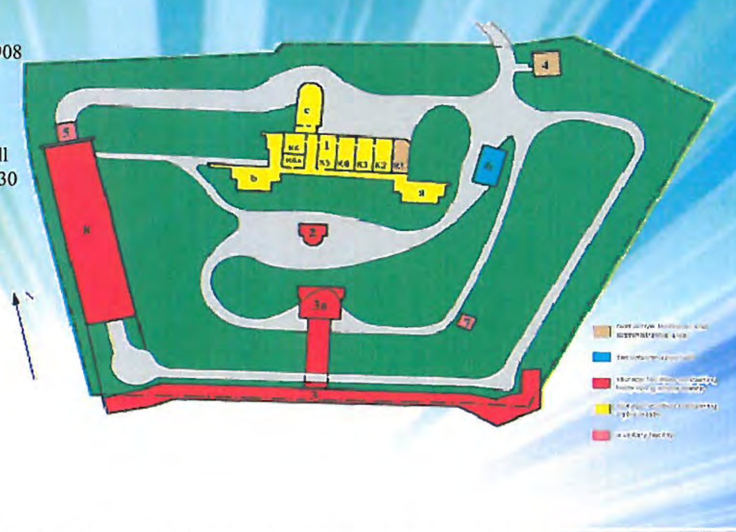
Acivity in 2011

	I Quarter	II Quarter	III Quarter	IV Quarter	2011 Year
Amout of solid radioactive waste received [m³],	*11,14*	*12,45*	*16,70*	*7,79*	48,09
Which inlcudes:					
- Low level radioactive waste	11,14	12,45	16,70	7,79	48,09
- Intermediate level radioactive waste	0,00	0,00	0,00	0,00	0,00
Amout of liquid radioactive waste received [m³]	0,04	4,10	22,00	0,02	26,16
Including:					
- Low level radioactive waste [m³]	0,04	4,10	22,00	0,02	26,16
- Intermediate level radioactive waste [m³]	0,00	0,00	0,00	0,00	0,00
Amount of radioactive waste processed [m³]	3,40	8,15	8,40	6,40	26,35
Solid waste	*1,40*	*7,55*	*8,40*	*0,00*	17,35
Liquid waste	2,00	0,60	0,00	6,40	9,00
Amount of dismantled smoke detectors [pcs]	4 268	3 524	1 883	5 830	15 505
Amount of the radioactive waste sent to the National Radioactive Waste Repository Plant					
Total Volume [m³]	12,60	13,85	10,80	15,13	52,38

RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

National Radioactive Waste Repository is located in one of the old military forts, built by the Russian army between 1905 - 1908. Waste storage facilities consist of the concrete objects of the fort, partially covered with soil (objects No. 1, 2, 3 and 3a) and part of the eastern dry moat (object No. 8).

- Near surface repository type
- Situated on ex-military fort built in 1905-1908
- Covering an area of 3,045 ha
- Four concrete objects, with the roof and wall thickness of 1.2 to 1.5m and the floor layer of 30 cm
- West moat is also used as a disposal facility
- Groundwater level at the depth of 15-20m



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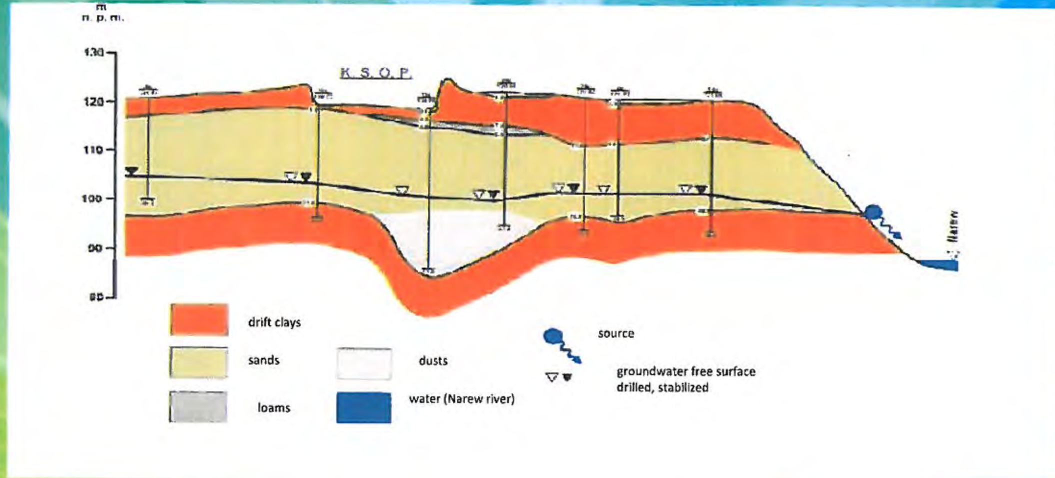
RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND



Groundwater can be found under a layer of clay with a very small permeability and a layer of soil with sorption properties at the depth of several meters below the repository. The composition of the substrate effectively prevents the migration of waste which, due to adverse events, could penetrate the soil and continue to spread in an uncontrolled manner by groundwater.

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

SPENT NUCLEAR FUEL IN POLAND

EK-10 fuel assembels (EWA REACTOR), used over forty years ago in the Ewa reactor. Enrichment in U-235 of this fuel (fresh) was 10%, it was used when the thermal power of this reactor was limited to 2 MW.

WWR-SM and WWR-M2 (EWA REACTOR) used in Ewa reactor, tubular strusture, made possible to raise thermal power of the reactor up to 8 MW, and to 10 MW in the next years. Enrichment level of that fuel was 36%.

MR-5 and MR-6 (MARIA REACTOR) used from the beginning of its life. The tubular structure of MR-5 and MR-6 fuel (but different from the WWRs), enriched to 80%, and at present 36%, made possible to rich reactor power up to 30 MW and high neutron flux $4x10^{18}$ n/m^2 s. Ultimately that reactor will use new fuel, enriched to 19,5% (some problems with the reactor conversion to the new type of fuel will be solved in 2012).

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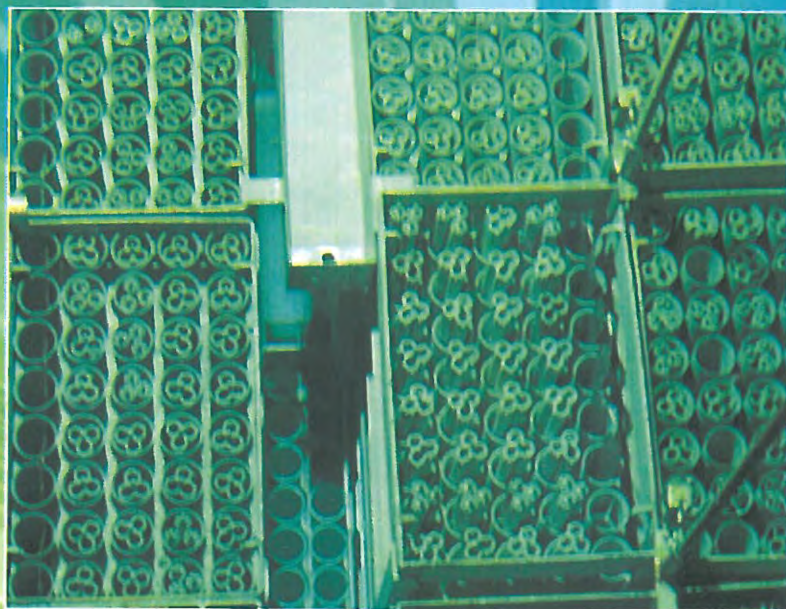
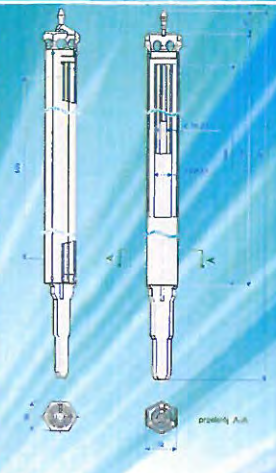
RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND





Diameter of the fuel element of the WWR type.

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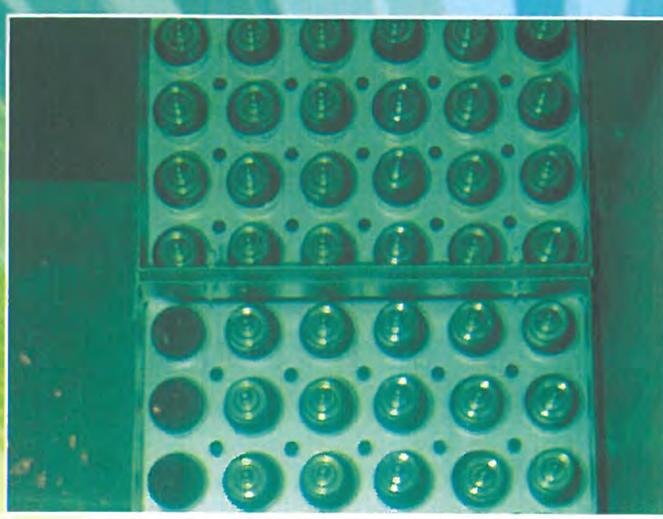
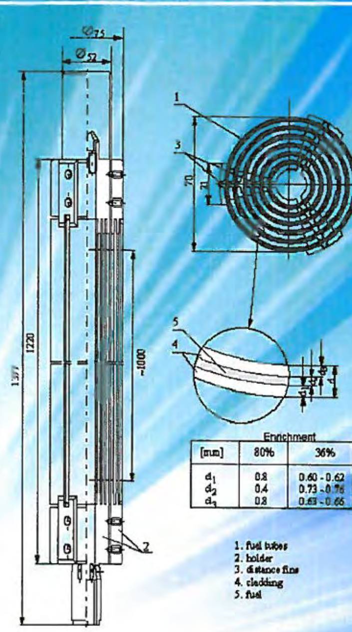
RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

Encapsulated Maria reactor fuel in the storage pool





[mm]	Enrichment 80%	Enrichment 36%
d_1	0.8	0.60 - 0.62
d_2	0.4	0.73 - 0.76
d_3	0.8	0.63 - 0.66

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

Because the EK-10 fuel type was stored in the water pool for the period over 40 years, the rust on the surface appeared, therefore we decided to encapsulate all the fuel rods.

EK-10 fuel rods

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

GTRI - Reducing Nuclear Threats

GTRI Program carried out in years 2010 - 2012 and included 6 transports of the spent nuclear fuel.

Date of transport	Fuel type	Type and amount casks		Amount nuclear fuel assembles
2010-09-12	WWR	VPVR/M	16	856
2010-02-27	WWR	VPVR/M	8	348
	MR	TUK-19	20	80
	WWR+MR			428
2010-05-08	MR	TUK-19	20	80
2010-07-24	MR	TUK-19	20	80
2010-09-25	MR	TUK-19	20	80
2012-09-??	EK10	VPVR/M	3	2595
	MR	TUK-19	15	60
Total amount nuclear fuel assembles:				4179
			In it WWR:	1204
			In it MR:	380
			In it EK-10:	2595

RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

RWMP POLICY GOALS (FUTURE PLANS)

✓ There are existing potential sites within the Polish territory for a future deep geological repository, which is prerequisite for final disposal of spent nuclear fuel as high level radioactive waste. Plans for possible construction of a **deep repository** will be taken into account when the fuel cycle will be determined and the first nuclear power unit in Poland will start. Poland is currently trying to gain experience in other countries, as well as to train future personnel.

✓ Undertaking the research works on the deposit of homogenous clay rocks, salt dams, which fulfill siting criteria for **deep repository**.

✓ Construction of a new **surface disposal of radioactive waste** in accordance with the Polish energy program should be completed by 2020,

✓ To close of the National Radioactive Waste Repository by 2020, and transport all of long-lived waste to a **new surface repository**.

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

Polish Nuclear Energy Program (Program PEJ)

Stage I - up to 30.06.2011:
development and acceptance by the Council of Polish nuclear energy program, acceptance and entry into force legislation necessary for the development and operation of nuclear power;

Stage II - 1.07.2011 - 31.12.2013:
determine the location and the conclusion of a contract for construction of the first nuclear plant

Stage III - 1.01.2014 - 31.12.2015:
technical project and obtaining required arrangements;

Stage IV - 1.01.2016 - 31.12.2020:
building permission and build the first block of the first nuclear power plant, start to build more blocks;

Stage V - 1.01.2021 - 31.12.2030:
Construction and start build next blocks / nuclear power plants

Government Plenipotentiary for nuclear power is supervisor of the program implementation

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

Stage II - 1.07.2011 - 31.12.2013:
determine the location and the conclusion of a contract for construction of the first nuclear plant

In 2009 we were selected 28 potential locations for nuclear power plants.

In 2010, list of potential location for a nuclear power plant meeting criteria was performed on ask of the Ministry of Economy. Based on these criteria and approaches to research methodology and procedures, rank of 27 locations was created.

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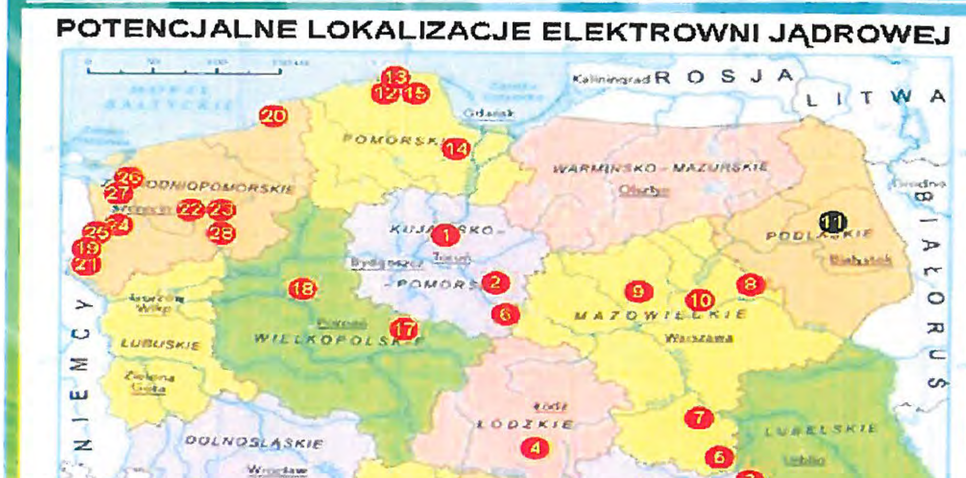
RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

POTENCJALNE LOKALIZACJE ELEKTROWNI JĄDROWEJ



Lp	Lokalizacja	Województwo	Lp	Lokalizacja	Województwo
1	Chełmno	Kujawsko-Pomorskie	16	Połaniec	Świętokrzyskie
2	Nieszawa		17	Pątnów	Wielkopolskie
3	Gościeradów	Lubelskie	18	Warta-Klempicz	
4	Bełchatów	Łódzkie	19	Dębogóra	Zachodnio Pomorskie
5	Chotcza	Mazowieckie	20	Kopań	
6	Karolewo		21	Krzymów	
7	Kozienice		22	Krzywiec	
8	Małkinia		23	Lisowo	
9	Nowe Miasto		24	Pniewo	
10	Wyszków		25	Pniewo Krajnik	
11	Brak wskazania	Podlaskie	26	Stepnica 1	
12	Choczewo	Pomorskie	27	Stepnica 2	
13	Lubiatowo-Kopalino		28	Wiechowo	
14	Tczew				
15	Żarnowiec				

Source: „Energoprojekt" S.A. Warszawa, marzec 2010

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

26 November 2011 Polish Energetic Grup announced that she had chosen 3 potential locations up to the first nuclear powerplant, about 3000 MW (2 or 3 energetic block):

- **localization "Choczewo" , "Gąski", "Żarnowiec"**

In the indicated locations, location and environmental analyses will be conducted by two consecutive years. Results of those surveys will allow to indicate the destination location. Choice of potential locations was preceded by many-months examinations taking such factors into account among others as properties of the area, availability of the cooling water, the natural environment, logistics and the infrastructure.

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RADIOACTIVE WASTE MANAGEMENT PLANT
OTWOCK – SWIERK, POLAND

<u>Radioactive waste repository location analysis, repository design and preparations to the construction</u>

The decree of the Minister of Economy of 27 August 2009, set up the team for the development of the National plan of radioactive waste management and spent fuel management. It includes representatives of agencies and institutions related to the management of radioactive waste and spent nuclear fuel. The team has already started work. In addition to the preparation of the National Plan there is also the task of preparing the information and proposed solutions for the Polish Nuclear Power Program.

The selection of the most suitable regions was done, with a prospect of a new near surface repository sitting. As a result of the analysis of these areas 19 sites situated in 12 communes were chosen for geological research in situ. Efforts should be continued to obtain acceptance from public and local authorities for the sitting of the repository

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RADIOACTIVE WASTE MANAGEMENT PLANT OTWOCK – SWIERK, POLAND

Potential location for future near surface repository:

1. *Batches of the rock salt;*
2. *Argillaceous rocks*
3. *Igneous rocks, granite*

5 localization market out by National Atomic Energy Agency:

- **Łanięta**
- **Damasławek**
- **Kłodawa**
- **Pogorzel**
- **Jarocin**

Potential date when the deep geological repository will be ready for use in Poland is 2075 year.

The final choice of location and type of potential deep geological repository will be possible only after establishment of nuclear power plants in Poland and determine the fuel cycle for nuclear energy in Poland.

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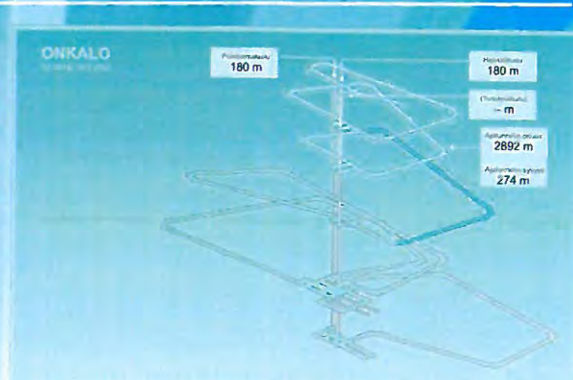
El Cabrin (Spain) Radioactive Waste Repository (source: http://www.enresa.es)



Schematic of the geologic repository research tunnel under construction at the Onkalo site near Olkiluoto Nuclear Power Plant, Finland.

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Status of radioactive waste management in LITHUANIA

Arūnas Sirvydas

Nuclear Engineering Laboratory
Lithuanian Energy Institute

Programme for the scientific visit on crystalline rock repository development
Prague, Czech Republic
24-27 September 2012

IGNALINA NPP

- There is only one nuclear power plant in Lithuania - Ignalina NPP with two units of RBMK-1500 reactors
- INPP reactors were commissioned in 1983 and 1987 respectively
- They original design lifetime was projected to 2010-2015
- Ignalina NPP was a vital component in Lithuania's energy balance because it was generating more than 70 % of the total electricity production in Lithuania
- In 2002 Government took a decision to perform "immediate dismantling" of INPP
- The first unit of INPP was shutdown in 2004, the second – 2009

Waste quantities

- Final management of existing operational and arising decommissioning radioactive waste will require disposing of:
  - 60000 m^3 of very low level short-lived solid waste
  - 100000 m^3 of low and intermediate level short-lived solid and solidified waste
  - 17000 m^3 of low level short-lived solidified bitumen compound

- In addition to already defined waste management routes an interim storage is required (until decision on final waste management technology will be taken) for:
  - 6500 m^3 (including 3000 m^3 of graphite) of low and intermediate level long-lived solid waste
  - 40000 spent sealed sources
  - 22000 of spent nuclear fuel assemblies (about 2500 tons of uranium)

- Therefore, a reliable and effective management of radioactive waste has become a key to the Lithuania's nuclear programme

3

National policy

- Lithuania has established an appropriate legislative and regulatory framework in order to ensure safety of radioactive waste management. All the legal acts concerning radioactive waste management are prepared according to the best national and international practices, including IAEA recommendations

- According to the Law on the Management of Radioactive Waste, the radioactive waste is defined as spent nuclear fuel and substances contaminated with or containing radionuclides at concentrations or activities greater than clearance levels and for which no further use is foreseen. The law defines principles of radioactive waste management

- The Strategy for Management of Radioactive Waste implements provisions of the Law and defines state policy for required changes in the existing radioactive waste management system

4

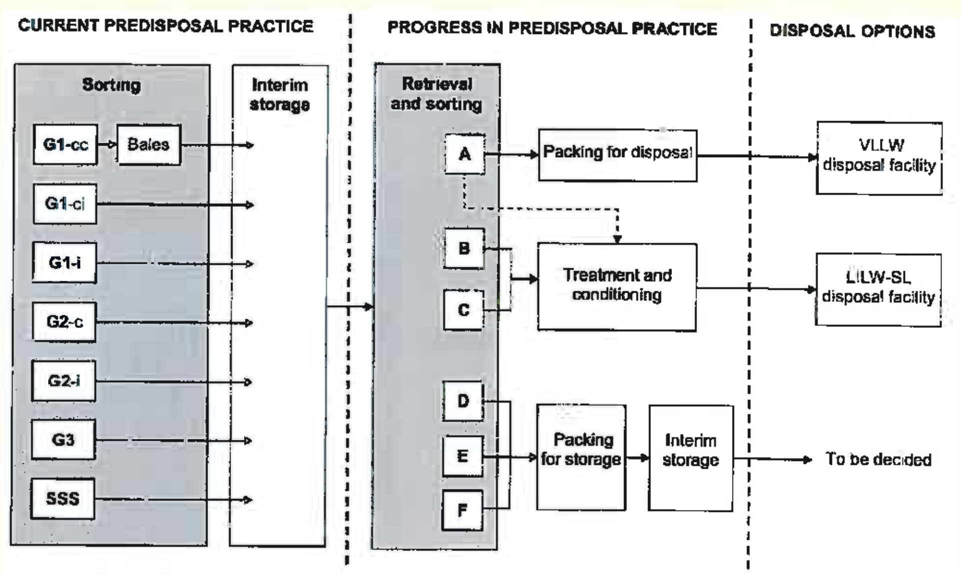
Predisposal management of solid radioactive waste (except SNF)

- All solid radioactive waste currently is stored in storage facility at the INPP site. The facility consists of four buildings
- The buildings have a total storage capacity of 29000 m^3, of which around 90% is filled today
- The radioactive waste to be stored in the existing facility is sorted into three groups (G1, G2, G3) according to activity level
- Different waste groups and categories are stored in separate compartments
- Since 1990 institutional waste from Lithuanian small producers is also stored in the facility of INPP

- The first step towards modernization of the predisposal solid radioactive waste management practice was establishing of the new waste classification system
- The new system for classification of solid radioactive waste in Lithuania is based on the anticipated waste disposal method

5

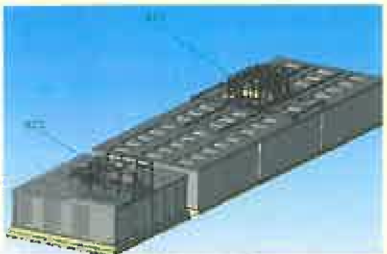
Predisposal management of solid radioactive waste (except SNF)



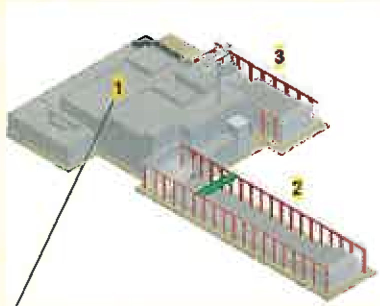
6

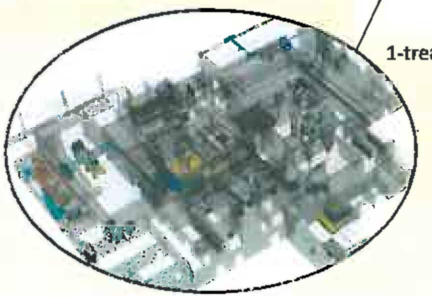
Predisposal management of solid radioactive waste (except SNF)

- The new Solid Waste Management and Storage Facility (SWMSF) will be constructed for characterization, treatment, conditioning and interim storage of the existing operational and during the INPP decommissioning generated solid radioactive waste (operation foreseen to start in 2013-2014)

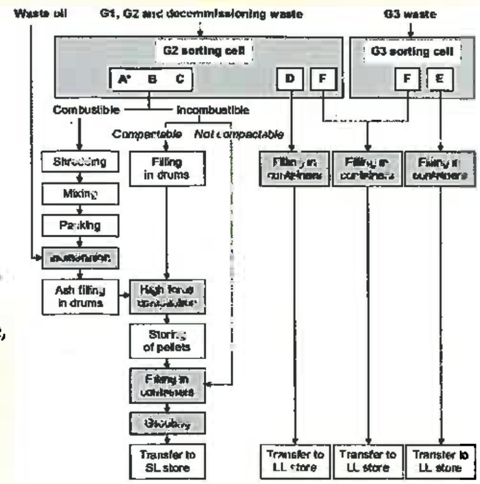


Waste retrieval from existing storages





1-treatment facility, 2-SL waste storage, 3-LL waste storage



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Waste storage

- Institutional waste storage facility at Maisiagala site
  - The facility was built in 1964 and closed in 1989 (as disposal facility)
  - The vault is only partially filled with waste (about 60% (120 m^3) of the volume)
  - The waste is inter-layered with concrete
  - In 2004-2006 safety and security of the waste storage facility was essentially upgraded
  - The facility was licensed as storage facility (i.e. it was not recognized being suitable as waste disposal facility)
  - A decision should be taken in the future when the waste shall be retrieved, sorted, characterized and disposed of or interim stored until appropriate disposal facility will become available

8

Predisposal management of solid radioactive waste (except SNF)

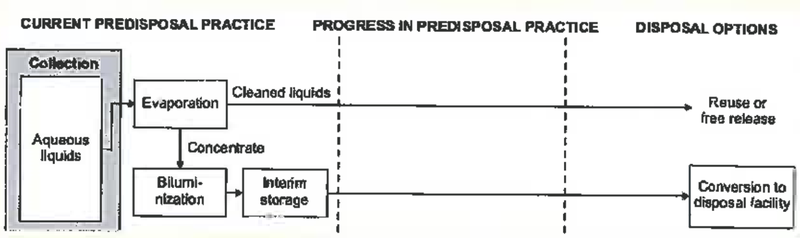
Free release measurement facility

- Regarding the clearance procedure in Lithuania, the operator shall measure waste, intended for free release, ensuring that the clearance levels are not exceeded
- Free release facility for INPP operational waste was commissioned in 2006 (not sufficient to cope with decommissioning needs)
- The new modern Free Release Measurement Facility for the INPP decommissioning waste has been commissioned in 2010 (throughput of 2.5-25 tons of material per shift).

9

Predisposal management of liquid radioactive waste at INPP

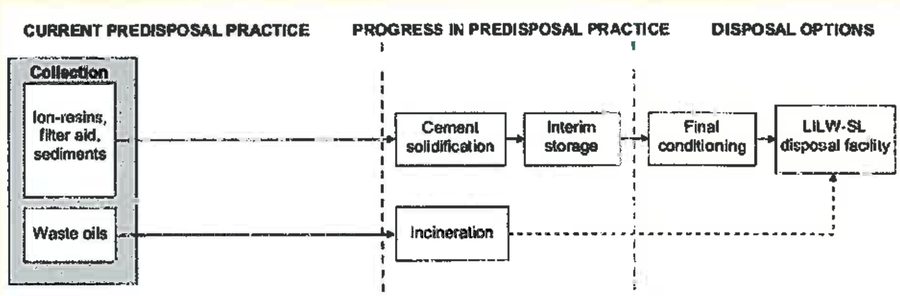
- The INPP operation, maintenance and decommissioning produced aqueous radioactive liquids, which are collected and treated in the INPP Liquid Radioactive Waste Treatment Facility (LWTF)
- Concentrates left after evaporation are solidified by mixing them with binding material – bitumen
- The bitumen compound, is then poured into the steel lined concrete vaults of the Bituminized Waste Storage Facility(Building 158) (capacity of the storage facility is up to 22800 m^3, at present filled up to about 60%)



10

Predisposal management of liquid radioactive waste at INPP

- Solidification of spent ion-exchange resins, evaporator concentrate and filter aid (Perlite))
- In the context of modernization, the INPP has installed a new Cement Solidification Facility (CSF), has constructed a new Interim Storage Building (ISB) (licence for operation of the facility received in 2006)
- Currently waste oils are collected and stored at the INPP in tanks separately
- from other waste
- Stored waste oils and generated during decommissioning will be incinerated in the new SWTF



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Predisposal management of spent nuclear fuel

- In 1992 it was decided to use dry storage technology for interim storage of SNF at the INPP
- GNB dual-purpose storage casks have been chosen
- Part of them (twenty casks) is ductile cast iron CASTOR RBMK-1500 casks and the remaining ones are metal-concrete CONSTOR RBMK-1500 casks (the existing "open air" SNF storage facility currently is filled up to its final capacity (120 casks).
- The remaining SNF will be stored in the newly built Interim Spent Nuclear Fuel Storage Facility (ISFSF) (operation foreseen in 2013-2014)
- All the SNF containers will be stored about 50 years and during this time final SNF management concept shall be developed

12

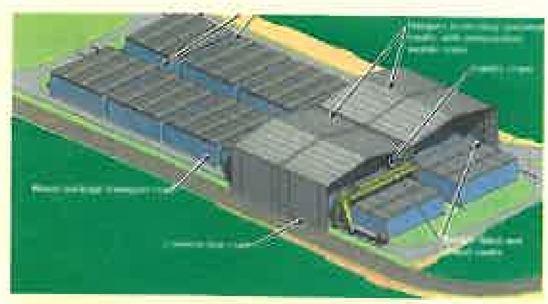
Waste disposal

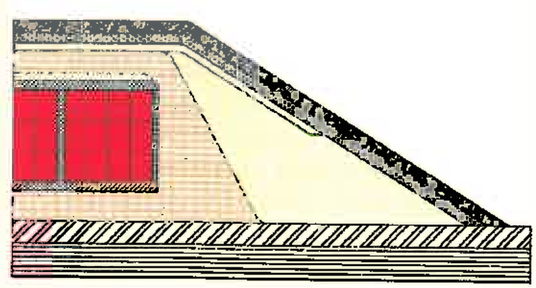
- Repository for very low level short-lived waste
  - The concept of the VLLW repository has been analyzed and proposed by Studsvik RadWaste AB basing on experience of design and operation of such facilities in Sweden
  - Activities on implementation of VLLW repository have been started in 2003
  - The INPP new VLLW repository will consist of two facilities (buffer storage and disposal units) located in two different sites
  - The VLLW buffer storage is constructed (construction finalised in 2011) in the INPP site and the disposal units will be constructed to the south from the new SWTSF and ISFSF site
  - Currently tendering documents for construction of the disposal units are under preparation

13

Waste disposal

- Repository for low and intermediate level short-lived waste
  - The reference design for repository for LILW-SL in Lithuania has been developed in 2002
  - Legislative framework was extended
  - Stabatiskes site that is very close to the INPP was finally selected (from other candidate sites) as the site for the near surface LILW-SL repository
  - Installation of the disposal facility is implemented in two stages
  - 1) The scope of the first stage includes conduction of detailed engineering-geological investigation of the site, development of the design and licensing for construction. The first stage has been started in 2009. It is expected to finish in 2013
  - 2) Availability of the disposal facility is planned in ~2018





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Waste disposal

- Disposal of bitumen compound
  - Production and interim storage of bitumen compound in Building 158 will last till end of the INPP decommissioning
  - Then, several options for safe disposal of bitumen compound could be possible:
    - Waste retrieval from its present location, packing, transfer and disposal in another facility, suitable for this type of waste
    - Conversion of the existing interim storage facility to an appropriate disposal facility without waste retrieval
  - The second option, if feasible, found to be preferable as risks, costs and technology uncertainties associated with waste retrieval, conditioning and disposal in a new location could be avoided
  - The first investigation of feasibility of the preferable option has been conducted in 1998 and the second, more detailed (incl. geological investigations, development of disposal concept, justification of long-term safety, etc.) – in 2006-2007
  - Both studies concluded that transformation of Building 158 into a repository is possible (e.g. by installation of a multilayered ground cover over the building structure)
  - Further steps (e.g. development of design and other licensing documentation) are planned to be taken at later stages of operation of bituminized waste storage facility

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Disposal of spent nuclear fuel and long-lived waste

- The Strategy for Management of Radioactive Waste indicates three potential options for management of SNF after interim storage:
  - Disposal in the national repository
  - Disposal in the EU established regional repository
  - Transfer to other country which possesses suitable SNF management technologies and can take full responsibility for management of the waste
- Investigations related to disposal of SNF and long-lived waste
  - With support of Swedish experts Lithuanian Geological Survey was working on selection of preferred geological media, on comparison of different geological formations, their characteristics, evaluation of INPP region suitability for implementation of repository
  - Lithuanian Energy Institute was working on development of the disposal concept (for clay and crystalline rock), criticality analysis of the disposal container, dose rate estimation, evaluation of temperature evolution in disposal tunnels, radionuclide migration, cost estimation and preliminary safety assessment

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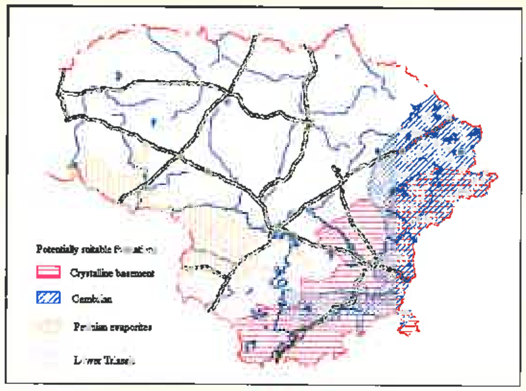
Disposal of spent nuclear fuel and long-lived waste

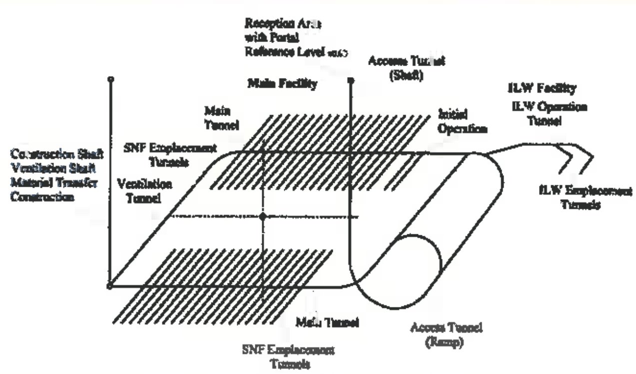
- Geological formations prioritized as prospective formations for SNF disposal in Lithuania:
  - The crystalline rocks in the southern Lithuania
  - The Lower Cambrian Baltic Group clay formation
  - The Lower Triassic clay formation



- The proposed repository concept is based on concept developed by SKB for disposal of the SNF in Sweden

Disposal of spent nuclear fuel and long-lived waste

- The main elements of the repository are:
  - an access shaft, transport tunnels
  - an array of SNF emplacement tunnels (deposition drifts)
  - emplacement tunnels for long lived intermediate level waste (activated metal structures, graphite, SSS)



- Sitting process for national repository should start at earliest in 2030 – if no changes of international policy regarding to SNF transfer to other countries and no developed of new SNF management technologies will occur

Disposal of spent nuclear fuel and long-lived waste

- The Programme for assessment of possibilities for the disposal of spent nuclear fuel and long-lived radioactive waste for the years 2008-2012 was prepared and approved in 2007
- The main purposes of this Programme are:
  - To assess possibilities for the final management of the SNF from Ignalina NPP
  - To assess possibilities for the final management of the irradiated graphite and other long-lived waste from Ignalina NPP
  - To assess possibilities for the final management of the radwaste generated by small producers and spent sealed sources
  - To analyse the tendencies in nuclear energy development and define measures necessary for management and disposal of radwaste and SNF from new NPP in Lithuania

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Disposal of spent nuclear fuel and long-lived waste

- The measures for the programme implementation are the following:
  - Analysis and synthesis of information about spent nuclear fuel and other long-lived radioactive wastes, and assessment of properties important for disposal of these types of waste
  - Analysis of possibilities for spent sealed sources and other LL waste disposal in boreholes ("Borehole disposal") and suitability study of boreholes implementation in Lithuanian geological formations
  - Updating information about disposal characteristics of SNF and long-lived radioactive waste
  - Revision of waste disposal infrastructure concept for deep and medium-deep repository
  - Development of detailed geological investigation program, development of database of geological investigation results
  - Performance of studies of geological formations in the Ignalina NPP region (in situ, laboratory tests), analysis of geological survey
  - Updating the estimation of costs related to implementation/construction of repository
  - Safety assessment of geological repository for SNF and LL waste

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Radioactive waste management strategy (2012)

- Radioactive waste management strategy (2012, draft project) foresees the following main tasks:
  - To implement Council directive 2011/70/Euroatom, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, requirements (provisions of the directive should be transferred to Lithuanian legislation)
  - Implement requirements of Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
  - Implement IAEA requirements and recommendations
  - Implement program of assessment of possibilities for the disposal of spent nuclear fuel and long-lived radioactive waste
  - Perform scientific researches, which would allow to adopt modern technologies for final treatment of SNF and LL waste (incl. graphite): asses possibility to extend storage of SNF in containers, asses SNF and LL characteristics and management possibilities, its disposal and suitable siting for this waste
  - Analyse the experience of other countries in the field of SNF and LL management
  - Prepare qualified specialists and raise qualification of the existing specialists
  - Evaluate waste quantities which could arise during operation of new NPP in Lithuania and their management costs
  - Provide relevant information to the public
  - Etc.

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Thank you

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Safe management of spent fuel and radioactive waste

Daniela DOGARU, CNCAN, Romania
Antonius GHEORGHE-SORESCU, AN&DR, Romania

Invitation to a Scientific Visit on Crystalline Rock Repository Development
Prague, Sept. 24-27, 2012

CONTENT

- *Legislative and regulatory system*
- *Sources of RW*
- *The National Strategy for Safe Management of Radioactive Waste*
- *Existing and future repositories*
- *The future actions*

2

Legislative and regulatory system

- **NATIONAL COMMISSION FOR NUCLEAR ACTIVITIES CONTROL (CNCAN)**
  - *regulatory body in the nuclear field*

- **NUCLEAR AGENCY & RADIOACTIVE WASTE (AN&DR)**
  - *Promoter of the nuclear energy development in Romania (power and non – power applications), exclusively for peaceful purposes*
  - *Responsible for disposal of radioactive waste (RW) and spent nuclear fuel (SNF), and ensure at national level the coordination of the nuclear installations decommissioning processes*

- **Waste producers**
  - *manage their own radioactive waste from its generation until disposal*

3

CNCAN

- The national authority competent in exercising regulation, licensing and control in the nuclear field;

- Independent body, reporting to the Prime Minister through the Chief of the Prime Minister's Chancellery

- Elaborates the strategy and the policies for regulation, licensing and control with regard to safe management of radioactive waste and spent nuclear fuel;

4

ANDR

- Established in December 2009;
- Specialized body of the central public administration financed by waste producers and from the State Budget;
- Under the coordination of Ministry of Economy, Trade and Business Environment;
- Elaborates and update at least every 5 year the National Strategy for safe management of radioactive waste;
- Develop and implement technical solutions for disposal;
- Maintain an update inventory of RW.

5

Regulations for RWM (1)

- Fundamental safety norms on safe management of radioactive waste (NDR-01/2004);
- Norms for clearance from authorization regime of materials resulted from authorized nuclear practices (NDR-02/2004);
- Norms on classification of radioactive waste (NDR-03/2005);
- Norms for the calculation of dispersion of radioactive effluents released by nuclear installations (NDR-04/2004);
- Norm on surface disposal of radioactive waste (NDR-05/2005);
- Norms for international shipments of radioactive materials involving Romanian territory (NDR-06/2002);

6

Regulations for RWM (2)

- Norms for decommissioning of nuclear objectives and installations (NSN-15/2002);
- Radiological safety norms for radioactive waste management from uranium mining and milling (NMR-02/2002);
- Radiological safety norms on the conservation and decommissioning of uranium and/or thorium mining and/or milling facilities – Criteria of release from CNCAN regulatory body in order to use for other purposes of the buildings, material, facilities, dumps and area, contaminated following the activities of uranium and/or thorium ore mining and/or milling (2003);
- Fundamental norms for safe transport of radioactive materials (2002);

7

Sources of RW

1. **Nuclear Power Plant (NPP)**
   - *SNN/CNE Cernavoda – U1, CANDU type, 720MWe, in operation from 1996;*
   - *SNN/CNE Cernavoda – U2, CANDU type, 720MWe , in operation from 2007;*
   - *SNN/CNE Cernavoda –U3&4, CANDU type: to be constructed by 2020;*
2. **Research reactors (RR)**
   - *RAAN/SCN Pitesti, TRIGA type, 14 MW, in operation from 1979*
   - *IFIN-HH Magurele, VVR-S type, shutdown in 1997, under decommissioning*
3. **Mining and milling (M&M)**
   - *CNU, various sites/uranium ores extraction mines*
   - *CNU/Feldioara, uranium ores processing plant*
4. **Nuclear Fuel Plant (NFP)**
   - *FCN Pitesti, CANDU type fuel fabrication plant*
5. **Institutional field**
   - *Medicine, Industry, Universities, Agricultural*

8

Basic principle

Basic principle of radioactive waste disposal in Romania:

- VLLW: less complex arrangement than LILW-SL;
- LILW-SL: near surface disposal facility;
- LILW-LL and SNF: geological repository;
- SNF is considered RW;
- Import of RW is forbidden.

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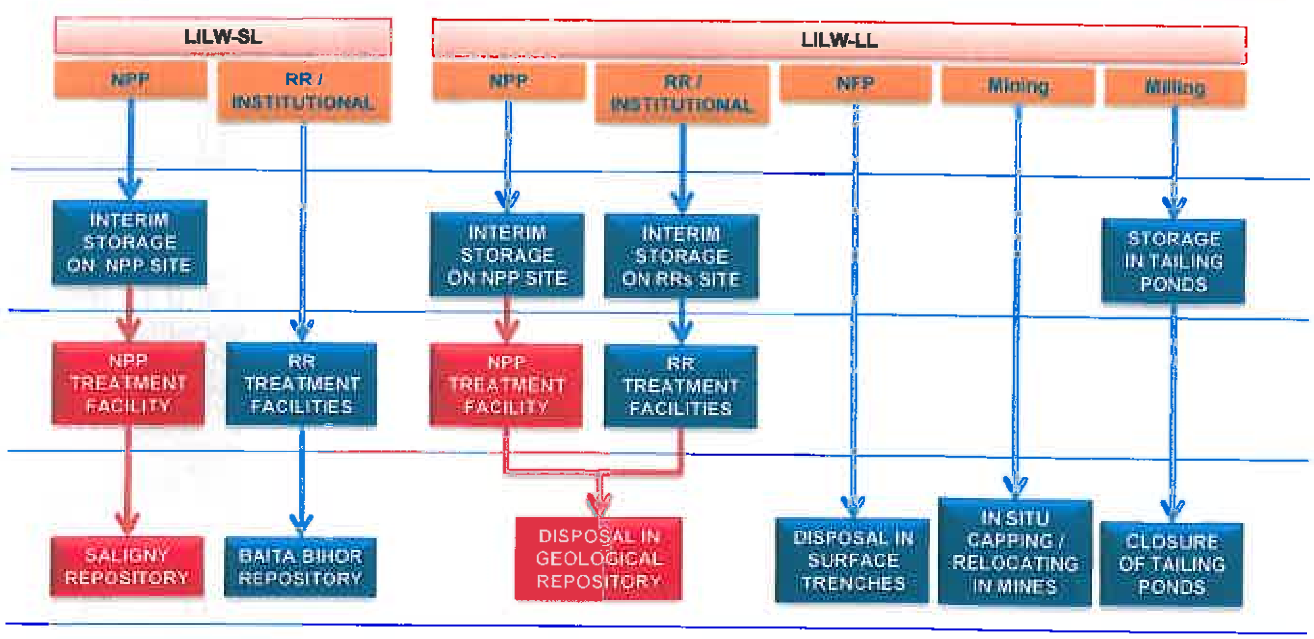
The National Strategy for Safe Management of Radioactive Waste - LILW -



EXISTING PLANNED

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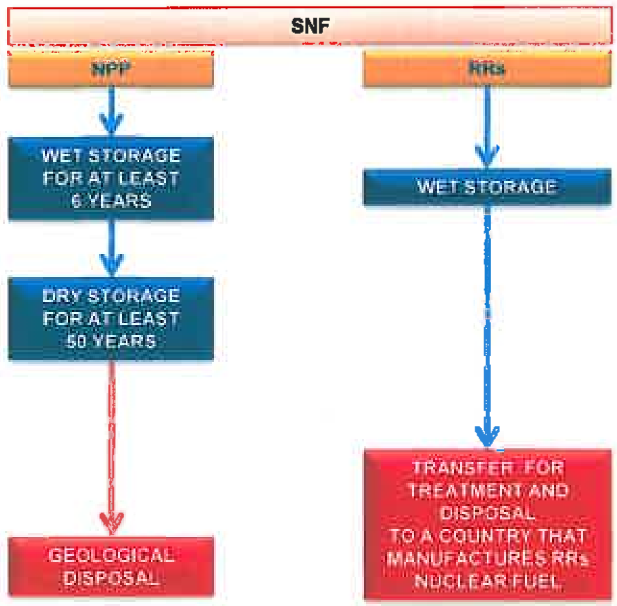
The National Strategy for Safe Management of Radioactive Waste - SNF -



EXISTING PLANNED

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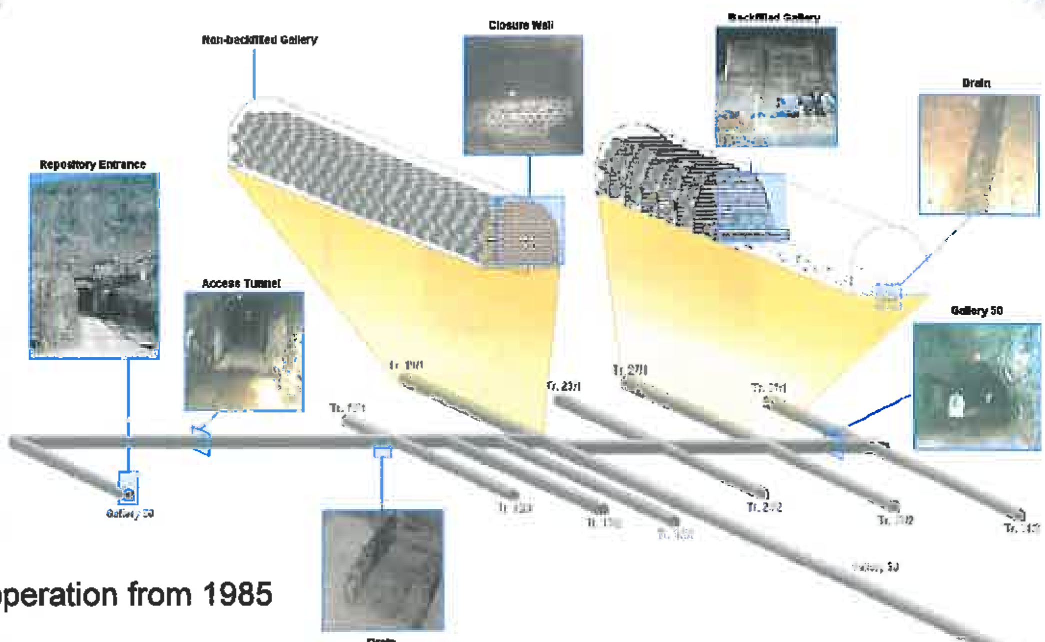
Baita Bihor Repository

(existing LILW-SL disposal facility)



- In operation from 1985
- Capacity: 21,000 standard drums (220 l)
- Type: an old exhausted uranium mine

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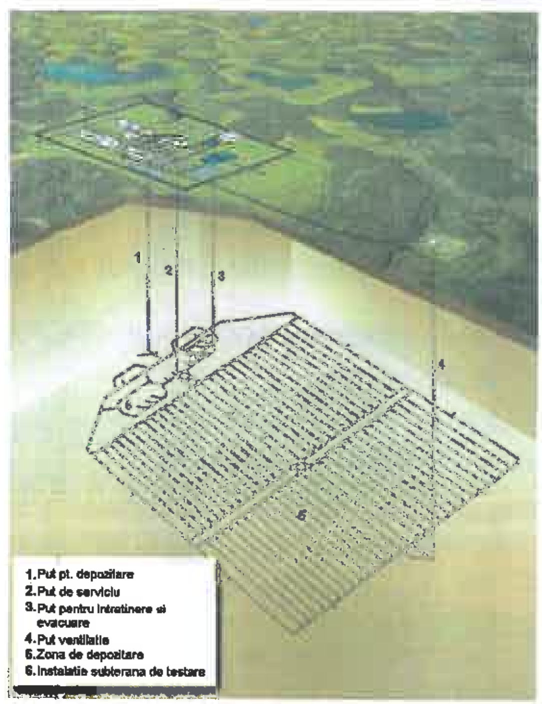
Saligny Repository
(future LILW-SL disposal facility)

- The proposed disposal concept: a near-surface facility with multiple barriers;
- Preferred site : the Cernavoda NPP area (Saligny);
- Site surface: 67 ha;
- Repository surface: 22 ha;
- RW: LILW-SL with certain quantities of LILW-LL generated by operation and decommissioning of 4 Units at Cernavoda NPP;
- Maximum capacity: about 122.000 m^3
- Cells: 64 cells, 27,9m x 15,23 m x 5,7 m
- Disposal modules: 24.576 DM, CBF-K type, 1,7 m x 1,7 m x 1,7 m
- Estimated cost: 263 MEuro (2009 price)

13

Deep Geological Repository
(future SNF/LILW-LL disposal facility)

- The DGR proposed concept will implement an existing and proven technology, adapted to local conditions.
- The proposal assumes the similarity of Canadian Concept for a Deep Geological Repository for CANDU spent fuel.
- DGR facility will dispose:
  - ✓ **Spent fuel**: 14,550 HMT (3,550 HMT/unit);
  - ✓ **Long lived wastes**: 15,660 standard drums from operation and 19,000 standard drums from decommissioning.



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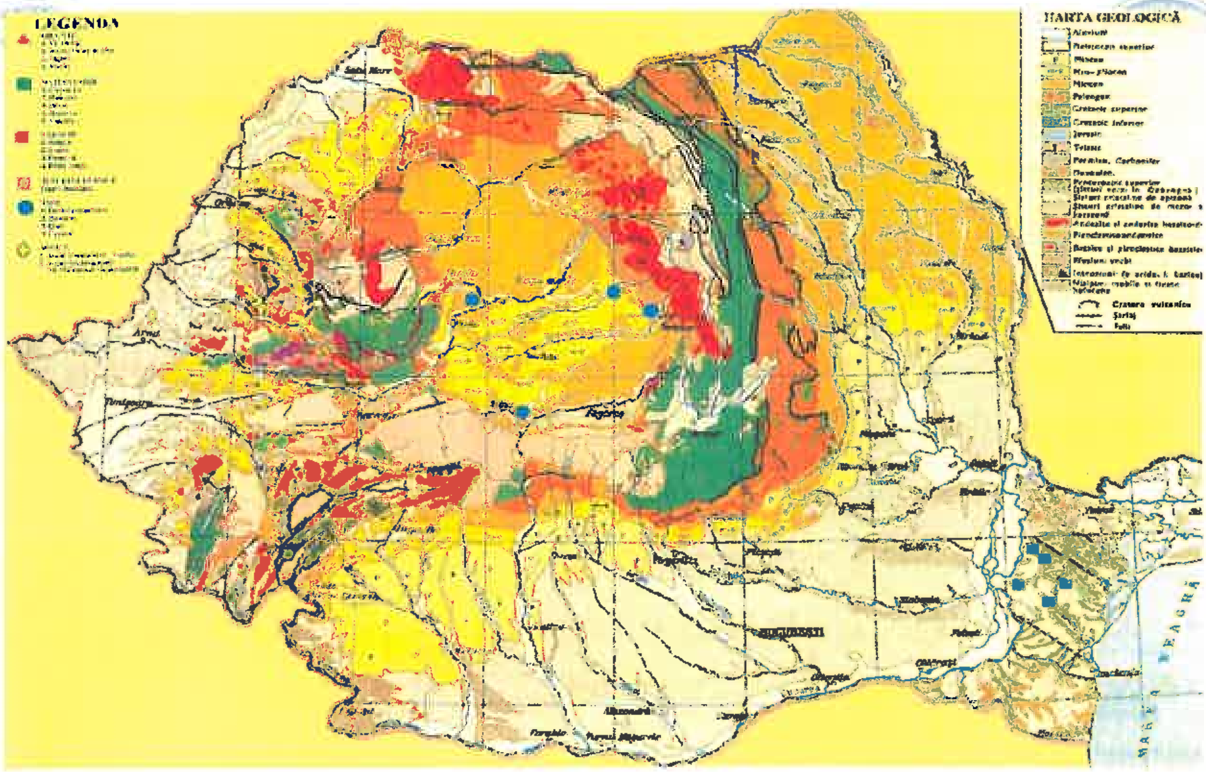
Geological map of Romania



The way ahead (1)

- 3 new regulations will issue by the end of 2012:
  - ✓ Storage of radioactive waste,
  - ✓ Storage of spent nuclear fuel,
  - ✓ Decommissioning of nuclear installations;
- Geological repository: CNCAN intends to endorse the IAEA relevant publications;
- Improvement of the Legal Framework in order to clarify specific issues regarding the Radioactive Waste Management;
- Up-dating the Medium and Long Term National Strategy for Safe Management of Radioactive Waste;
- Elaboration of the AN&DR's Institutional Development Strategy in order to enhance the capacity to achieve its mission;

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The way ahead (2)

- Licensing the Saligny Repository Site;
- Refurbishment of existing conditioning facilities;
- Upgrading of Baita-Bihor national repository;
- Licensing of a new conditioning facility;
- Approval of the Road Map for Geological Repository Development;
- Strengthening the efforts to increase the Public Acceptance for Radioactive Waste Repositories;

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LILW-SL, REPOSITORY DEVELOPMENT IN PAKISTAN STATUS & CHALLENGES

Syed Zia Hasnain Shah
Director, NR

National Repository
Pakistan Atomic Energy Commission

1

CONTENTS

- Pakistan – an introduction
- Sources of radioactive waste in Pakistan
- Waste management obligations
- RWM – policy
- RWM-strategy
- Repository development Program
- General site selection criteria
- Potential rocks/sites identification
- Current status & challenges
- Exposures of clay Formation
- Summary

2

Pakistan – an introduction

3

Pakistan

- Pakistan is situated in South Asian region between longitudes 61° & 76° E and latitudes 24° & 37° N covering a total land area of 796,095 sq. km.
- Pakistan may be divided into four geographic regions
- The plateau of W Pakistan
- The plains of the Indus and Punjab rivers
- The hills of NW Pakistan
- The mountains of N Pakistan

4

continued...

- Himalayas, Hindukush and Karakuram Ranges meet in the Northern Pakistan.
- In rest of the country there is a belt of sub-mountain Potwar plateau and Salt range, western bordering highlands the Balochistan plateau and southern Indus plain.
- The country shares its borders with Iran to the West, India in the Southeast, Afghanistan in the Northwest, and China in the North.

5

continued...

- The country has a generally hot and dry climate, with desert conditions prevailing throughout much of the area
- The Indus is the chief river of Pakistan and is the nation's lifeline. It flows the length of the country and is fed by the combined waters of three rivers i.e Chenab, Jhelum, and Ravi.
- Along the Indus and its tributaries are found most of Pakistan's population, its chief agricultural areas, and its major hydroelectric power stations.

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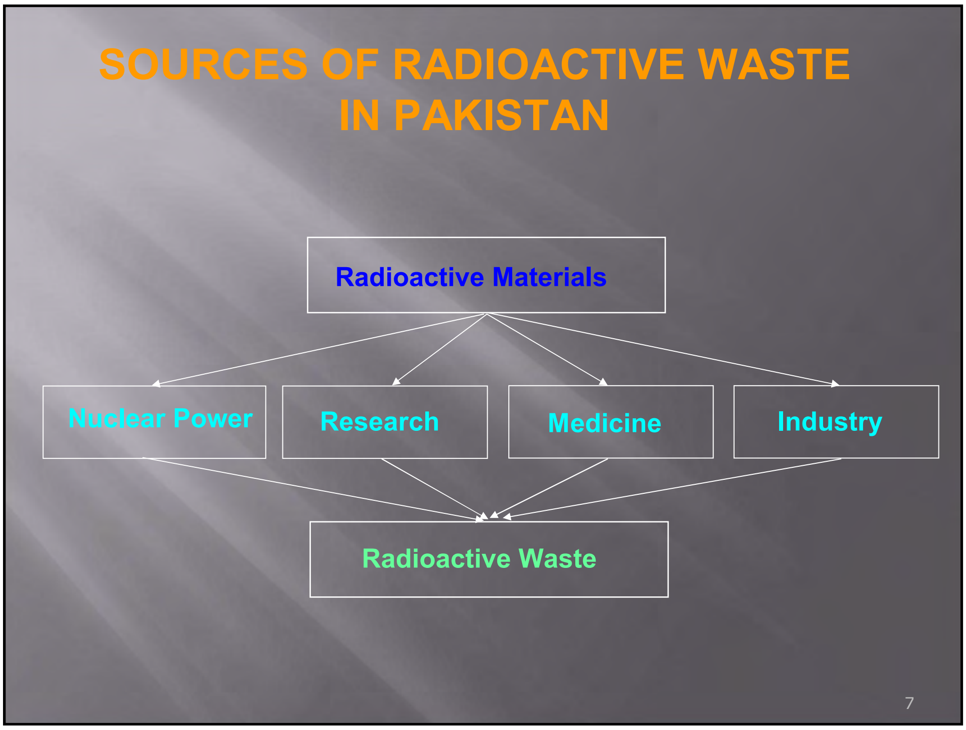

MAJOR GENERATORS OF RADIOACTIVE WASTE IN PAKISTAN

1. **Nuclear Power**

KANUPP	137MW(e)	CANDU TYPE	Karachi, Since 1972
CHASNUPP-1	300MW(e)	PWR (China)	Chasma, Since 2000
CHASNUPP-2	300MW(e)	PWR (China)	Chasma, Since 2011
CHASNUPP-3&4	300MW(e)	PWR (China)	Under Construction,2016-17
Planned	~8800MW(e)	-	By 2030

2. **Research and Development**

- PINSTECH Research Center Research Labs./Isotope Production Plant
  Research Reactors PARR - 1 & 2

3. **Nuclear Medical Centers**
4. **Nuclear Agriculture Centers**
5. **Industries**
6. **Universities**

8

WASTE MANAGEMENT OBLIGATIONS

- **Pre-Disposal**

  (Pretreatment, Treatment & Conditioning of Solidified RAW)

  Responsibility of Waste Generators

- **Disposal**

  (Off site transportation, repository development & disposal of conditioned RAW)

  Responsibility of Directorate General National Repository

9

NATIONAL POLICY ON CONTROL AND SAFE MANAGEMENT OF RADIOACTIVE WASTE

- Approved statement of National Policy, issued on 17th February 2011, is as under:-
- "1. Radioactive waste is generated by Nuclear Power Plants, Nuclear Research Reactors, radioactive sources used by industry and hospitals and research establishments. This radioactive waste needs to be properly managed and stored at safe and secure purpose built sites to protect human health and environment. PAEC, the main producer of the radioactive waste, is managing it with safety and security and storing it at PINSTECH and KANUPP. Safe management of radioactive waste in Pakistan will be ensured by SPD/PAEC. The finances of radioactive waste will be managed through Central Radioactive Waste Management Fund (RWMF) established and maintained by PAEC for the safe management of radioactive sources in the country.

10

Continued…

- 2. As regards radioactive sources, used by hospitals and industry, these will be imported and returned to the supplier as per PNRA Regulations. Those radioactive sources which could not be returned to supplier or orphan sources will be stored at safe and secured sites in the country. As there is no other site developed for the safe storage/disposal of disused and orphan radioactive sources utilized by private/public sector, PAEC will also be responsible for storage/disposal of disused and orphan radioactive sources and ownerless waste. Every generator of radioactive waste will be responsible for safe and secure management of radioactive waste until such time the radioactive waste is sent to designated storage sites of PAEC for ultimate disposal and shall pay its cost for the safe disposal to PAEC. PAEC will work out charges required for such disposal. In case of management of orphan sources, sources cleared by PNRA for disposal, the expenditure will be borne by SPD/PAEC.

- 3. Radioactive waste except for Disused Sealed Radioactive Sources (DSRS) will neither be imported nor exported as a policy until and unless specifically permitted by SPD. Pakistan Nuclear Regulatory Authority shall ensure safe control of all radioactive waste including DSRS that is generated in the country."

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RWM - STRATEGY

Pre-disposal Activities (pretreatment, treatment, conditioning, packaging & interim storage)	Transportation/Disposal (off-site transportation, siting and development of disposal facilities)
Waste Generators	**Directorate General of National Repository**

12

Continued…

Waste Class	Type of Disposal Facility
Very Low Level Waste (VLLW)	Near surface earthen trenches
Low & Intermediate Level Short-Lived Waste (LILW-SL)	Near Surface
Low & Intermediate Level Long-Lived Waste (LILW-LL) (i) LLW-LL (ii) ILW-LL	 Near Surface Intermediate Depth
High Level Waste (HLW)/SF	Geological

13

Continued…

1st Priority	2nd Priority
Single Site:- Near Surface & Geological (Granite/Clay)	Two Sites:- Near Surface (Clay) Geological (Granite)

14

Repository Development Program

- Development of a disposal facility is a big task
- International waste disposal programs reveals that granite, salt and clay formations act as favorable hosts

Almost all potential host rocks under investigation in the world for disposal exist in Pakistan

15

General Site Selection Criteria

- Availability of favourable geology, tectonics, seismicity, hydrogeology and topography
- Absence of natural resources
- Avoidance of areas of special cultural, scientific or ecological interest
- Availability of local infrastructure, including utilities, human resources, transportation routes and basic services

16

Potential Rocks/Sites Identification

- All kinds of rocks (e.g. sedimentary, metamorphic and igneous) are present in the stratigraphic sequence of Pakistan
- Due to unstable political as well seismo-tectonic conditions we have to focus on risk-free or least venturous regions of the country
- As a part of conceptual planning stage of the siting process, 39 sites/formations from the stratigraphic sequence of Pakistan were studied for evaluation of their initial potential for the disposal of various type of radioactive waste

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Current Status & Challenges

- Following formations have been identified for disposal facilities;

  - Clay
  - Granite

(Rock salt is not considered due to its economic values)

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Continued...

Activity	Near Surface Disposal Facility	Deep Geological Repository
Siting Process	In-progress	Planning
Facility Development	-	-

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Continued...

- The challenges we are facing:-

  - Tectonic setup

  - Security issues

  - Public acceptance

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Major tectonic trends on and around the northwest part of the Indo-Pakistan subcontinents

21

Clay Formation

Clay Formation has potential for development of disposal facility

Characteristics:-

- Brick red clay with subordinate sand stones having general dip of 10 degree
- Thickness is about 750m
- Exposed in 3.5 Km wide strip with several kilometer lateral extension
- Age late Miocene (20Ma)

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Continued…

- Area displays vast peneplained, depressed topography because of abundance of clay/shale as compared to overlying and underlying by dominantly sandstone Formations
- The proposed site is part of Potwar Plateau and lies within the gently dipping southern flank of Soan Syncline where topography is flat and undergone very little internal deformation

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Continued…

- The area falls in semi-arid zone with high evaporation rate
- The area falls on higher side of the local watershed, therefore, drainage system is quite immature and the whole area is almost devoid of any perennial stream
- Most of the area is covered with clay, naturally impermeable, which does not allow much infiltration of water

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Summary

- Pakistan has a peaceful nuclear program
- Main sources of radioactive waste are; nuclear power, R&D, hospitals, industry etc
- According to national policy, disposal of radioactive waste is responsibility of PAEC
- DGNR is involved in the development of radioactive waste disposal facilities
- Nature has blessed Pakistan with all kinds of geological environments
- The siting process for development of radioactive waste disposal facilities is in progress

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Thank You
27

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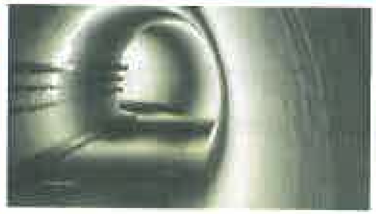
Sandia National Laboratories



Repository Programme Development

From Concept to Licensing

Andrew Orrell
Director of Nuclear Energy & Fuel Cycle Programs
Sandia National Laboratories

Presented to the Scientific Visit on Crystalline Rock Repository Development, Prague, Czech Republic

25 September 2012

U.S. DEPARTMENT OF ENERGY NNSA

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Repository Programme Development

- **Purpose**
  - To review the overall process of repository programme development and to provide a framework for subsequent discussions
- **Background**
  - Material presented based on
    - IAEA Safety Standards: No. SSR-5 "Disposal of Radioactive Waste"
    - OECD Radioactive Waste Management Document: "Post-Closure Safety Case For Geological Repositories: Nature And Purpose"
    - National Academy of Sciences: "One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste"
    - Nuclear Energy Agency: "Confidence in the Long-term Safety of Deep Geological Repositories: Its Development and Communication"
    - And other examples and perspectives from various institutional and personal experience

Terminology

- Disposal
  - Emplacement of radioactive waste with no intention of retrieval, i.e., permanent disposal
    - If the material is an asset, store it. If the material is a waste, dispose it.
  - Waste containment and isolation from the accessible environment through use of passive natural (e.g., reducing environment) and engineered (e.g., corrosion resistant waste containers) features
- Storage
  - Retention of waste (or material) with the intention of retrieval pending some future action (e.g., reprocessing)

Introduction

- Repositories can be developed in many different ways
- Significant international experience exists, but with key differences
  - Don't reinvent the wheel, but be prepared to modify it

- Repository development is a technical/scientific/engineering challenge (relatively easy) combined with a sociopolitical challenge (relatively difficult)
  - If the science and engineering effort appears straightforward do not assume that a solution has been found that sociopolitical factors will accept

What is a Successful Repository Program?

- From the implementer perspective, it might be having all of its waste underground in a sealed repository, by a given time, for a reasonable cost
- From a stakeholder perspective, it might be that the decisions to develop, operate and close the repository was with their participation to provide consensus and/or approval

- Both perspectives meet at the issue of safety; i.e., the extent to which the repository program will provide confidence that the waste will be isolated from the accessible environment
  - Every repository development programme addresses both actual and perceived risk
  - Public acceptance and stakeholder participation, along with technical excellence, are prerequisites for success

5

Fundamental Safety Premise

- To manage the waste burden through permanent disposal in a manner that protects the accessible biosphere (groundwater and other resources used by or accessed by people.
  - Disposal facilities are to be developed in such a way that people and the environment are protected both now and in the future
  - To leave future risks no greater than one would accept at present.
- The fundamental safety objective is to protect people and the environment from the potential for harmful effects of radioactive waste.
- The strategy to achieve this fundamental safety objective is to *contain and isolate* the waste from the accessible biosphere, to the extent that is necessary.

6

Repository Programme Life-Cycle

- Typically characterized by long timeframes
  - International experience *should* lessen the technical challenges
  - Workforce planning, information management, institutional performance, etc., become issues with career-long development cycles
- All programmes characterized by stages of development that build upon prior effort
  - Staged, adaptive management approaches with stakeholder engagement is broadly recommended
    - Step-wise (and adaptive) development enables the accumulation of technical data, evaluation of alternative disposal concepts, iterative safety and design assessments with progressive improvement (*confidence and defensibility*), public consultations, political decision-making, etc.
    - Adaptive Staging is a management process characterized both by specific objectives and by a formal and deliberate decision-making process

7

Repository Programme Life-Cycle

- Pre-Operational Phase
  - Selection of Geologic Disposal Concepts and Options
  - Site Selection & Characterization
    - Conceptual Planning
    - Area Survey, Site Characterization & Site Confirmation
  - Licensing and Construction
- Operational Phase
  - Pilot and Full-Scale Operations with Transportation
  - Closure
- Post-Closure Phase
  - Performance Confirmation, Monitoring, Institutional Controls, Permanent Markers

8

Fundamental Needs

- **Government Responsibilities**
  - ***Establishes the need, objectives, timeline and decision points, allocates responsibilities (including independent functions), financing***
- **Regulatory Body Responsibilities**
  - ***Establishes regulatory requirements (i.e., the safety objectives, compliance metrics, etc.) & procedures for demonstrating compliance and other licensing conditions***
- **Operator / Implementer Responsibilities**
  - ***Responsible for the disposal facility safety***
  - ***Implements site selection, characterization, facility design, etc.***
  - ***Assembles the safety assessments and safety case, license application***
  - ***Works in accordance with national strategy, in compliance with regulatory requirements and within the legal regulatory framework***
  - ***Maintains management systems for quality assurance, quality control, information management, workforce training, etc.***

9

REPOSITORY PROGRAMME DEVELOPMENT

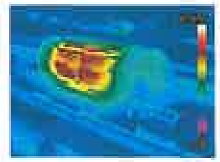
Pre-Operational Phase:

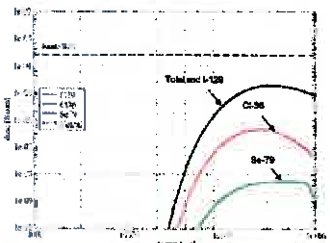
Considerations of Disposal Concepts to Licensing

10

Selection of Disposal Concepts

- **Disposal Concepts (and the repository development program) will typically reflect:**
  - **Waste Inventory Characteristics**
    - **Volume, size, chemistry, heat, radioactivity concentrations, generation rate, etc.**
  - **Siting Information**
    - **Repository site characteristics and their possible evolution, waste locations vs. repository locations, infrastructure needs, etc.**
  - **Regulatory Framework**
    - **The criteria and objectives against which safety assessments and safety cases are judged for performance (how does the disposal concept perform its safety function), compliance and confidence (how well does the disposal concept meet or exceed the safety criteria and objectives)**
    - **Dose vs. containment standards, timeframes involved, pass-fail or advisory safety assessments**



Select IAEA Safety Requirements (SSR-5) for Repository Programme Development

- Requirement 4: Understand the relevance and implications for safety for the available disposal concepts
  - Attempt to optimize safety for operations and post-closure
- Requirement 5: Safety should be ensured by passive means
  - Minimize safety that depends on future *actions* being taken
- Requirement 6: Understand the disposal concept (facility, host environment) over sufficiently long time periods to have confidence safety (isolation and containment) can be achieved
  - Confidence is documented by means of safety assessments and safety cases
- Requirement 7: Employ multiple safety functions
  - Containment and isolation by multiple physical barriers = confidence
  - Defense in depth, no single points of failure, use both natural and engineered barriers

Select IAEA Safety Requirements (SSR-5) for Repository Programme Development

- Requirement 8: Containment of waste with engineered barriers
  - Use engineered barriers designed to retain integrity for a long enough period of time to enable most of the shorter lived radionuclides to decay and for the associated generation of heat to decrease substantially
- Requirement 9: Isolation of waste from accessible environment
  - Provide isolation for time periods commensurate with the hazard to the accessible biosphere and people, and consider the natural evolution of the disposal system and events that disturb the facility
- Requirement 11: Use staged development and evaluate the safety of the disposal system with iterations
  - Facilitate the decision and acceptance processes by incorporating new information

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Select IAEA Safety Requirements (SSR-5) for Repository Programme Development

- Requirement 15: Site characterization
  - Characterize the site to sufficient detail to a specific understanding of the impact on safety of features, events and processes associated with the site and the facility. Understand the site's present condition, its probable natural evolution, possible natural events, and human actions affecting safety
- Requirement 16: Facility design for isolation
  - Design and site facility and its engineered barriers in a compatible host formation to provide safety features after closure that complement the natural barriers (i.e., use both engineered and natural barriers in complementary ways to provide defense in depth).

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Safety Assessment & Safety Case[1]

- **Safety assessment**
  - **Safety assessment is the evaluation of long-term performance, of compliance with acceptance guidelines and of confidence in the safety indicated by the assessment results.**
- **Safety case**
  - **A safety case is a collection of arguments, at a given stage of repository development, in support of the long-term safety of the repository. A safety case comprises the findings of a safety assessment and a statement of confidence in these findings. It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages.**

[1]NEA: "Confidence in the Long-term Safety of Deep Geological Repositories: Its Development and Communication"
http://www.oecd-nea.org/rwm/reports/1999/confidence.pdf

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Select IAEA Safety Requirements (SSR-5) for Repository Programme Development

- Requirement 12: Use safety case and safety assessment
  - Prepare and update at each step in repository development a sufficiently detailed and comprehensive safety case and supporting safety assessment
- Requirement 13: Safety case and safety assessment scope
  - Need to address all relevant safety aspects for both operational and post-closure phases (see FEP screening presentation)
- Requirement 14: Safety case and safety assessment documentation
  - Document the safety case and safety assessment with detail and quality to allow independent review, and to support decision making

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Licensing

- Repository licensing is a complex process that lasts throughout the repository program
  - It begins with the capturing the information associated with the initiation of the repository development program
  - Licensing can be for construction, waste acceptance, closure, termination, or combinations depending on the regulation
  - Construction licensing will typically expect a safety case for the full emplacement inventory (and needs to be known at the outset of the disposal concept and facility design process)
- The operator / implementer prepares and submits a license application to the regulatory authority(ies) in accordance with the standards and processes defined, demonstrating that the proposed repository is safe and complies with regulatory requirements
- Primary elements of a license application are the safety assessment and the safety case, along with all other supporting information needed

Institutional Issues

- Public attitudes about nuclear energy and nuclear waste place the institution(s) charged with implementing a repository programme, at best, under great scrutiny, and at worst, great distrust or suspicion
- Trust is asymmetric
  - trust-decreasing events have greater impact on public perceptions of trust (personal or institutional) than trust increasing events
  - trust is easily and quickly lost, even by a single event, but once lost is typically difficult to regain—if it can be regained at all

- As noted at the introduction, repository development is a technical/scientific/engineering challenge combined with a sociopolitical challenge that stands on trust

- Thus there are extraordinary demands placed on the institution and the people in it to perform with integrity and transparency over long time frames


nuclear
waste
facilities
storage
safety
fuel
disposal
Commission
States
consolidated
federal
standards
technologies
develop
efforts
health
possible
research
security
high-level
systems
current
reactor
cycle
integrated
existing
program
interim
substantial
aspects
time
continue
regulatory
leadership
materials
currently
local
agencies
siting
affected
Blue
adaptive
levels
transport
sites
new
government
management
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joint
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However
potential
available
confidence
approach
must
transparent
performance
facility
global
important
coordinated
long-term
protecting
consent-based
relevant
process
support
19

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Technical Bases for Repository Construction in Crystalline Rock

Paul Mariner

Scientific Visit on Crystalline Rock Repository Development
Prague, Czech Republic
25 September 2012

U.S. DEPARTMENT OF ENERGY NNSA

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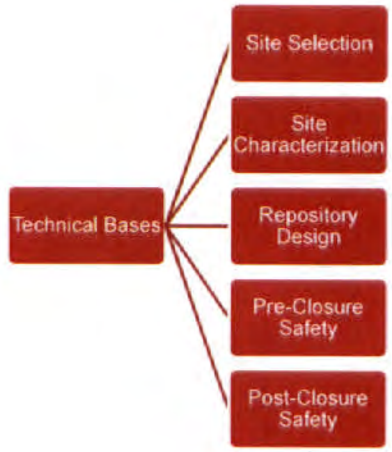
Outline

Sandia National Laboratories

- Technical bases for a geologic repository
- Attributes of a mined repository in crystalline rock
- Post-closure safety assessment results
- FEPs important to post-closure safety
  - Features, Events, and Processes (FEPs)
- Implications for
  - Site selection, site characterization, repository design
- Prioritization of site selection and site characterization activities

Technical Bases for a Geologic Repository

- Technical bases
  - Data and arguments that build confidence that technical objectives are achieved
- Technical objectives
  - Functional and socioeconomic objectives
    - Capacity, timing, specific wastes to be disposed, operational, political, legal constraints, retrievability(?), etc.
  - Safety criteria
    - Pre-closure
    - Post-closure



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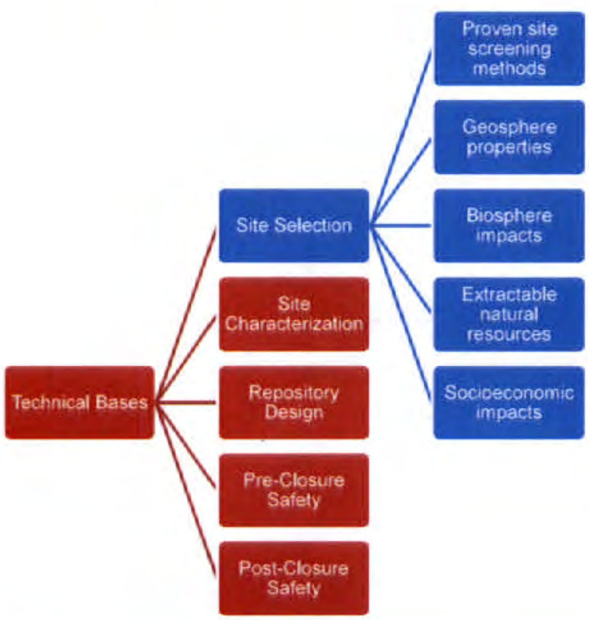
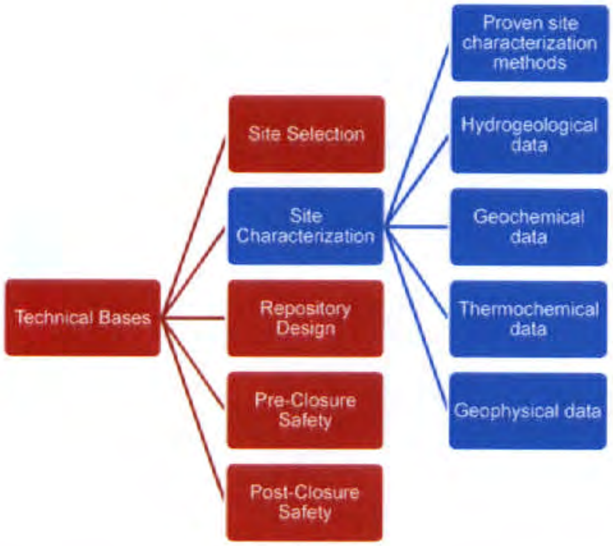
Site Selection Bases



- Objective
  - Build confidence in
    - site selection process
    - site(s) selected
- Inputs from
  - Site characterization activities
  - Knowledge of important FEPs
  - Historical resource drilling data
  - Community involvement
  - Lessons learned from previous site selection experiences
- Meet objective by sufficiently demonstrating/documenting
  - Knowledge of the subject areas
  - Sufficiently low risk of an unacceptable outcome

4

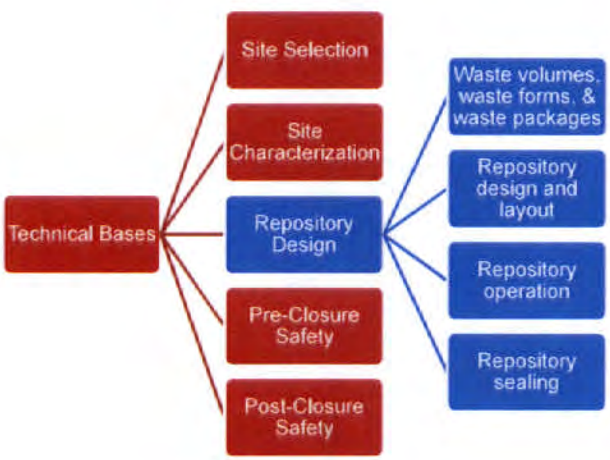
Site Characterization Bases



- Objective
  - Obtain sufficient site characterization data to assess the long-term safety of a repository at the site
  - Reduce parameter uncertainty
- Inputs from
  - Surface based characterization
    - 3D seismic imaging
    - Gravity survey
    - Magnetic survey
    - Electrical resistivity profile
  - Borehole-based characterization
    - Geophysical logging
    - Geological and hydrological sampling and analyses

5

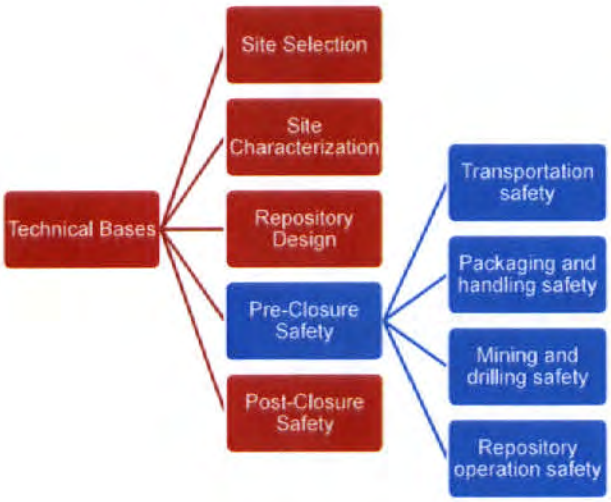
Repository Design Bases



- Objective
  - Demonstrate a feasible repository design for the site
- Inputs from
  - Projected inventory, waste forms, and waste packages
  - Repository design needed to accommodate
    - Waste volumes and number of waste packages
    - Thermal load
  - Design specifications
    - E.g., thermal limits for engineered barriers
  - International programs

6

Pre-Closure Safety Bases



- Objective
  - Demonstrate pre-closure safety for the proposed repository
- Inputs from
  - Repository design
    - E.g., shielding
  - Standard operating procedures
  - Safety data from drilling, mining, handling, and transportation
  - Radioactive waste disposal programs
  - Underground research laboratories
  - Waste containers can be analyzed for failure potential due to potential event sequences

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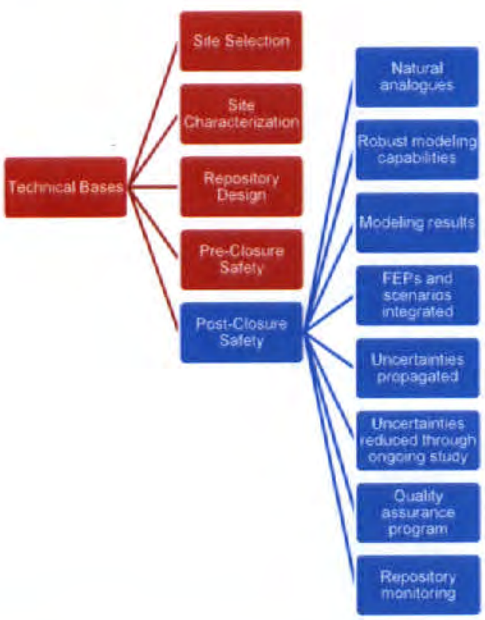
Post-Closure Safety Bases



- Objective
  - Demonstrate long-term safety for disposal concept
- Bases
  - Natural analogs (long-term stability of bentonite, copper deposits; UO_2 ore bodies)
  - Models used are adequate and robust
  - Long-term performance evaluations indicate long-term safety
  - FEPs screening and scenario development are well developed, demonstrated, and integrated with performance evaluations (IAEA 2004)
  - Uncertainties in parameter values and processes are propagated
  - Reductions in uncertainty are actively pursued via studies and collaboration as part of the post-closure safety assessment program
  - A well established quality assurance program
  - A repository monitoring program to confirm repository performance

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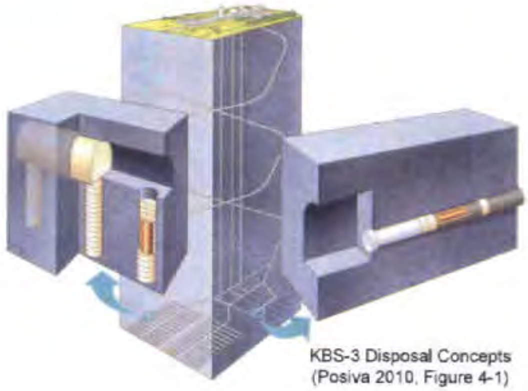
Post-Closure Safety Attributes for Disposal in Mined Crystalline Rock

Sandia National Laboratories

- Far from biosphere
- Minimal rock pressures
  - Long-lasting excavations reduce stresses on canisters
  - Retrievability
- Low permeability at depth (300 – 500 m)
  - $\sim 10^{-13}$ to $\sim 10^{-10}$ m s^{-1}
  - Age dating indicates old water, little movement
- Favorable chemical environment
  - Reducing conditions
    - low degradation rates, low radionuclide solubilities, increased sorption, UO_2 stable
  - Salinity at depth reduces colloid stability
- Low probability of accidental human intrusion
- Long-term stability of bentonite, UO_2 ore, and copper based on natural analogues
- Much supporting data from studies and programs around the world



KBS-3 Disposal Concepts (Posiva 2010, Figure 4-1)

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Post-Closure Safety Resources

Sandia National Laboratories

- Technical reports and data from established programs in crystalline rock, e.g.:
  - Sweden (SKB): http://www.skb.se/Templates/Standard____17139.aspx
  - Finland: http://www.posiva.fi/en/databank
  - Japan (JAEA): http://www.jaea.go.jp/04/tisou/english/index/l2_03.html, and NUMO: http://www.numo.or.jp/en/reports/
  - South Korea (KAERI): http://www.kaeri.re.kr:8080/english/sub/sub02_01.jsp, and KRMC http://www.krmc.or.kr/krmc2011/user/index.jsp
  - Canada (NMWO): http://nwmo.ca/publications, and AECL: http://www.aecl.ca/site3.aspx
  - Switzerland (NAGRA): http://www.grimsel.com/media-and-downloads/grimsel-test-site-publications/gts-nagra-technical-reports-ntb, and Grimsel: http://www.grimsel.com/media-and-downloads/grimsel-test-site-publications/grimsel-test-site-publications-list-
- Scientific literature (books, journals, proceedings, etc.)
- Technical reports from agencies, laboratories, and institutions

10

Post-Closure Safety Analyses

- Site-specific performance assessments for disposal in crystalline rock
  - Posiva 2010. *Interim Summary Report of the Safety Case 2009*. POSIVA 2010-02. Posiva Oy, Olkiluoto, Finland.
  - SKB 2011. *Long-term safety for the final repository for spent nuclear fuel at Forsmark*. TR-11-01. Svensk Kärnbränslehantering AB, Stockolm, Sweden.
- Generic performance assessments for disposal in crystalline rock
  - ANDRA 2005. *Dossier 2005 Granite – Safety Analysis of a Geological Repository*. ANDRA, Paris, France. December 2005.
  - Gierszewski, P., J. Avis, N. Calder, A. D'Andrea, F. Garisto, C. Kitson, T. Melnyk, K. Wei, and L. Wojciechowski 2004. *Third Case Study - Postclosure Safety Assessment*. Report No: 06819-REP-01200-10109-R00. Ontario Power Generation, Toronto, Ontario.
  - JNC 2000. *H12: Project to establish the scientific and technical basis for HLW disposal in Japan, Supporting Report 3*. JNC TN1410 2000-004. Japan Nuclear Cycle Development Institute.
  - Mariner, P.E., J.H. Lee, E.L. Hardin, F.D. Hansen, G.A. Freeze, A.S. Lord, B. Goldstein, and R.H. Price 2011. *Granite Disposal of U.S. High-Level Radioactive Waste*. Sandia National Laboratories, Albuquerque, New Mexico. http://prod.sandia.gov/techlib/access-control.cgi/2011/116203.pdf
  - Vaughn, P., D.J. Clayton, G.A. Freeze, T. Hadgu, E. Hardin, J. Lee, J. Nutt, H.H. Liu, L. Zheng, J. Birkholzer, S. Chu. *Generic Disposal System Modeling - Fiscal Year 2011 Progress Report*. SAND2011-5828P. Sandia National Laboratories, Albuquerque, New Mexico.

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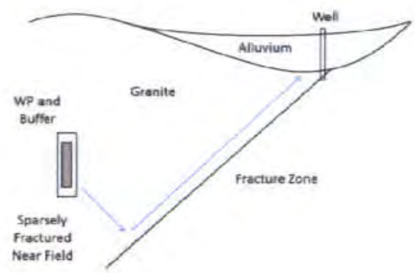
Recent Post-Closure Safety Analyses Results



- Base case/defective WPs/intact buffer
  - Undetected WP failure rate
  - Dose rates due to radionuclides that are
    - Low-sorbing in buffer and geosphere, highly soluble, long-lived, instantly released
      - E.g., ^{129}I, ^{14}C, ^{36}Cl
    - However, dose rates stay well below 0.3 mSv/a recommended by ICRP 81 (ICRP 2000)
- Buffer failure
  - Eroded (advective conditions), transformed, frozen, etc.
  - Dose rates due to radionuclides that are
    - Low-sorbing in geosphere, highly soluble, long-lived, often instantly released
      - E.g., ^{129}I, ^{36}Cl, ^{226}Ra, ^{237}Np, ^{79}Se, ^{59}Ni (neutron activation)
    - Radionuclides with lower half-lives (e.g., ^{226}Ra) become important
      - No (or little) buffer to sorb radionuclide
      - Eroded buffer implies high flow rates
    - Still, dose rates well below 0.3 mSv/a

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Post-Closure Safety FEPs Important to Siting, Site Characterization, and Repository Design

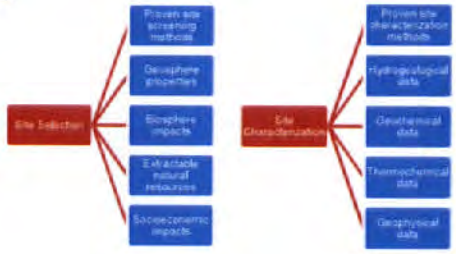
- Geology
  - Stratigraphy, properties of host rock (permeability, porosity, mechanical stability, fracture networks, variations with depth)
  - Sorption in geosphere (mineralogy in flow and matrix porosity)
- Hydrogeology
  - Fracture flow, matrix diffusion, hydraulic gradients, potential for buffer erosion
  - Evidence of deep groundwater circulation (age dating)
- Chemical conditions
  - Oxygen, redox potential, pH, salinity, and other chemical parameters relevant to degradation rates (e.g., sulfide), radionuclide solubility, sorption, colloid stability, buffer performance
  - Colloids (stability, composition, abundance)
- Biosphere
  - Population, agriculture, aquaculture, etc.
- Potential disruptive events
  - See next slide

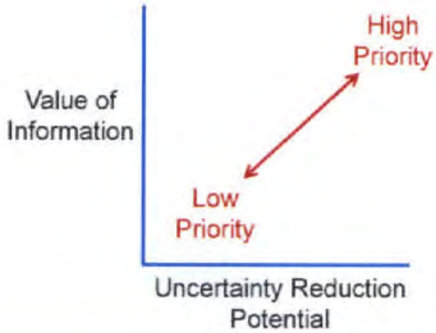
Disturbed Scenario FEPs Important to Siting, Site Characterization, and Repository Design

- Disruptive events include
  - Earthquakes
    - Probability of size and frequency
  - Glaciation, ice sheets, climate change, and periglacial effects
    - Potential effects on earthquakes, deep groundwater circulation, chemical conditions
  - Igneous or volcanic intrusion
    - Probability based on evidence of Quaternary-age volcanic rocks or igneous intrusions in the vicinity
  - Human intrusion
    - Probability of
      - Drilling/mining for resources, disposal of wastes, building a bunker, etc.
      - Potential consequences
- Disturbed scenarios are important for their potential to
  - Damage the repository and engineered barriers
  - Alter flow pathways and properties in the geosphere

Prioritizing Siting and Site Characterization Activities

- Site screening and site characterization activities prioritized by
  - Importance in demonstrating technical bases
  - Importance in post-closure dose rate calculations
  - Potential to reduce uncertainty in dose rate calculations
  - Other factors (e.g., cost, maturity of activity, redundancy)
- Prioritization process can be formalized
  1. Identify a set of metrics
     - Value of information, uncertainty, cost, maturity, etc.
  2. Define an objective function to rank the scores of the metrics
  3. Have experts evaluate each activity using the metrics
  4. Tally the objective function results





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Summary

- Successful site selection and site characterization programs fully demonstrate the necessary technical bases
- Site selection activities
  - Depend on well-established site screening methods to evaluate geosphere suitability, biosphere impacts, exploitable natural resources, and socioeconomic impacts
- Site characterization activities
  - A primary objective is to reduce uncertainty in parameters important to post-closure dose rate calculations
  - A systems engineering approach can be used to prioritize these activities

16

Resources and References

- Gierszewski, P., J. Avis, N. Calder, A. D'Andrea, F. Garisto, C. Kitson, T. Melnyk, K. Wei, and L. Wojciechowski 2004. *Third Case Study - Postclosure Safety Assessment*. Report No: 06819-REP-01200-10109-R00. Ontario Power Generation, Toronto, Ontario.
- IAEA (International Atomic Energy Agency) 2004. *Safety assessment methodologies for near surface disposal facilities. Results of a co-ordinated research project. Vol. I: Review and enhancement of safety assessment approaches and tools*. IAEA. Vienna, Austria.
- ICRP (International Commission on Radiological Protection) 2000. *Radiation protection recommendations as applied to the disposal of long-lived solid radioactive waste*. Annals of the ICRP 28(4). ICRP Publication 81, Pergamon Press, Oxford, UK.
- JNC 2000. *H12: Project to establish the scientific and technical basis for HLW disposal in Japan, Supporting Report 3*. JNC TN1410 2000-004. Japan Nuclear Cycle Development Institute.
- MacKinnon, R.J., S.D. Sevougian, C.D. Leigh, and F.D. Hansen 2012. *Towards a Defensible Safety Case for Deep Geologic Disposal of DOE HLW and DOE SNF in Bedded Salt*. SAND 2012-6032. Sandia National Laboratories, Albuquerque, New Mexico.
- Mariner, P.E., J.H. Lee, E.L. Hardin, F.D. Hansen, G.A. Freeze, A.S. Lord, B. Goldstein, and R.H. Price 2011. *Granite Disposal of U.S. High-Level Radioactive Waste*. SAND2011-6203. Sandia National Laboratories, Albuquerque, New Mexico.
- Posiva 2010. *Interim Summary Report of the Safety Case 2009*. POSIVA 2010-02. Posiva Oy, Olkiluoto, Finland.
- SKB 2011. *Long-term safety for the final repository for spent nuclear fuel at Forsmark*. TR-11-01. Svensk Kärnbränslehantering AB, Stockolm, Sweden.

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Disposal Concepts in Crystalline Rock

Ernest Hardin

Scientific Visit on Crystalline Rock Repository Development
Prague, Czech Republic

25 Sept. 2012
SAND2012-7783C

U.S. DEPARTMENT OF ENERGY NNSA

Disposal Concepts - Outline

Sandia National Laboratories

- *Disposal concept* defined: waste inventory, geologic setting, concept of operations
- Systematics: KBS-3 *and other options* for crystalline rock
- Using the KBS-3 "method": buffer material & configuration, waste package options, prefabrication
- In-drift disposal
- Thermal analysis of SNF disposal in a KBS-3 repository
- "Open" and "enclosed" emplacement modes
- Large waste packages and associated challenges for disposal in crystalline rock

Disposal Concept Systematics:

Crystalline Rock

Disposal Concept/
Emplacement Mode

- "Enclosed" Mode
  - Saturated or Unsaturated
    - Borehole Emplacement
      - SKB (2011)
      - AECL (1994)
      - KAERI/SNL (2007)
      - Pastina and Hellä (2006)
      - Taipower (2009) *
      - Wang (2010)
    - In-Drift (buffer)
      - CTECH (2002)
      - Santiago & Astudillo (1999)
      - JNC (2000)
      - Zuidema et al. (2006)
- "Open" Mode
  - Saturated or Unsaturated
    - In-Drift (backfill)
      - CARE - McKinley et al. (2008)
  - Unsaturated
    - Moisture Barriers (unbackfilled)
      - Hardin et al. (2012)
      - U.S. DOE (2008)

Buffer Material/Config.
Invert/Pedestal/Baseplate
Package Options
Prefabrication

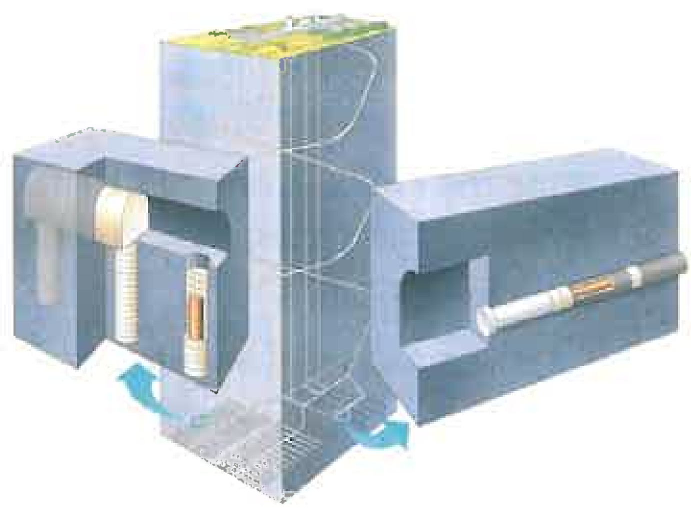
Hardin – Disposal Concepts (25 Sept. 2012)

* Both borehole and in-drift emplacement modes are being considered.

3

KBS-3H/V Summary

- Vertical or horizontal borehole emplacement
- Waste packages for chemically reducing conditions (Fe, Cu)
- Clay-based buffer material
- Avoid highly conductive faults or fractures
- Backfill access tunnels
- Borehole & shaft seals
- Modes of radionuclide release:
  - Buffer erosion (e.g., fracture flow of fresh water, as from glaciation) → waste package corrosion
  - Other processes under investigation (e.g., gas generation, seismicity and faulting)

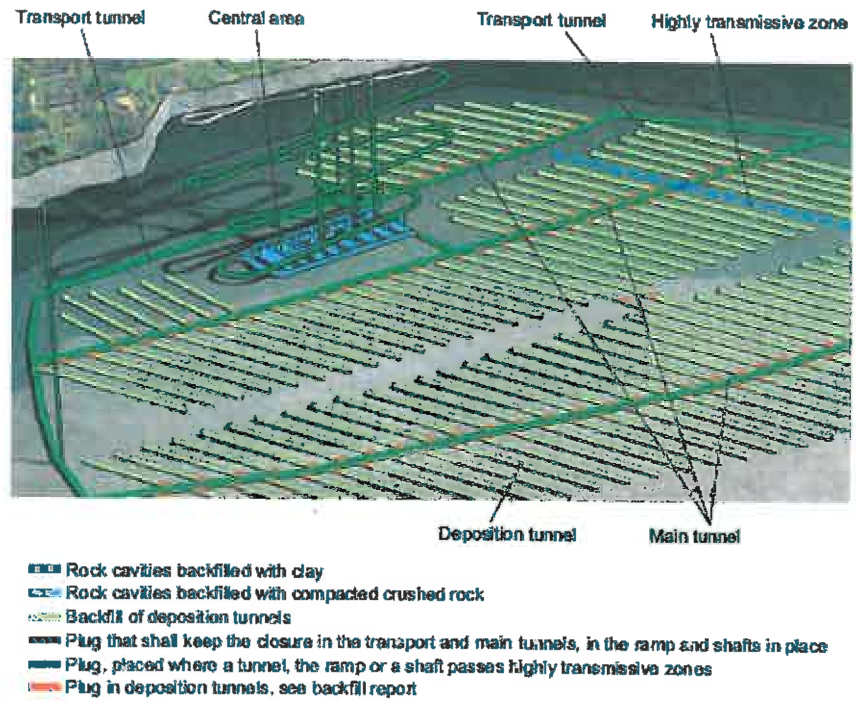


Hardin – Disposal Concepts (25 Sept. 2012)

4

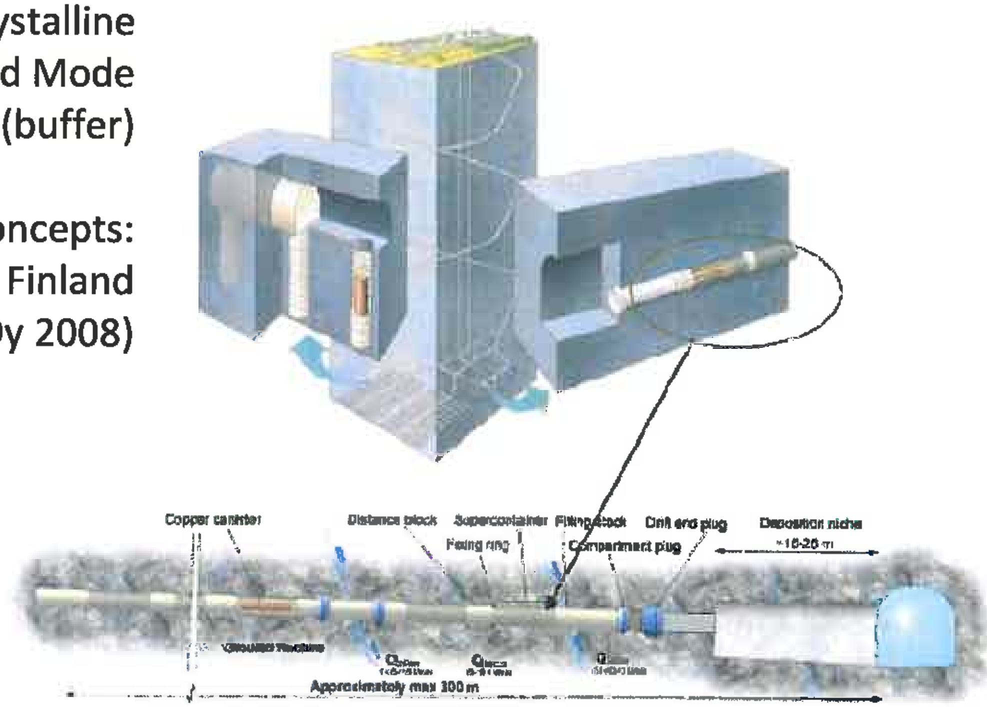
KBS-3H/V Summary, cont.

- Conceptual drawing of Forsmark KBS-3V repository (SKB 2011)
- Relatively large diameter (> 5 m) "deposition tunnels"
- Staggered intersections
- Waste handling ramp
- Shielded transport and underground operations
- Rockbolt support; concrete floors
- Completely backfill, plug, and seal at closure



Crystalline Enclosed Mode (buffer)

Example Concepts: Finland (Posiva Oy 2008)



Crystalline (buffer) Enclosed Mode Discussion

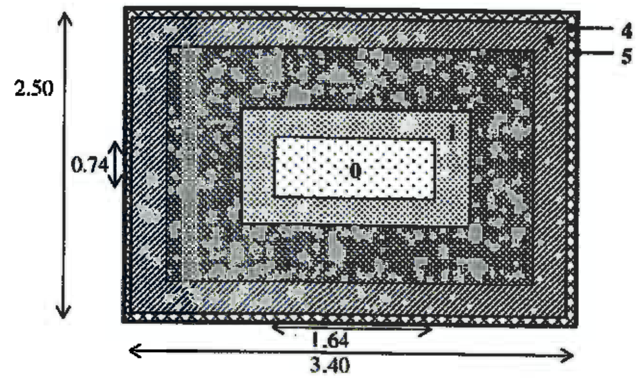
- Buffer Material
  - Swelling pressure as performance measure (SKB 2006)
    - > 0.2 MPa limits package sinking
    - > 1 MPa inhibits advective transport ($K_{sat} < 10^{-12}$ m/s)
    - > 2 MPa (or "high" per SKB 2011) inhibits microbial transport
    - < 2,050 kg/m³ (hydrated) dampens 5-cm rock shear (also withstands PGV ≤ 1 m/s)
    - < 15 MPa limits load on packages
  - Na- or Ca-smectite materials (freshwater, seawater, in situ brine)
  - Admixtures: sand, crushed rock, graphite
- Buffer Configuration Control
  - Thickness, compaction and initial (dehydrated) density
  - Emplacement in humid environments
  - Optional features, e.g., multi-layer EBS with porous "reservoir"

Crystalline (buffer) Enclosed Mode Discussion

- Waste Package Options
  - Corrosion allowance (Cu, Fe)
  - Slow corrosion
    - Cu corrosion damage insignificant for >> 10^5 yr at "undisturbed" conditions
    - Fe (carbon steel, low-alloy steel) limited by hydrolysis (> 1 μm/yr)
      - ➢ Oxygen-limited (1st order) down to f_{O2} ~ 0.01 atm (e.g., 5 μm/yr)
  - Corrosion resistant
    - Ni-Cr alloys, Ti
- Supporting Features
  - Borehole collar (design limits access drift size?)
  - Shield plug
  - Remove concrete from access drift floors (?)
  - Access drift backfill
- → <u>Prefabrication</u>

Prefabricated EBS Module (PEM)

- After McKinley et al. (2006)
- Sand/sandstone "reservoir"
  - Mechanical support
  - Permeable
  - Phase separation mediates H_2 gas generation
- Shell corrosion products and bentonite/sand limit buffer erosion
- Shell protects dehydrated buffer during thermal period (potentially >> 100°C)



		Volume (m^3)	Mass (Mg)
0	Vitrified waste in 15 cm thick steel canister		
	Glass	0.15	0.40
	Fabrication container (stainless steel)	0.01	0.08
	Canister (steel)	0.5	3.80
			4.28
1	Sand / sandstone (20 cm thick)	1.38	3.20
2	Bentonite (40 cm thick)	6.31	9.50
3	Bentonite/Sand 50:50 (25 cm thick)	8.29	14.90
4	Geotextile: 2 cm thick	0.72	0.27
5	Shell: 1 cm thick (steel)	0.36	2.72
			Σ = ~35

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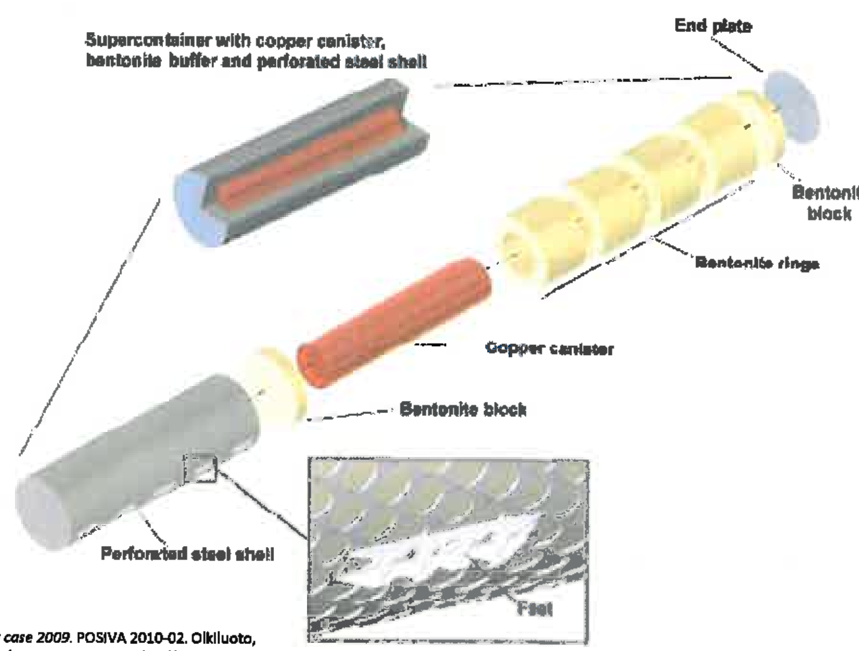
Prefabrication for Horizontal Emplacement

- Long ~horizontal boreholes
- Grouting to seal fracture zones
- Acceptance criteria for rock fracturing
- Similar to successful borehole sealing technology



Posiva Oy 2010. *Interim summary report of the safety case 2009.* POSIVA 2010-02. Olkiluoto, Eurajoki, Finland: Posiva Oy. www.posiva.fi/files/1226/POSIVA_2010-02web.pdf.

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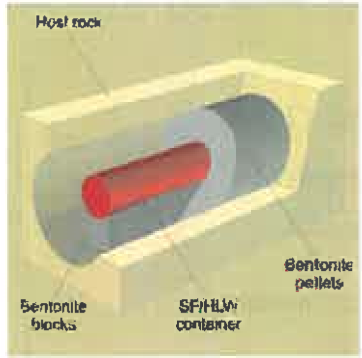
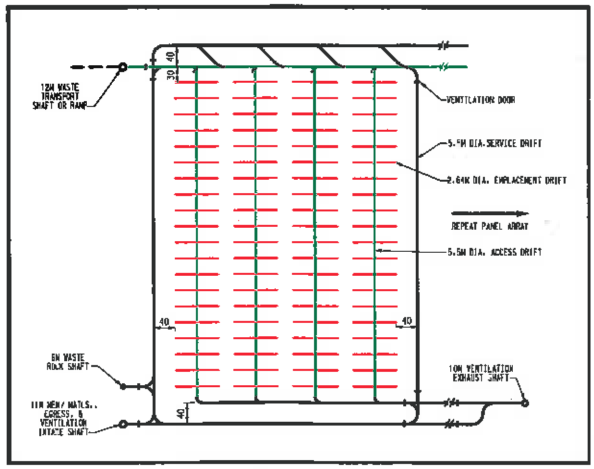
In-Drift Disposal (buffer)

- Small-diameter emplacement openings (< 3 m, blind headings)
- More excavation options, less excavated volume
- Low-permeability buffer/backfill
- Waste package pedestal (compacted clay)
- Logistics of backfilling (unshielded?)
- Prefabrication options (see clay/shale concept; Hardin et al. 2012)



Picture from Nagra (2009)



Hardin – Disposal Concepts (25 Sept. 2012)

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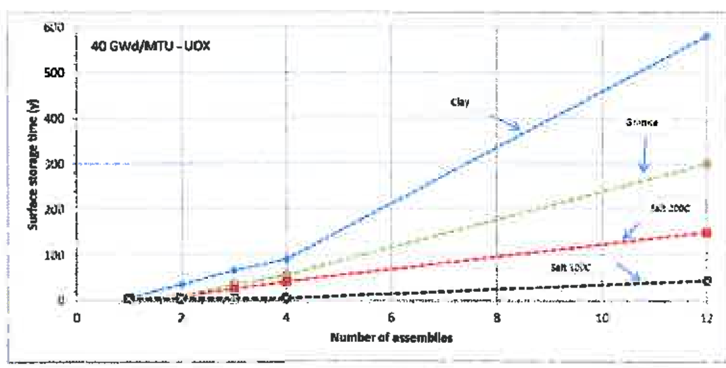
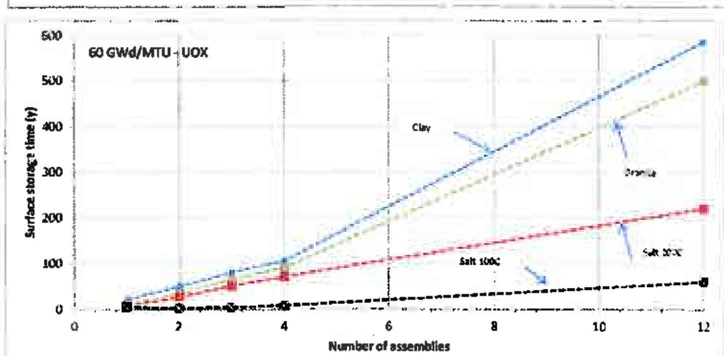
Thermal Analysis of Enclosed-Mode Disposal Concepts Including KBS-3V Comparing Crystalline, Clay/Shale, and Salt Disposal Media

- **Effect of UOX SNF burnup: 40 and 60 GW-d/MT**
- **Peak salt temperature limit: 200°C**
- **Peak clay buffer or clay/shale formation temperature: 100°C**
- **Longer decay storage required for clay-based buffer/backfill concepts**





Source: Greenberg et al. 2012.

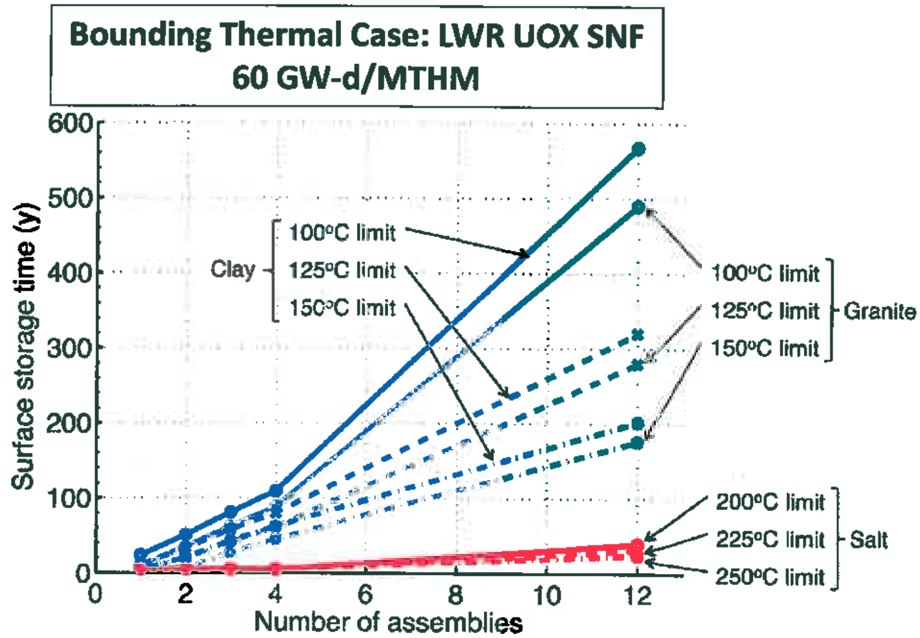
Thermal Analysis of Enclosed-Mode Disposal Concepts Including KBS-3V

Surface Storage Time vs. Waste Package Capacity

(meeting 100°/200°C waste package surface/buffer temp. limits)

Concerns:

- Long storage time (≥ 100 yr)
- Many small waste packages
- KBS-3 solution cost effective?



Hardin – Disposal Concepts (25 Sept. 2012) Source: Greenberg et al. 2012. 13

Mined Disposal Concepts: "Open" vs. "Enclosed" Emplacement Modes

- **Enclosed**: clay buffer and/or backfill (salt, clay/shale) surrounds the waste package at emplacement
  - **Greater near-field thermal resistance → higher EBS temperatures**
- **Open**: in-drift emplacement, and excavated emplacement openings persist
  - **Heat spread by thermal radiation across gaps**
  - **Larger, hotter waste packages**
  - **Pre-closure ventilation for heat removal**
  - **Earlier emplacement (e.g., eliminate dry cask surface storage, and/or avoid transporting older SNF)**
  - **Potentially lower cost, less worker dose**

Hardin – Disposal Concepts (25 Sept. 2012) 14

Disposal Concept Systematics:

Crystalline Rock

Disposal Concept/
Emplacement Mode

"Enclosed" Mode

Saturated or Unsaturated

- Borehole Emplacement
  - SKB (2011)
  - AECL (1994)
  - KAERI/SNL (2007)
  - Pastina and Hellä (2006)
  - Taipower (2009) *
  - Wang (2010)
- In-Drift (buffer)
  - CTECH (2002)
  - Santiago & Astudillo (1999)
  - JNC (2000)
  - Zuidema et al. (2006)

"Open" Mode

- Saturated or Unsaturated → In-Drift (backfill)
  - CARE - McKinley et al. (2008)
- Unsaturated → Moisture Barriers (unbackfilled)
  - SNL (2012)
  - U.S. DOE (2008)

* Both borehole and in-drift emplacement modes are being considered.

"Open" Modes for Large Waste Packages

Dual-Purpose Canisters

- **Existing cast iron storage/transport cask (CASTOR V, ~120 MT containing 10 MT SNF)**
- **Variations are used internationally**

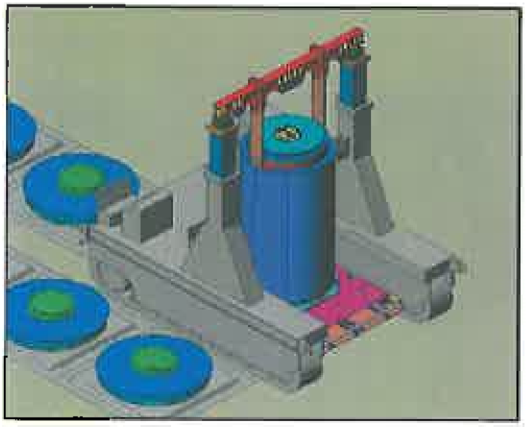
- **Over 50% of U.S. UNF is stored in Transnuclear (TN, part of Areva) designed systems**
  - >650 TN horizontal casks
  - >23,000 assemblies
  - 31 U.S. sites at the end of 2010

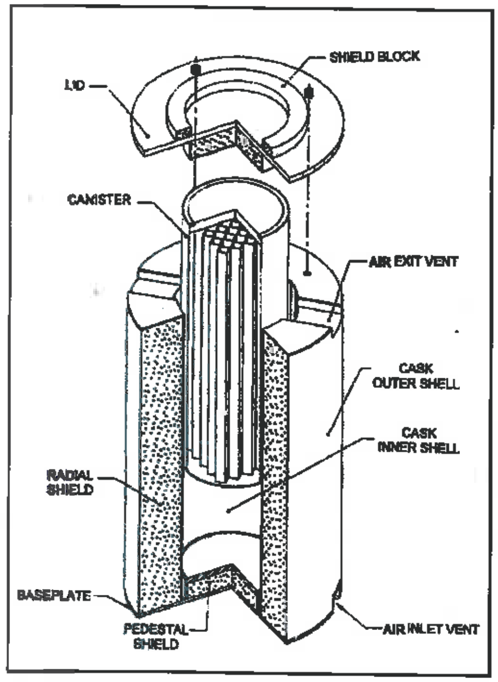
Pictures and data from Transnuclear/AREVA

"Open" Modes for Large Waste Packages

Dual-Purpose Canisters - Subterranean

- Holtec HI-STORM 100U subterranean canister overpack system (32 PWR/68 BWR)
- Based on HI-STORM 100 shielded overpack with bolted closure, and welded stainless "multi-purpose" canister for SNF (24 PWR/68 BWR)
- Uses HI-TRAC (125 ton max.) transfer cask
- Mitigates aircraft crash hazard





Pictures from EPRI Spent Fuel Storage Handbook

Hardin – Disposal Concepts (25 Sept. 2012)

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"Open" Modes for Large Waste Packages

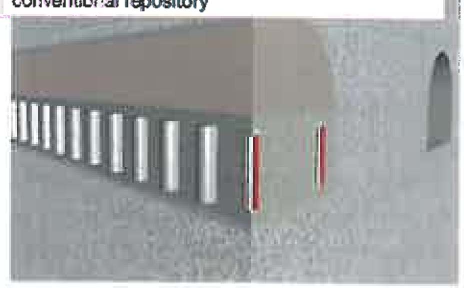
CARE (Cavern Retrievable) Concept

– Focus on interim storage, with conversion to permanent disposal (e.g., at 300 yr)

A Initial **Emplacement Phase** of storage casks in CARE uses standard technology which can be tele-operated

B During the extended ***Storage Phase***, casks in CARE are fully inspectable and can be easily retrieved for reprocessing or moved to allow cavern refurbishment

C. When a decision is made for a final ***Disposal Phase***, the CARE facility can be backfilled and sealed with safety barriers similar to those in a conventional repository



Hardin – Disposal Concepts (25 Sept. 2012)

After McKinley et al. (2008) & EPRI (2010)

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"Open" Modes for Large Waste Packages
Hard-Rock Unsaturated Open-Mode Disposal Concept

- Near-surface access (unsaturated)
- Long-term opening stability
- High-temperature host rock tolerance
- Underground access
- Retrievability
- Oxidizing environment
- Corrosion resistant waste package
- Engineered barriers to water contact with waste
  - Clay-based backfill
  - Drip shield
  - Richards barrier

Hardin – Disposal Concepts (25 Sept. 2012)   Source: Hardin et al. (2012)   19

Large Waste Package Disposal Challenges:
Shaft Conveyance

- **U.S.A. (WIPP)**
  - TRU waste
  - Container weights (unshielded): various   Max. weight for loaded RH containers: 2.8 MT max.
  - Shaft diameter: 5.7 m; depth 671 m
- **Belgium (Mol)**
  - Supercontainer dimensions maximum 6.25 m long and 2.15 m diameter
  - Supercontainer weight: ~65 MT   Capacity: 4 PWR assemblies
  - Shaft diameter: ~7.8 m; depth ~225 m (proposed)
- **Germany (Gorleben)**
  - POLLUX container dimensions 5.5 m long and 1.5 m diameter
  - Container weight: ~64 MT   Capacity: up to 10 PWR assemblies (consolidated)
  - Shaft diameter: ~7.5 m; depth 840 to 933 m (2 shafts, inactive)
- **Canada (Bruce Site, Tiverton, Ontario)**
  - ILW and LLW
  - Container weight (unshielded): ~30 to 35 MT
  - Shaft diameter: 6.5 m (finished); depth 680 m (proposed)
- **Germany (Alternative Gorleben design)**
  - CASTOR V container dimensions 5.5 m long and 2 m diameter
  - Container weight (with iron disposal cask): ~120 MT   Capacity: 10 MT SNF
  - Shaft diameter: ~8 m; depth ~900 m (under evaluation by DBE TEC)

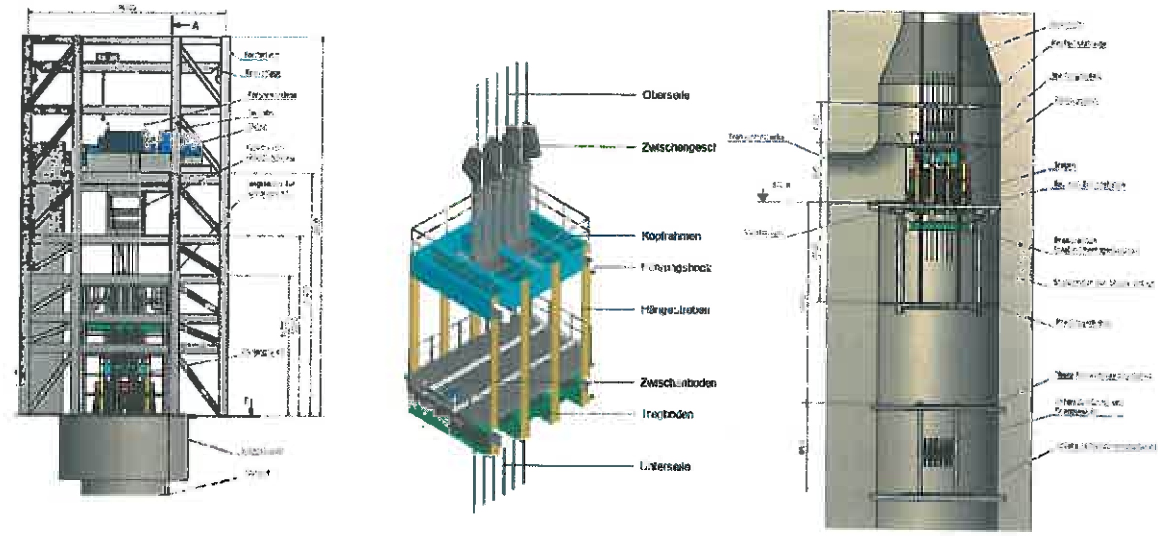
Hardin – Disposal Concepts (25 Sept. 2012)   20

Large Waste Package Disposal Challenges:

Conveyance – DIREGT Concept (GNS/DBE TEC)

Sandia National Laboratories

Concept would double the existing maximum Gorleben hoist capacity (~175 MT payload)



Reinhold Graf, Dr. Klaus-Jürgen Brammer (GNS), Wolfgang Filbert (DBE TECHNOLOGY GmbH). Direkte Endlagerung von Transport- und Lagerbehältern - ein umsetzbares technisches Konzept. Jahrestagung Kerntechnik 2012, Stuttgart, 24.05.2012.

Hardin – Disposal Concepts (25 Sept. 2012) 21

Rough Cost Estimates for 140,000 MT Projected U.S. SNF Inventory

Sandia National Laboratories

- Estimates include: repository design, construction, operation, overpacks, maintenance, closure, and monitoring
- Don't include: siting, characterization, initial licensing, waste canisters, and transport

Costs in $Millions (2012)	Crystalline (enclosed)		Generic Salt Repository (enclosed)		Clay/Shale (enclosed)		Shale Unbackfilled (open)		Sedimentary Backfilled (open)	
Element	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
Facility Design, Construction, Startup	3,754	5,495	3,896	5,595	6,872	10,064	3,303	4,711	5,410	7,599
Operations & Maintenance	17,545	22,475	7,947	10,259	26,884	34,525	9,702	12,408	9,614	12,264
Closure	9,563	13,704	832	1,363	5,556	8,334	1,622	2,515	2,263	3,558
Waste Packages	17,489	21,647	3,998	4,950	7,542	9,337	2,882	3,569	2,882	3,569
Regulatory & Licensing	424	441	368	379	414	429	417	421	668	679
Monitoring	10,685	14,571	4,580	6,246	9,021	12,302	3,395	4,629	3,775	5,148
Performance Confirmation	411	561	567	773	758	1,034	423	576	798	1,088
Program Integration	1,575	2,142	2,136	2,907	2,914	3,965	3,732	5,084	6,878	9,370
Design/Construction/Operation/Maintenance/Closure in $ per kg SNF	$439	$579	$174	$232	$428	$571	$182	$242	$231	$309

Hardin – Disposal Concepts (25 Sept. 2012) Source: Hardin et al. (2012). 22

Summary (1/2)

- KBS-3 concept
  - Vertical or horizontal borehole emplacement
  - Low or high host rock permeability (avoid fracture zones)
  - Saturated or unsaturated
  - Grouting may be needed
  - Can be prefabricated (!)
- In-drift emplacement mode
  - Enclosed mode: similar to KBS-3
  - Additional excavation method options
  - Reduce excavation volume
- Comparative thermal analysis (crystalline, shale, salt)
  - KBS-3 → Long storage times (~100 yr) or small waste packages (4-PWR size)
- Potential adjustments for increased thermal loading
  - PEM (prefabricated EBS) with steel "shell" to protect clay buffer (borehole or in-drift emplacement)
  - "Open" modes (in-drift)

Summary (2/2)

- How to dispose of fewer, larger waste packages (e.g., storage casks)?
- Open emplacement modes in crystalline rock
  - CARE concept (backfilled and sealed for permanent closure)
  - Hard rock unsaturated disposal concept
- Other challenges with large packages
  - Waste package conveyance (e.g., shaft hoist or ramp transport)
- Rough estimates for disposal cost
  - 3x range among alternatives considered
  - <u>Number of waste packages</u>
  - <u>Reliance on natural vs. engineered barriers</u>

References

AECL (1994). Environmental Impact Assessment on the Concept for Disposal of Canada's Nuclear Fuel. Document AECL-10711, COG-93-1. Atomic Energy of Canada, Ltd., Whiteshell, Canada.

Andra (2005). *Dossier 2005 argile – architecture and management of a geological disposal system.* December 2005.

Arnold, B.W., et al. (2010). "Into the deep." *Nuclear Engineering International.* pp. 18-20. February, 2010.

Carter, J.T., F. Hansen, et al. (2011). *A generic salt repository for disposal of waste from a spent nuclear fuel recycle facility.* SRNL-RP-2011-00149 Rev. 0. Aiken, SC: Savannah River National Laboratory.

CTECH (2002). Conceptual design for a deep geologic repository for used nuclear fuel. CTECH Report 1106/MD18085/REP/01. (http.//www.nwmo.ca)

EPRI (2010). *EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste, Volume III: Review of National Repository Programs.* Electric Power Research Institute, Palo Alto, California. Report #1021614. December, 2010.

Greenberg, H.R. et al. 2012. *Investigations on Repository Near-Field Thermal Modeling – Repository Science/Thermal Load Management & Design Concepts.* Lawrence Livermore National Laboratory. LLNL-TR-491099 Rev. 2. August, 2012.

Hardin, E. et al. (2012). *Disposal Concepts/Thermal Load Management (FY11/12 Summary Report).* U.S. Department of Energy, Office of Used Nuclear Fuel Disposition. FCRD-UFD-2012-00219 Rev. 1.

JNC (2000). *H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan.* Report TN1410 2000-001. Japan Nuclear Cycle Development Institute, Muramatsu, Tokai-Mura, Japan.

KAERI/SNL (2007). *Preliminary Conceptual Design and Performance Assessment of a Deep Geological Repository for High-level Waste in the Republic of Korea.* Korea Atomic Energy Research Institute and Sandia National Laboratories. Final Report. Sept. 28, 2000.

McKinley et al. (2006). "Geochemical optimisation of a disposal system for high-level radioactive waste." *Journal of Geochemical Exploration.* V.90, pp. 1-8.

McKinley et al. (2008). "Cavern disposal concpets fvor HLW/SF: assuring operational practicality and safety with maximum programme flexibility." International Technical Conference on the Practical Aspects of Geological Disposal of Radioactive Waste, 16-18 June 2008, Prague, Czech Republic.

Nagra (2009). *The Nagra Research, Development and Demonstration (RD&D) Plan for the disposal of radioactive waste in Switzerland.* Nagra Technical Report 09-06. Nagra, Wettingen, Switzerland.

Pastina, B. and P. Hellä (eds.) (2006). *Expected Evolution of a Spent Nuclear Fuel Repository at Olkiluoto.* POSIVA 2006-05. Posiva Oy, Olkiluoto, Finland.

Posiva Oy (2008). *KBS-3H Design Description 2007.* POSIVA 2008-01 Posiva Oy, Olkiluoto, Finland.

Posiva Oy (2010). *Interim summary report of the safety case 2009.* POSIVA 2010-02. Posiva Oy, Olkiluoto, Finland.

Santiago, J.L. and J. Astudillo (1999). "Overview of the Spanish Program for High-Level Waste Disposal." Waste Management Conference WM '99, Phoenix, Arizona, February 28-March 4, 1999.

SKB (2011). *Long-term safety for the final repository for spent nuclear fuel at Forsmark: Main report of the SR-Site project, Volume I.* Swedish Nuclear Fuel and Waste Management Co. Technical Report TR-11-01.

Taipower (2009). *Spent Fuel Disposal Program – investigation and assessment of potential disposal host rock.* Taiwan Power Company 2008. Taipei, Taiwan (in Chinese).

U.S. DOE (2008). *Yucca Mountain Repository License Application for Construction Authorization.* U.S. Department of Energy.

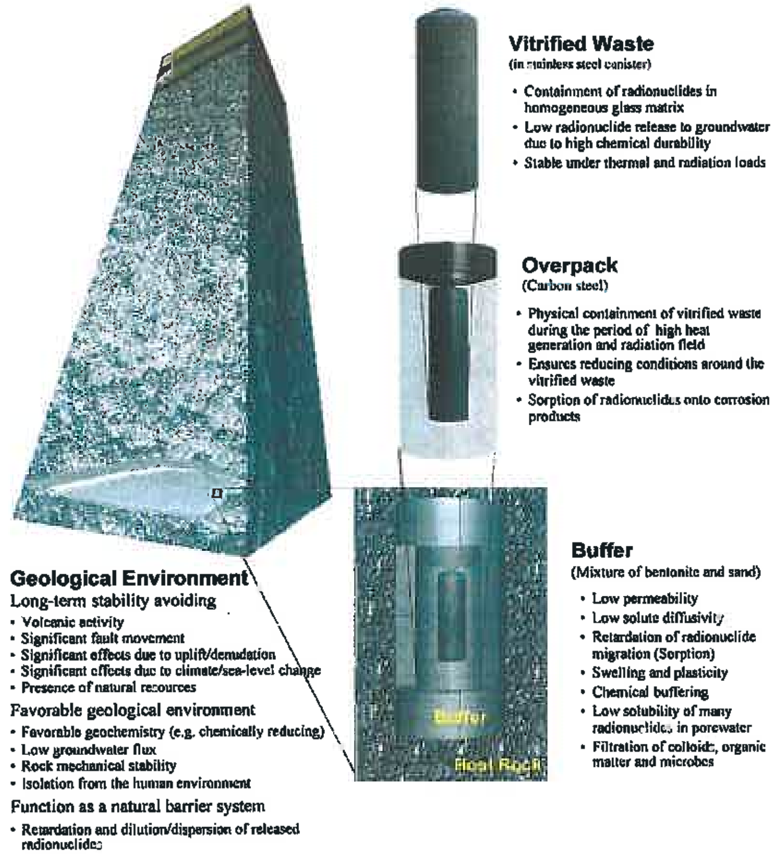
Wang (2010). "High-Level Radioactive Waste Disposal in China: 2010 Update." *Journal of Rock Mechanics and Geotechnical Engineering.* 2010 V. 2(1), pp. 1-11.

Zuidema et al. (2006). "The Swiss high-level waste programme: Status and future challenges." Proceedings: 11th Intl. High-Level Radioactive Waste Mgmt. Conf. (IHLRWM). April 30-May 3, 2006. Las Vegas, Nevada.

Backup Slides

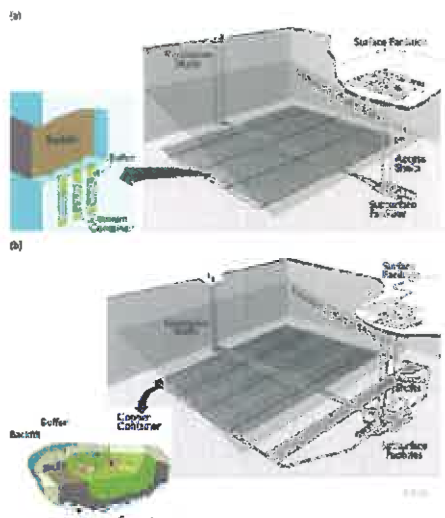
Crystalline (buffer) Enclosed Mode

Example Concepts: Japan (JNC 2000)



Crystalline (buffer) Enclosed Mode

Example Concepts: Canada (AECL 1994)



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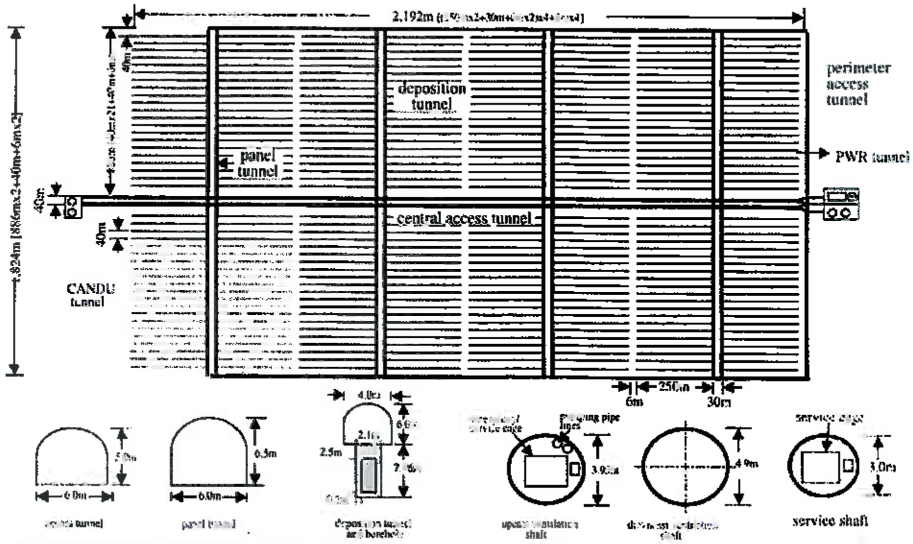
Crystalline (buffer) Enclosed Mode

Example Concepts: China (Wang 2010)

Crystalline (buffer) Enclosed Mode

Example Concepts: Korea (KAERI/SNL 2007)



Deposition tunnel/borehole(PWR)	1,993,811
" (CANDU)	311,821
Panel tunnels	512,722
Shafts	28,519
Access tunnel	263,776
Total	*3,110,649*

No. of deposition tunnel (PWR)	300
No. of deposition tunnel(CANDU)	34
No. of canister(PWR)	11,375
No. of canisters(CANDU)	2,529
Vol. for Buffering (m^3)	322,641
Vol. for backfill(dep. tunnel, m^3)	1,860,646

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Generic Disposal Concept "Taxonomy"

Emplacement Mode [1]

- Plastic Host Media (low perm., nominally sat. or unsat.)
  - Low Perm.[2]
    - Nominally Sat. or Unsat.[3]
      - Buffer/ Backfill
      - No Buffer/ Backfill[4]
- Indurated ("competent") Host Media
  - Higher Perm.
    - Saturated
      - Buffer/ Backfill
    - Unsat.
      - No Buffer/ Backfill[5]
  - Low Perm.[2]
    - Nominally Sat. or Unsat.[3]
      - Buffer/ Backfill
      - No Buffer/ Backfill[4]

1. Consider postclosure performance, nominal scenario (disruptive scenarios are site-specific)
2. Less than ~10^{-16} m^2
3. Effectively diffusion dominated transport, whether hydraulically saturated or unsaturated.
4. Rely instead on remote plugging/sealing of emplacement openings
5. Use diversion barriers (e.g., drip shields, or capillary barriers)

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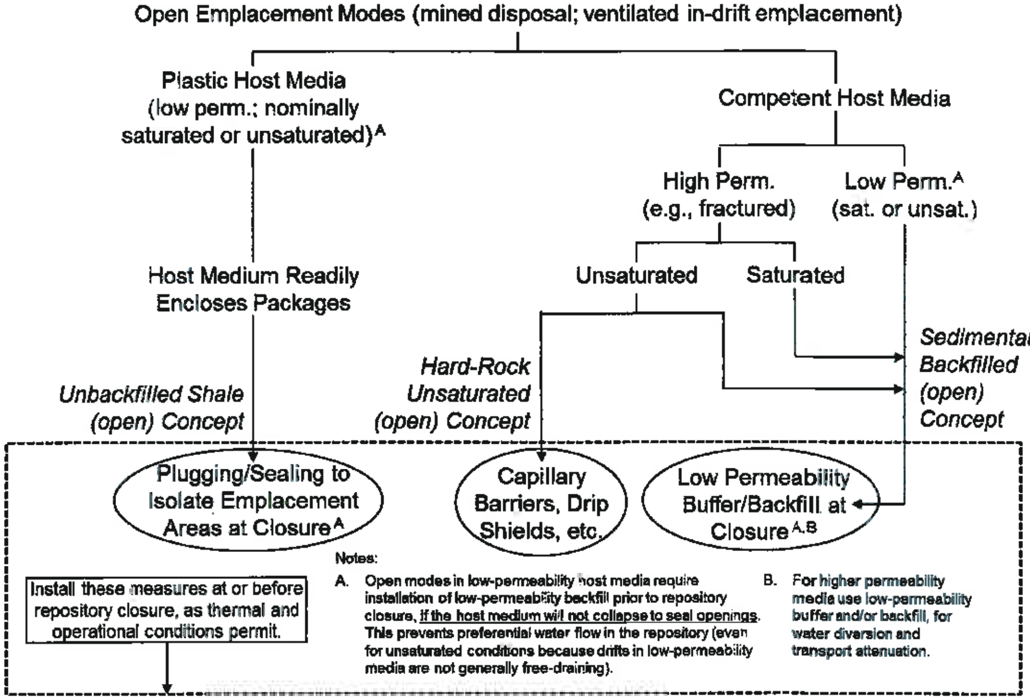
Open Emplacement Mode "Taxonomy"



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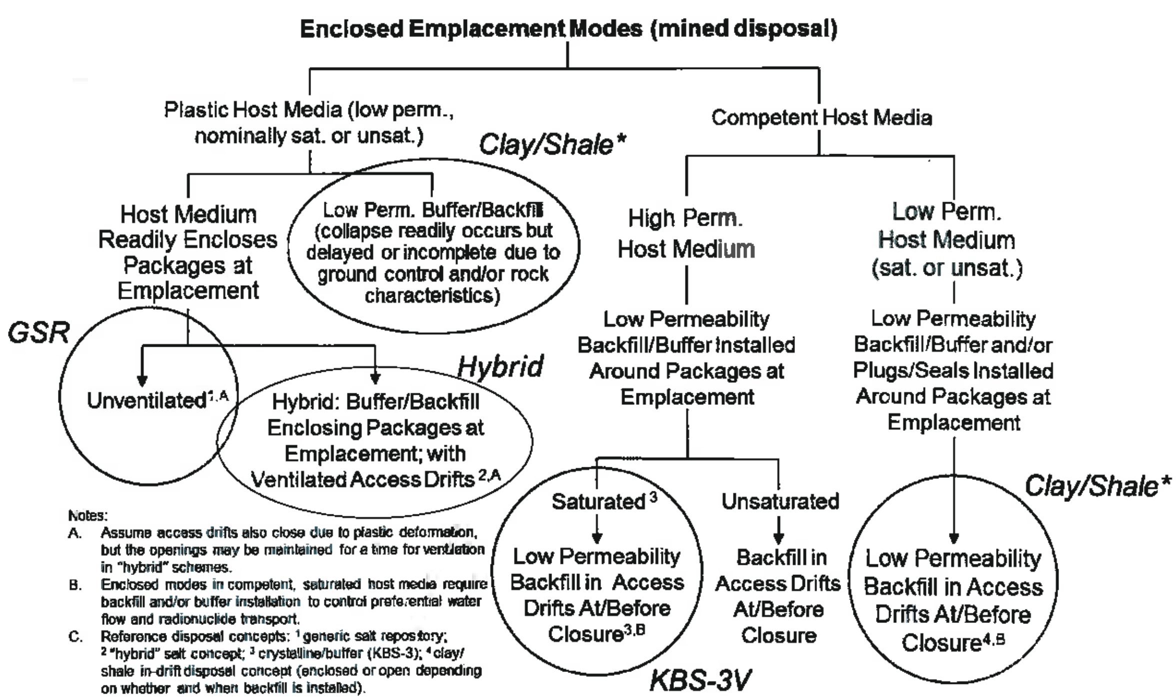
Enclosed Emplacement Mode "Taxonomy"



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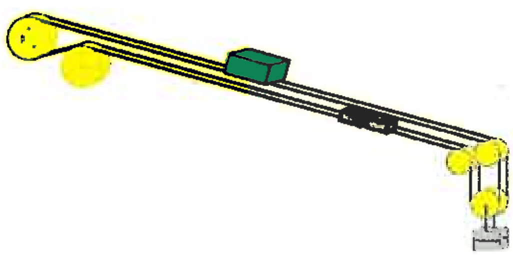
Large Waste Package Disposal Challenges:

Ramps and Other Solutions



- Ramp concepts
  - Shallow (~2% grade) to deep (~10%)
- Transporters
  - Rail (≤2.5% grade) or rubber-tired (≤ 15%)
- Power
  - Diesel or battery
  - Electric (pantograph)
- Performance
  - 90 MT payload (Äspö) but essentially unlimited
  - ~30 m/min; self-leveling
- Hazards
  - Fire, runaway
- Funicular railway
  - Inclination up to 15°
  - Payload >100 MT
  - ~3 m/sec
  - Counterweighted
  - Redundant drive and braking

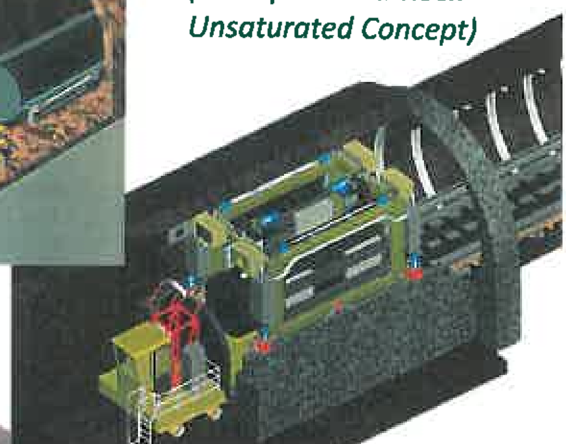
Large Waste Package Disposal Challenges:

Conveyance – Underground

Alternative Underground Conveyances (Example: Hard-Rock Unsaturated Concept)

Wheelift® Concept*

Rail-TEV Concept
- Rail gauge 11 ft.
- Turning radius 200 ft.
- Top speed 150 ft/min
- Design grade 2.5%
- Load capacity < 99 MT
- U.S. DOE (2008)



Rail-Gantry Concept*

* As shown, emplacement handling is unshielded, and an underground transfer station is needed.

Wheelift and rail-gantry figures: www.wheelift.com

Thermal Management Trends

Comparison of Disposal Concepts

Crystalline options considered (Hardin et al. 2012):

Enclosed Emplacement Modes

	High Kth*	Tolerance (EBS up to 200°C?)	WP (PWR assy.'s)	Min. UOX Fuel Age at Emplacement (yr)	Constraint
Crystalline (KBS-3)			4	~ 100	Clay-based buffer (~100°C)
Generic Salt (Carter et al. 2011)	√	√	12	~ 50	Peak salt temp. (200°C)
Clay/Shale (Andra 2005)			4	~ 100	Clay-based buffer (~100°C)
Deep Borehole (Arnold et al. 2010)		√	1	~ 10	None

Open Emplacement Modes

	High Kth*	Tolerance (EBS up to 200°C?)	WP (PWR assy.'s)	Min. UOX Fuel Age at Closure (yr)	Constraint
Hard Rock Unsaturated		√	≥ 21	≥ 50 (+/-)	Host rock (200°C)
Shale Unbackfilled			≤ 21	≤ 250 (21-PWR WP)	Host rock (~100°C)
Sedimentary Backfilled			≤ 21	≤ 300 (21-PWR WP)	Clay-based backfill (~100°C)

* Host rock thermal conductivity > 3 W/m-K; possible for some crystalline rock types.

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AMPHOS 21

SCIENTIFIC AND STRATEGIC ENVIRONMENTAL CONSULTING

Modelling hydrogeology and hydrochemistry in support of Safety Assessment for radwaste repositories in fractured rocks. Case studies from Sweden and Finland

Jorge Molinero

INDEX OF THE PRESENTATION

- Motivation
- Modelling approach
- Verificaton example
- Application example
- Conclusions

AMPHOS 21

MOTIVATION

- Reactive Transport Modelling (RTM) is the most powerful tool for quantitative coupling of hydrogeology and geochemistry

- In the context of geosphere studies for sitting Deep Geological Repositories, RTM has enormous potential for:

  - Evaluation of radionuclide migration
  - Evaluation of hydrochemical evolution of the repository

- However, big RTM models (site-descriptive, large-scale, long term…) are unaffordable for computational reasons

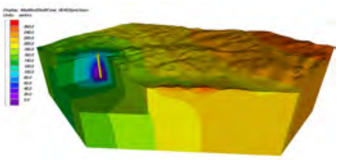
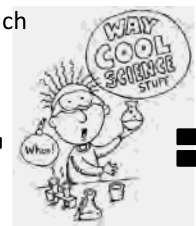
AMPHOS 21

MOTIVATION

The "short blanket" dilemma

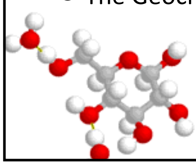
Is the blanket too short?

- The Hydrogeological approach

 + 

= **The feet uncovered**

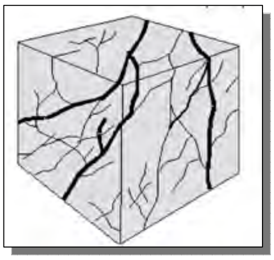
- The Geochemical approach

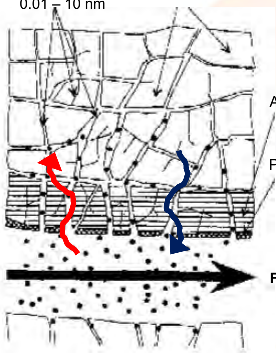
 +  = **The neck exposed**

AMPHOS 21

MODELLING APPROACH

- Main assumption: In crystalline fractured rock, the groundwater flow is highly channelized, so a streamtube conceptualization of solute transport can be adopted:





MODELLING APPROACH

3D hydrogeological models→ Velocity fields

↓

A number n of particles can be released generating a number n of independent streamlines

↓

Each streamline has its own length, mean velocity, minerals, etc…

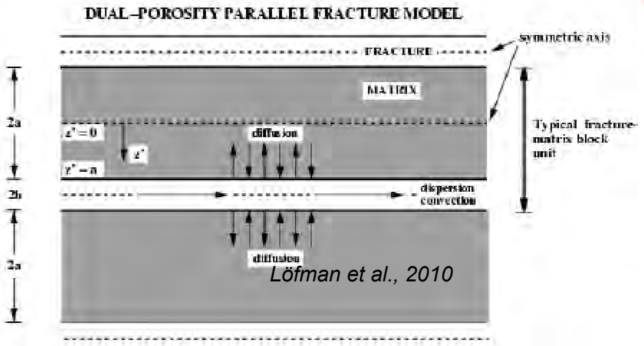
↓

Reactive transport processes are coupled to groundwater flow along each streamline

The complex 3D problem is decomposed to multiple simple 1-D problems

MODELLING APPROACH

- Matrix diffusion is accounted in the streamtubes



$$\phi_{matr}\frac{\partial c_{matr}}{\partial t}=\frac{\partial}{\partial z}\left(D_e\frac{\partial c_{matr}}{\partial z}\right)\approx\alpha\left(C_{fract}-C_{matr}\right)$$

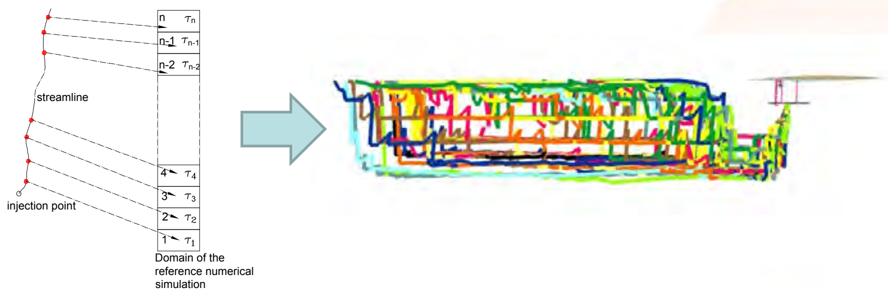
$$\alpha=\frac{D_e}{(a\cdot f_s)}$$

D_e : effective diffusion coefficient [L^2T^{-1}]
a : half of matrix thickness
f_s : shape factorc

MODELLING APPROACH

- If the geochemical problem is homogeneous:

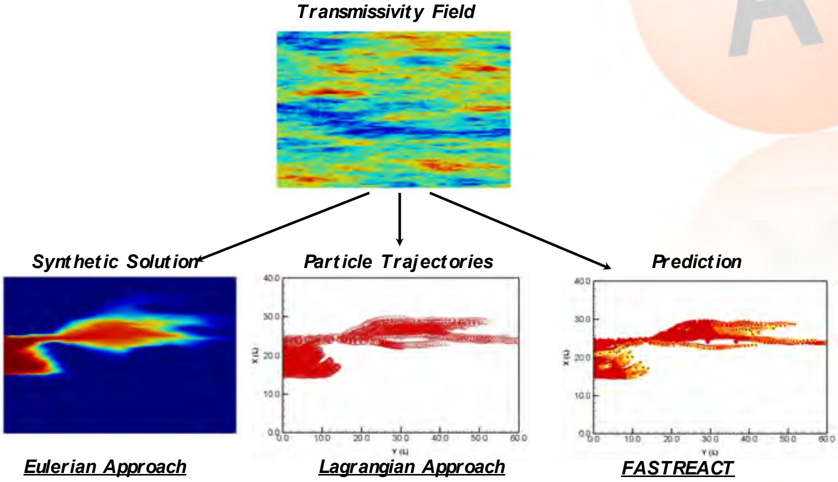
The 1-D RTM can be written as a function of travel time
→ Only 1 RTM simulation is required, writen as a function of travel time



FASTREACT: a **F**r**A**mework for **ST**ochastic **REAC**tive **T**ransport

Does it works? How accurate such a method would be?

VERIFICATION EXAMPLE



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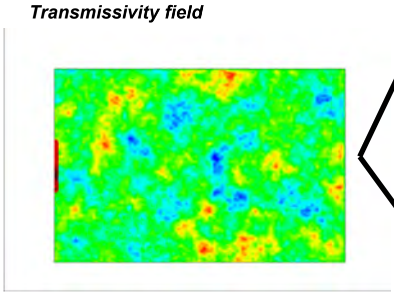
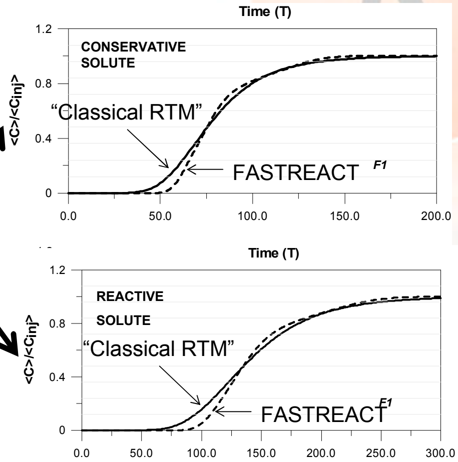
VERIFICATION EXAMPLE

Transmissivity field





RTM for migration of Stromtium:

"Posible" co-precipitation with Calcite
Cation exchange in planar sites

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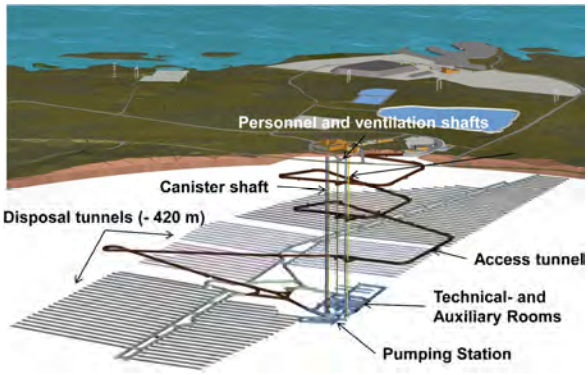
APPLICATION EXAMPLE

- In 2004, **POSIVA** started the construction of the **Onkalo tunnel (Olkiluoto, Finland)**. It is an Underground Rock Characterisation Facility being built **for the final disposal of spent nuclear fuel**



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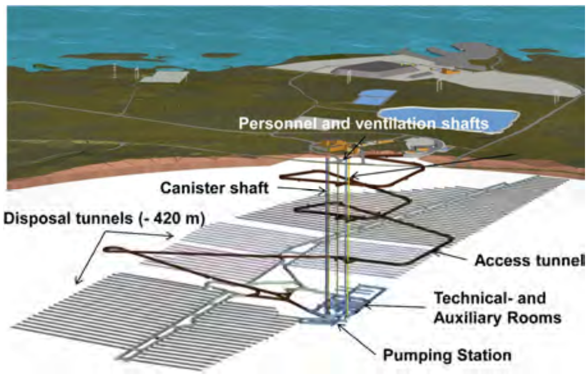
APPLICATION EXAMPLE

- In 2009, **POSIVA** started the **Safety Assessment exercise** for the Onkalo Facility. One of the key requirements is to **evaluate the long-term hydrogeochemical evolution** at repository depth



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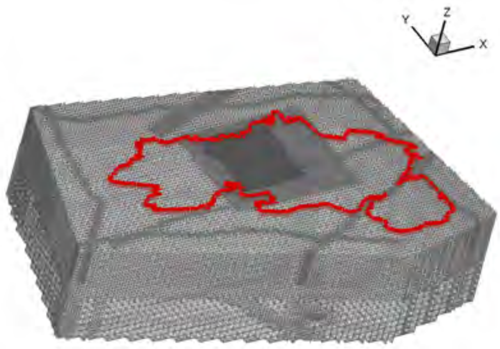
APPLICATION EXAMPLE

- Site-scale hydrogeological model developed by VTT

FEM mesh:
970731 nodes
5638571 elements



3D velocity fields

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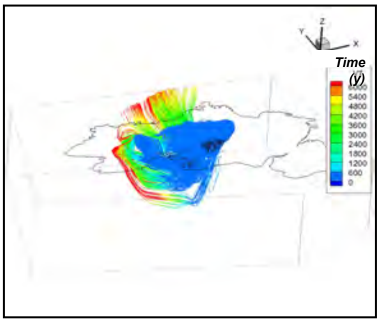
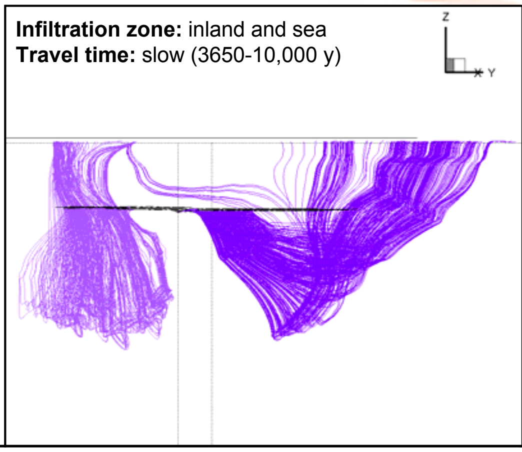
APPLICATION EXAMPLE

- **Particle back-tracking** for water trajectories (streamtubes). One particle at each projected canister position (**3926 injection points**)





APPLICATION EXAMPLE

- Hydrochemical Initial and Boundary Conditions

	Altered Meteoric PVP-4A_2	Sea Water Baltic RW
TDS (mg/L)	567	
pH	7.3	7.7
TOTAL CONC. (mol/L)		
Cl	3.39E-03	8,53E-02
SO_4	9.99E-04	4,68E-03
DIC	1,12E-02	
Alk (mol HCO_3/L)	9,54E-03	1,29E-03
SiO_2	7,12E-04	9,65E-06
F	6,32E-05	1,42E-05
Br	2,50E-06	1,29E-04
Al	1,93E-07	
Na	2,14E-03	7,70E-02
K	3,42E-04	1,69E-03
Ca	4,61E-03	2,00E-03
Mg	1,28E-03	9,00E-03

BOUNDARY CONDITIONS

	Brackish HCO_3 KR4_81_1	Brackish SO_4 Ol-KR6_135_8	Brackish/saline OL-KR20_465_1	Saline OL-KR10_498_1	Highly saline OL-KR12_741_1
TDS (mg/L)	1122	7225	10544	22099	49483
pH	7.44	7.6	7.4	8	8.2
Eh (mV)	-260	-237			
TOTAL CONC. (mol/L)					
Cl	9.90E-03	0,260	1.81E-01	3.81E-01	8.63E-01
SO_4	9,58E-04	4,79E-03	2.10E-04	1.00E-05	5.00E-05
DIC	4.87E-03	1,86E-03	5.50E-04	1.10E-04	4.00E-05
Alk (mol HCO_3/L)	4.57E-03	1,82E-03	6.60E-04	1.10E-04	1.20E-04
PO_4	1.68E-06			1.00E-10	2.60E-09
SiO_2	2.00E-04	3,66E-04	3.60E-04	2.80E-04	2.10E-04
F	3.16E-05	3,16E-05	1.00E-08	9.80E-08	
Fe	1.02E-05	6,45E-06	2.50E-06	2.00E-06	3.80E-07
Al	1,48E-06				
Na	1.31E-02	1,53E-01	1.15E-01	2.10E-01	3.61E-01
K	2.48E-04	9,72E-04	2.80E-04	3.60E-04	4.90E-04
Ca	1.34E-03	3,24E-02	3.24E-02	8.91E-02	2.55E-01
Mg	7.40E-04	1,48E-02	2.60E-03	1.60E-03	1.50E-03
Mn	3.46E-06	4,37E-05	5.80E-06	7.30E-06	9.30E-06

INITIAL CONDITIONS

APPLICATION EXAMPLE

- Mineralogy and geochemical conceptual model

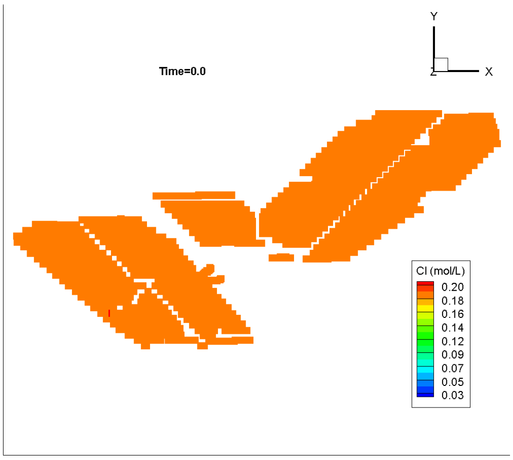
		Assumptions	Initial amount (mol/L)	Reactive surface area (m²/L)	Reference kinetic law
Calcite	Present in fractures	Equilibrium Dissol./Precip.	6.065	1.120	
Pyrite	Present in fractures	Equilibrium Dissol./Precip.	1.170	0.280	
K-feldspar	Present in fractures	Kinetics dissolution	0.239	0.260	Schweda (1989)
Illite	Present in fractures	Kinetics dissolution	0.144	0.482	Wieland and Stumm (1992)
Albite	Present in fractures	Kinetics dissolution	0.289	0.292	Chou and Wollast (1985)
Am.. SiO_2	Able to precipitate	Equilibrium precipitation	0.000	0.000	
Am. $Fe(OH)_3$	Able to precipitate	Equilibrium precipitation	0.000	0.000	
Illite	Able to precipitate	Equilibrium precipitation	0.000	0.000	
Kaolinite	Able to precipitate	Equilibrium precipitation	0.00	0.428	

Porosity = 0.5

APPLICATION EXAMPLE

- Type of results obtained: **Open Repository (0-90y)**

Chloride Evolution



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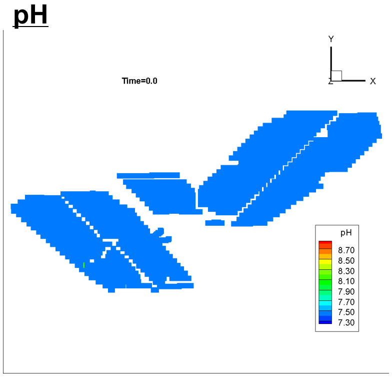
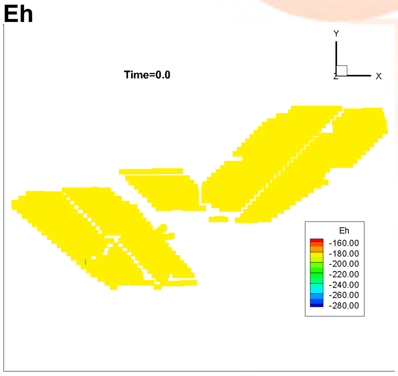
APPLICATION EXAMPLE

- Type of results obtained: **Open Repository (0-90y)**

pH



Eh



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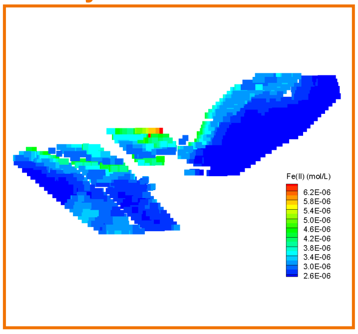
APPLICATION EXAMPLE

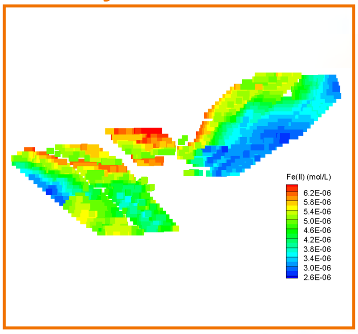
- Type of results obtained: **Temperate period (10,000 y)**

Iron [Fe (II)]

t= 1 Kyr



t= 10 Kyr



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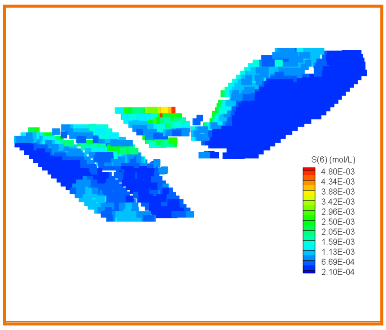
APPLICATION EXAMPLE

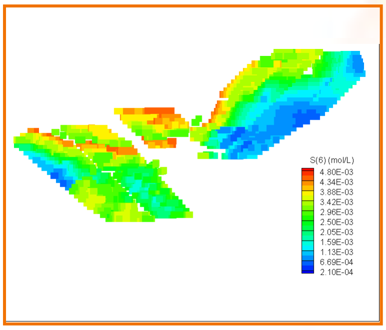
- Type of results obtained: **Temperate period (10,000 y)**

Sulphate

t= 1 Kyr



t= 10 Kyr



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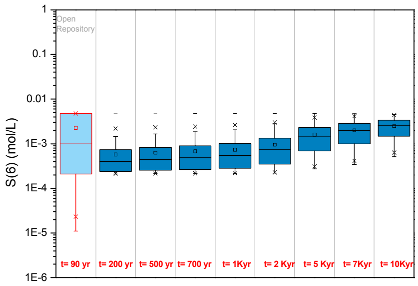
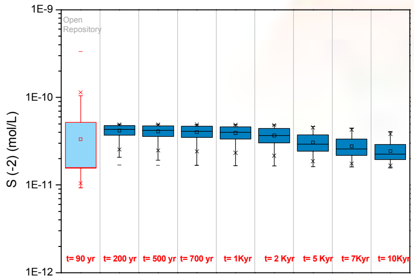
APPLICATION EXAMPLE

- Type of results obtained:

  Statistical analysis of the long-term hydrochemical evolution of the repository





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CONCLUSIONS

- RTM is a powerful tool for integrating hydrogeology and hydrochemistry in the Geosphere. The main applications of RTM in SA exercises are the simulation of radionuclide migration and the evaluation of hydrochemical evolution of the geosphere.
- Stochastic-convective hybrid approach allows undertaking complex, 3D, site-scale, long-term models that would be unaffordable by conventional Eulerian RTM techniques.
- A methodology called FASTREACT has been developed and successfully verified, to perform stochastic – convective reactive transport along multiple streamtubes. The methodology has been applied to evaluate the long-term hydrochemical evolution of the Onkalo repository in Finland.

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POSIVA

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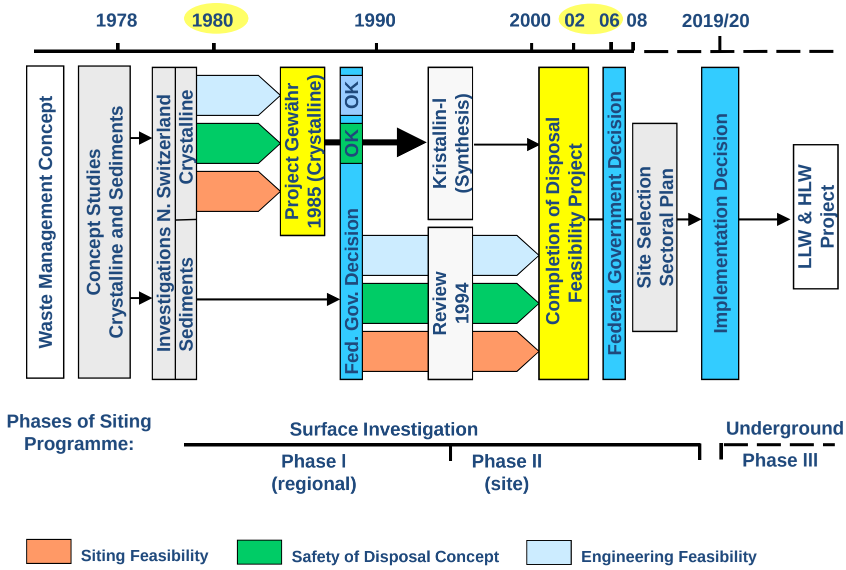
Siting process – Experience from the Swiss Radioactive Waste Management Programme

Crystalline Rock Repository Development
24-27 September 2012, Prague

Dr. Stratis Vomvoris

nagra

HLW geologic repository - overview



Demonstration of Disposal Feasibility

- Demonstration that a repository for spent fuel, vitrified high-level waste and long-lived intermediate-level waste of Swiss origin can be built in Switzerland (meeting all required standards, e.g. regulatory guideline HSK-R-21). It consists of three elements:
  - Siting Feasibility: Demonstration that a **site exists** in Switzerland where a repository can be built
  - Construction Feasibility: Demonstration that a repository can **be built** at a given site and **using current technology**
  - Long-Term Safety: Demonstration that **a given repository design** for a repository at **a given site**, meets the applicable standards for **long-term safety**

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Nagra projects (1980 - 2006)

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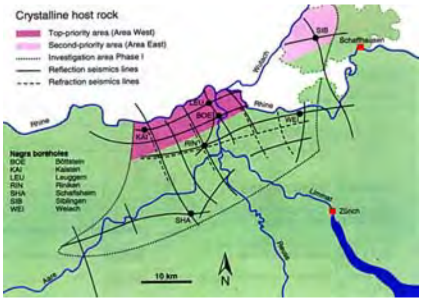
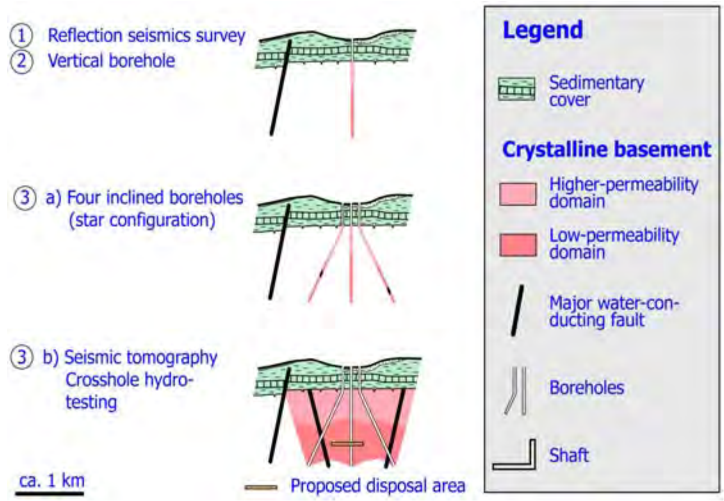
NAGRA's Crystalline Project (KRI): Phase 1



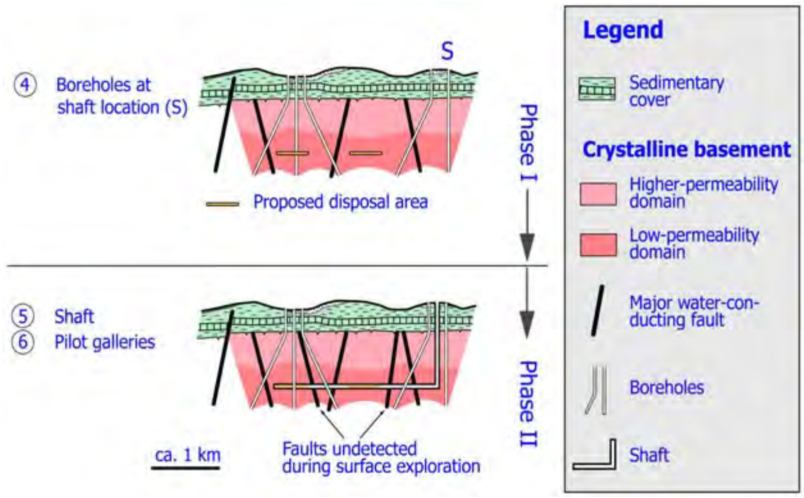
- A deep drilling campaign comprising 7 boreholes with final depths between 1306 and 2482 m.
- Geophysical investigations consisting of reflection and refraction seismic lines, gravimetric and aeromagnetic surveys, etc.
- Long-term monitoring of deep groundwaters
- Hydrogeological modelling
- Hydrochemical studies
- Geological mapping and data compilation
- Geological reconnaissance studies of exposed basement rock in nearby Germany
- Neotectonic studies, including a micro-earthquake recording network, geodetic measurements, geomorphological studies and stress measurements

Conclusion of Phase 1 with a proposal for site investigations and initiation of Phase 2

KRI Project: Phase 2 exploration programme 1/2



KRI Project: Phase 2 exploration programme 2/2



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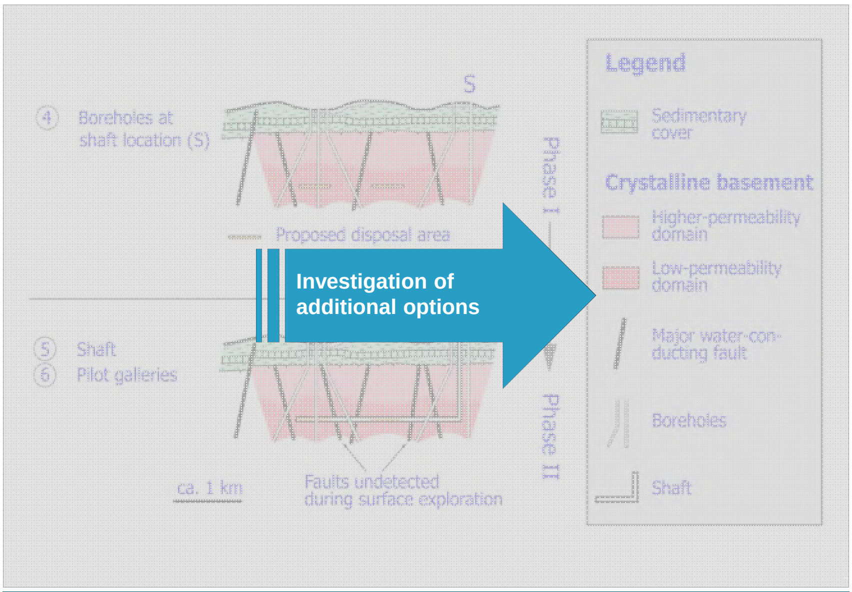
KRI Project: Phase 2 exploration programme 2/2



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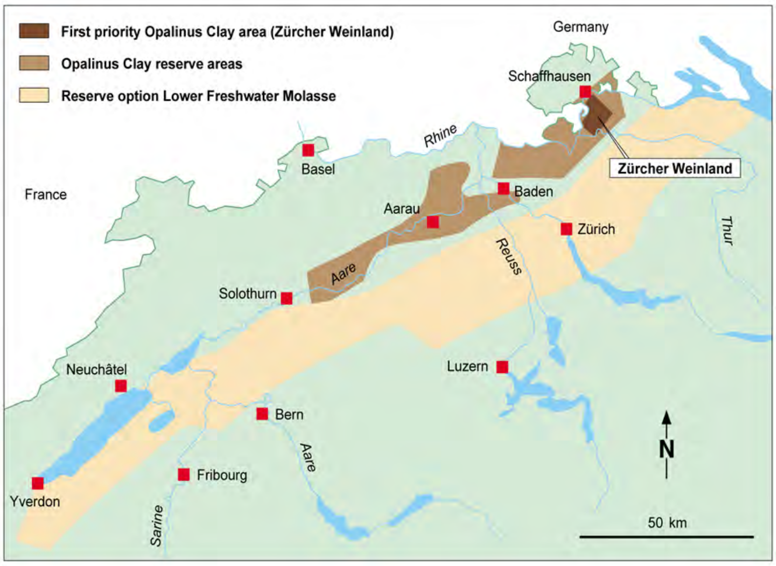
Options in sedimentary formations



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Borehole Benken, 2-D and 3-D seismics

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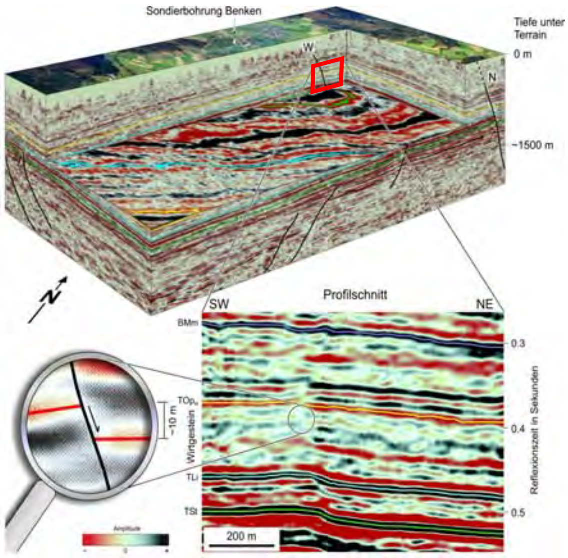
3D - Seismics: Resolution

- Displacements > 10 m are directly visible
- Displacements can be clearly located
- **Geometry of rock layers and structures known**



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Investigation Area Zürcher Weinland

High-Level Waste

View towards north

Nagra deep borehole

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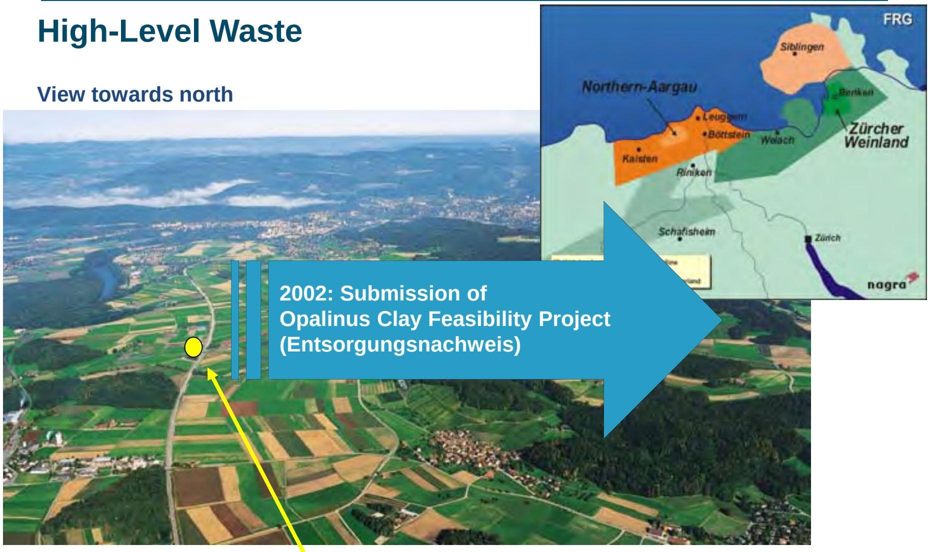
Investigation Area Zürcher Weinland

High-Level Waste

View towards north



Nagra deep borehole

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How to dispose of? Milestone 2006

- The feasibility of safe disposal of radioactive waste in deep geologic repositories in Switzerland **was approved** by the Swiss Government
  - Projekt Gewähr (LLW) 1988
  - Entsorgungsnachweis (HLW) 2006

How to dispose of the waste was clearly answered.

but where?

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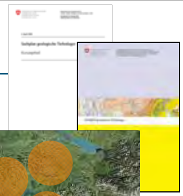
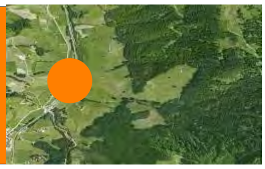
Site selection process – The Sectoral Plan



Selection of potential siting regions for L/ILW & HLW Criteria: safety, technical feasibility, preliminary evaluation of spatial planning issues	**Stage 1** **2008 - *2011***	
Selection of at least two sites for L/ILW and HLW Criteria: socio-economic, environment, preliminary safety assessment, overall evaluation	**Stage 2** **ca. 4 yrs**	
Site selection & general licence (L/ILW and HLW repositories) Criteria: safety, detailed evaluation of socio-economic issues, EIA (stage 1), overall evaluation	**Stage 3** **ca. 3.5 – 4.5 yrs**	

Source: Federal Office of Energy (SFOE)

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Site selection - the Swiss approach

Nomination	Voluntary Approach	Swiss Stepwise Site Selection and Decision-making Approach
Implementor investigates and evaluates various sites	Implementor announces criteria and call for volunteers	Plan, criteria, roles, responsibilities are defined and agreed upon
	One or more communities volunteer	Implementor proposes **siting regions** *Authorirties evaluate & approve*
	Implementor investigates and evaluates sites	Implementor proposes (at least) **two sites** *Authorirties evaluate & approve*
		Implementor investigates and evaluates sites
Implementor proposes site		
Authorities evaluate		
Approval (in Switzerland subject to facultative national referendum)		

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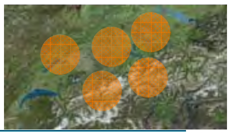
Stage 1: Siting Regions

Methodology for 'Narrowing-Down' to the proposed siting regions

1. Allocation of waste to LLW or HLW repository
2. Safety concept and requirements
3. Suitable geological-tectonic regions
4. Suitable host rocks (incl. adjacent formations)
5. Evaluation with respect to repository configuration/lay-out

Quantitative evaluation for each criteria group ⇨



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Safety & Engineering Criteria for Site Selection (1/3)

Group of criteria	Criteria
1. Properties of host rock	1.1 Spatial extent 1.2 Hydraulic barrier efficiency 1.3 Geochemical conditions 1.4 Migration paths
2. Long-term stability	2.1 Stability of properties 2.2 Erosion 2.3 Repository induced effects 2.4 Resource conflicts
3. Reliability of geological information	3.1 Characterisation of host rock 3.2 Spatial explorability 3.3 Temporal predictability
4. Suitability for construction	4.1 Rock mechanical properties 4.2 Underground access

Source: Bundesamt für Energie (BFE)

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Safety & Engineering Criteria for Site Selection (2/3)

Group of criteria	Criteria	Indicators (example)
1. Properties of host rock	1.1 Spatial extent 1.2 Hydraulic barrier efficiency 1.3 Geochemical conditions 1.4 Migration paths	Thickness Lateral extent Depth - construction Depth - erosion
2. Long-term stability	2.1 Stability of properties 2.2 Erosion 2.3 Repository induced effects 2.4 Resource conflicts	
3. Reliability of geological information	3.1 Characterisation of host rock 3.2 Spatial explorability 3.3 Temporal predictability	Regional fault model Continuity of formations Heterogeneity
4. Suitability for construction	4.1 Rock mechanical properties 4.2 Underground access	

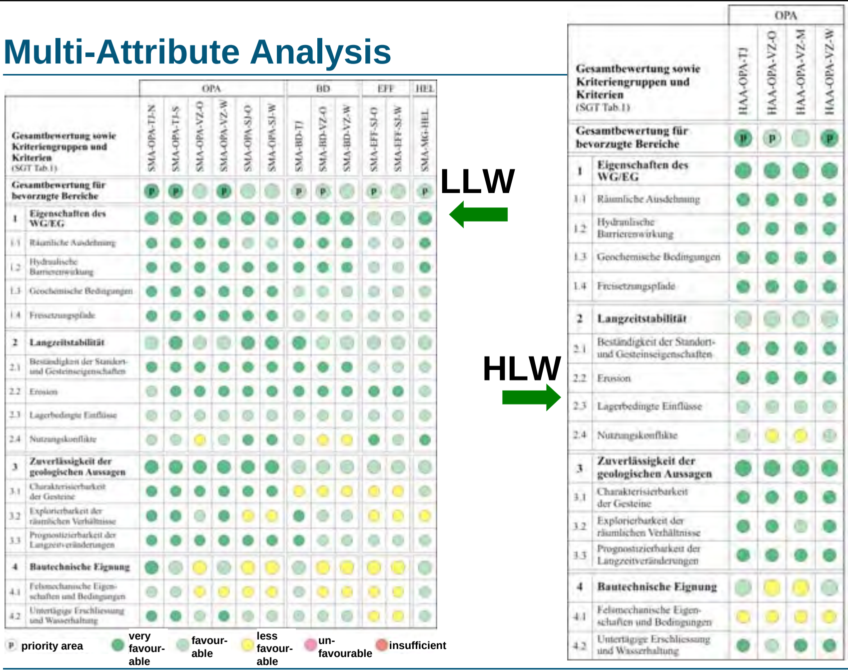
Source: Nagra

Safety & Engineering Criteria for Site Selection (3/3)

Group of criteria	Criteria	Indicators (example)	Requirements
1. Properties of host rock	1.1 Spatial extent 1.2 Hydraulic barrier efficiency 1.3 Geochemical conditions 1.4 Migration paths	Thickness Lateral extent Depth - construction Depth - erosion	> 100 m > 4 km2 < 900 m.b.s. > 400 m.b.s
2. Long-term stability	2.1 Stability of properties 2.2 Erosion 2.3 Repository induced effects 2.4 Resource conflicts		
3. Reliability of geological information	3.1 Characteris. of host rock 3.2 Spatial explorability 3.3 Temporal predictability	Regional fault model Continuity of formations Heterogeneity	
4. Suitability for construction	4.1 Rock mechanical properties 4.2 Underground access		

Source: Nagra

Multi-Attribute Analysis



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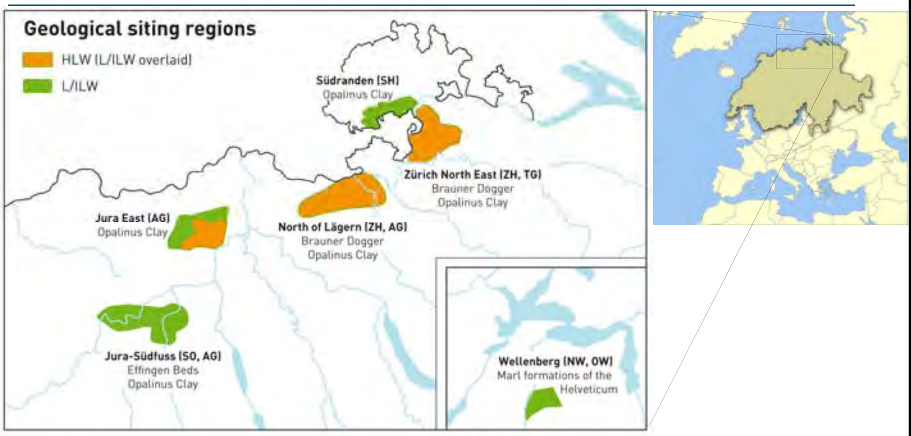
Proposed siting regions – geology



- A result of systematic application of **requirements of Sectoral Plan**
- Considered the geological possibilities of the **whole of Switzerland**
- Derived in a systematic, step-wise narrowing-in process **based on safety and engineering feasibility**

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Narrowing down to the 20 sites (proposed in January 2012)

Goals/Requirements	Criteria
Ensure operational safety and feasibility	▪ Access/Connection to existing transportation network ▪ Topographical and geological situation ▪ Access to underground (repository) ▪ Operational safety
Guarantee compatibility with land use and environment	▪ Zonation ▪ Surface water bodies ▪ Grundwasser ▪ Mineral water wells /hot springs ▪ Protection of nature and landscape
Appropriate local integration in the region	▪ Current use ▪ Embedment in urban development and landscape ▪ Recreational infrastructure/usage ▪ Landscape and natural scenery

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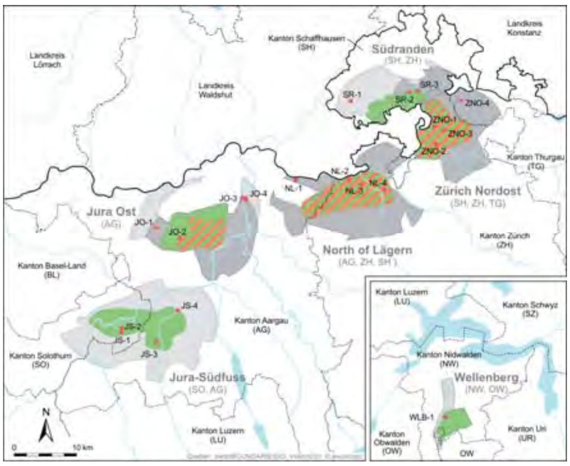
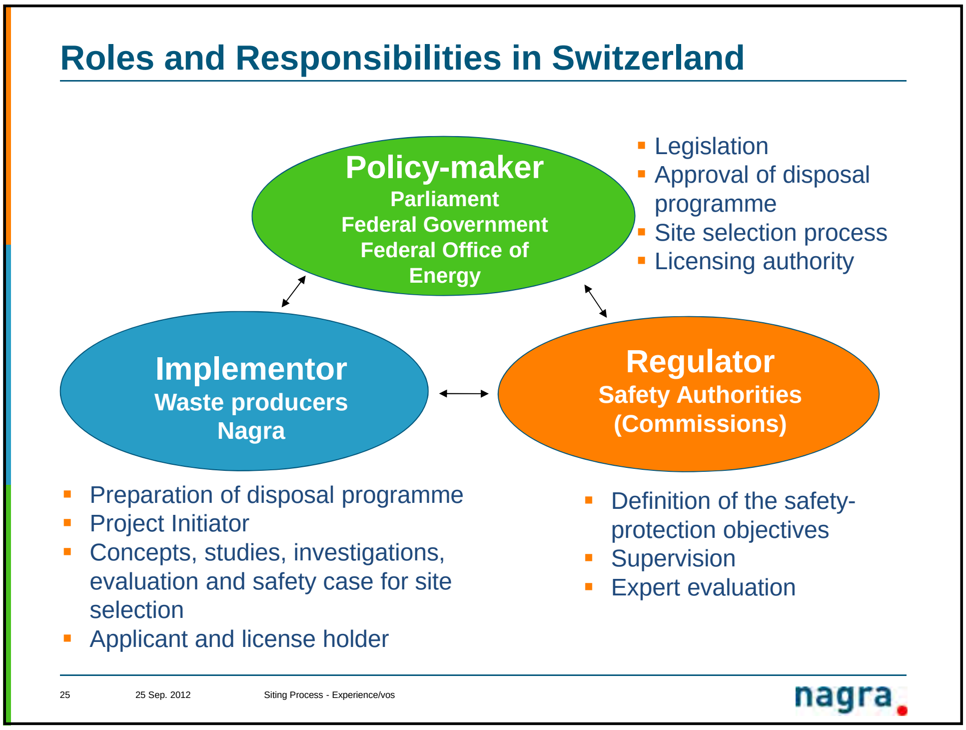
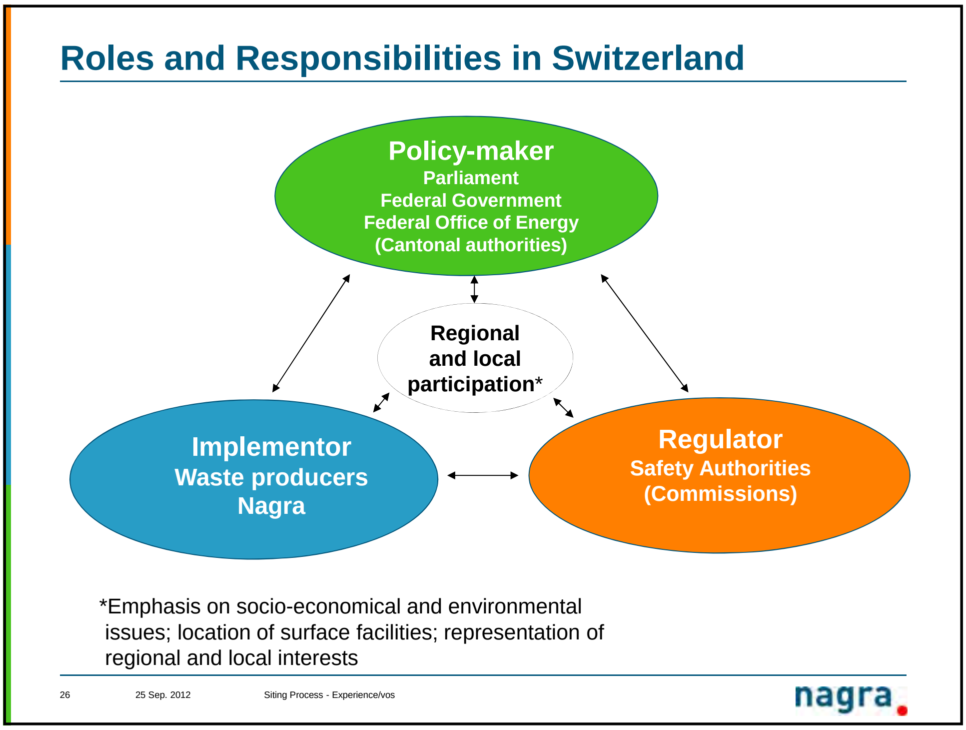
Stage 2: Selection of sites for the surface facilities

Discussion of proposals within regional conferences



24 25 Sep. 2012 Siting Process - Experience/vos nagra


Roles and Responsibilities in Switzerland
Policy-maker
Parliament
Federal Government
Federal Office of Energy
▪ Legislation
▪ Approval of disposal programme
▪ Site selection process
▪ Licensing authority
Implementor
Waste producers
Nagra
Regulator
Safety Authorities
(Commissions)
▪ Preparation of disposal programme
▪ Project Initiator
▪ Concepts, studies, investigations, evaluation and safety case for site selection
▪ Applicant and license holder
▪ Definition of the safety-protection objectives
▪ Supervision
▪ Expert evaluation
25
25 Sep. 2012
Siting Process - Experience/vos
nagra


Roles and Responsibilities in Switzerland
Policy-maker
Parliament
Federal Government
Federal Office of Energy
(Cantonal authorities)
Regional and local participation*
Implementor
Waste producers
Nagra
Regulator
Safety Authorities
(Commissions)
*Emphasis on socio-economical and environmental issues; location of surface facilities; representation of regional and local interests
26
25 Sep. 2012
Siting Process - Experience/vos
nagra

Swiss Site Selection Approach: Key strengths

1. Nomination with respect to the host rock and the siting regions, on the basis of safety and engineering criteria defined explicitly and in advance; strong participatory component for the surface facilities and their location
2. Clear roles and responsibilities
3. Leadership by the Swiss Federal Office of Energy
4. Step-wise decision making and step-wise approval
5. Recognised and accepted technical and scientific know-how from the implementer and the regulator
6. Transparent and traceable decision making (also recognised by the authorities in their review)

27 25 Sep. 2012 Siting Process - Experience/vos nagra

Thank you for your interest

nagra

GEOLOGICAL WORK FOR THE FIRST MILLESTONE ACHIEVEMENT

Frantisek Woller
RAWRA Consultant

SCIENTIFIC VISIT ON CRYSTALINE ROCK REPOSITORY DEVELOPMENT

Prague, September 24 – 27 2012

THE FIRST MILESTONE

The Concept of Radioactive Waste and Spent Nuclear Fuel Management in the Czech Republic defines the first milestone of deep geological repository as follows:

"To select sites with proper geological conditions taking into account local developments at proposed sites. After evaluation of relevant results include two sites into land use plans (main and reserve one) for deep geological repository".

Date: 2018

(Ministry of Industry and Trade, May 2002)

SÚRAO | RADIOACTIVE WASTE REPOSITORY AUTHORITY

GEOLOGICAL WORK (1)

At the stages of site selection and characterization geological work represent the fundamental activity, which is essential for:

- **description of the site geology (s.l.) and site suitability evaluation;**
- **data acquisition for two sites selection;**
- **data acquisition for initial safety report elaboration.**

Elaboration of initial safety report is necessary for the planning permit delivery.

(Building Act 183/2006 Coll.)

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Prague, September 24 – 27 2012

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GEOLOGICAL WORK (2)

Geological work for deep geological repository siting is geological exploration for special intervention affecting Earth crust.

This exploration may be carried out solely in the exploration area established by the Ministry of Environment.

(Geological Act 62/1988 Coll.)

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GEOLOGICAL WORK (3)

Geological exploration on each site will start by the performance of the following main surface methods:

- geological mapping and structure geology;
- hydrogeological and hydrological mapping;
- geophysical exploration;
- geochemical exploration;
- performance of shallow boreholes, trenches and pits;
- samples collection, analyses, tests.

Basic scale of maps: 1 : 10,000

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GEOLOGICAL WORK (4)

Results of the above mentioned activities allow:

- to construct the first model of the site surface geology;
- decision on efficient borehole location in the next step;
- decision on additional work (if necessary).

GEOLOGICAL WORK (5)

Realization of boreholes up to 300m, 500m and 1.000m and their examination will be fundamental activity of the next step.

Namely the following operations will be made:

- ❖ core description and sampling;
- ❖ borehole logging;
- ❖ hydrogeological and hydrochemical testing, sampling and monitoring;
- ❖ rock mechanic tests in borehole;
- ❖ borehole – surface (borehole – borehole) geophysical exploration;
- ❖ core analyses and tests (petrology, geochemistry, physical properties, rock mechanic, radionuclide sorption and diffusion……).

GEOLOGICAL WORK (6)

Results of geological work on each site and its interpretation will be elaborated and published in the form of separate final report.

Explored sites will be compared in separate report concerning geology and other aspects investigated at the same time (monitoring of environment, monitoring of human activities, conflicts of interest, and socio-economic and demographic development…..).

Initial safety report according to design required by the State Office for Nuclear safety will be compiled using data from geological exploration among other think.

GEOLOGICAL WORK (7)

Mentioned geological reports and initial safety report are documents necessary for the establishment of a protected area for special intervention affecting Earth crust.

"Protected area is established by the Ministry of the Environment after a consultation with the Regional Authority through a decision issued in accordance with the Ministry of the Industry and Trade, with the District Mining Authority and in accordance with the territorial planning authority and the Construction Office".

"The boundaries of the protected area are entered into the territorial planning documentation".

(Mining Act 44/1988 Coll.)

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Prague, September 24 – 27 2012

Conclusion

Establishing of a protected area for special intervention affecting Earth crust for two sites represents achievement of the first milestone given by the Concept of Radioactive Waste and Spent Nuclear Fuel Management in the Czech Republic.

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THANK YOU FOR YOUR ATTENTION

fwoller@seznam.cz

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Prague, September 24 – 27 2012

Radioactive Waste Disposal Conflicts of Interest

Jitka Mikšová
Technical Development Project Manager
Geological Repository Development Department

Radioactive Waste Disposal Process:

Main aim of the radioactive waste disposal process:
→ safe repository operation

Main assumption of safe repository operation:
→ appropriate repository design and construction

Main assumption of appropriate repository design and construction:
→ suitable site for repository construction

Main assumption of suitable site selection:
→ successful site selection process including geological investigation

Main assumption and condition of successful site selection process:

solving conflicts of interest in advance

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Repository Life-Cycle

Site Characterisation and Evaluation

Based on desk studies and remote area screening:

archive geological data and information
RS - satellite images, airborne landscape images
airborne geophysical measurement/prospection

Geological investigation on site:

- surface geological investigation
  geological mapping, geophysical measurement, geochemistry, hydrogeology,…
- drilling work
  well logging, core sampling, hydrogeological monitoring,…
- underground work
  underground laboratory, confirmation laboratory, generic laboratory, repository excavation,…

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Site Characterisation

Necessary Prerequisite for Geological Investigation Realisation

Stakeholder Acceptance

Conflicts of interest identification:

- State administration – legislative requirements
- Municipalities – local public approval
- Land owner and land user approval

Basic requirement for the successful solving of conflicts of interest - to be willing to provide all the information required

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Potential Conflicts of Interest

Legislative origin

Placement of Nuclear Facilities and Very Significant Ionising Radiation Sources

- **Excluded areas – uncertain tectonics, earthquake zones,…**

Anthropogenic origin

- **Man-made – dams, power plants, urban areas, historical buildings,…**

Environmental origin

- **Forests, soil,…**

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Potential Conflicts of Interest

Czech legislative requirements - examples

Principal general and specific acts:

- **Environment**
- **Environmental Impact Assessment Act**
- **Conservation of Nature and the Landscape**
- **Town and Country Planning and Building Code (the Building Act)**
- **Wastes and Amendments to certain other Acts**
- **Water and Amendments to certain Acts (the Water Act)**
- **Protection of the Air and Amendments to certain other Acts (the Clean Air Act)**
- **Protection of the Agricultural Land Fund**
- **Forests (the Forestry Act)**
- **Public Health Care**
- **Public Health Protection**

– **Basic mining legal regulations**

– **Basic legal regulations in the field of the peaceful utilisation of atomic energy and ionising radiation**

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Potential Conflicts of Interest

Czech legislative requirements - examples

Basic mining legal regulations:

- Protection and Utilisation of Mineral Resources (the Mining Act)
- Mining Activities, Explosives and the State Mining Administration
- Rational Exploitation of Reserved Deposits, Permission for and Notification of Mining Activities and Notification of Activities carried out by means of Mining Methods
- Establishment, Operation, Safeguarding and Liquidation of Facilities used for Underground Waste Disposal
- Safety and Health Protection and Operational Safety regarding Mining Operations and the Extraction of Non-reserved Minerals
- Principle of the Ministry of the Environment and the Czech Mining Office No. 400/3517/1816 concerning environmental impact assessments for the site and activities pursued in mining operations and the exploitation of non-reserved mineral deposits
  – Basic legal regulations in the area of the peaceful utilisation of atomic energy and ionising radiation

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Potential Conflicts of Interest

Czech legislative requirements - examples

Basic legal regulations in the area of the peaceful utilisation of atomic energy and ionising radiation:

- Peaceful Utilisation of Nuclear Energy and Ionising Radiation (the Atomic Act)
- Radiation Protection as amended
- Nuclear Safety and Radiation Protection Assurance during the Commissioning and Operation of Nuclear Facilities
- <u>Placement of Nuclear Facilities and Very Significant Ionising Radiation Sources</u>
- Basic Design Criteria for Nuclear Installations with Respect to Nuclear Safety, Radiation Protection and Emergency Preparedness
- Decommissioning of Nuclear Installations or Category III or IV Workplaces

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Potential Conflicts of Interest

International legislative requirements and recommendations:

The implementation of Nuclear Installation Projects with regard to International Conventions and Relations:

- **Convention on Environmental Impact Assessments exceeding state boundaries, Espoo, 1991**
- **Aarhus Convention, 1998 -** concluded for the purpose of making environmental information available, creating conditions for the active participation of the public and ensuring legal protection in the area of environmental protection
- **Treaty of the Establishment of the European Atomic Energy Community (Euratom)** - each Member State shall provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever forms which make it possible to determine whether the implementation of such a plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State.
- **Directive of the Council of the European Communities (85/337/EEC**) – If a competent institution of a neighbouring state shows, for political reasons, interest in bilateral meetings, it will be necessary to act so as to meet the requirements arising out of membership of the European Union.

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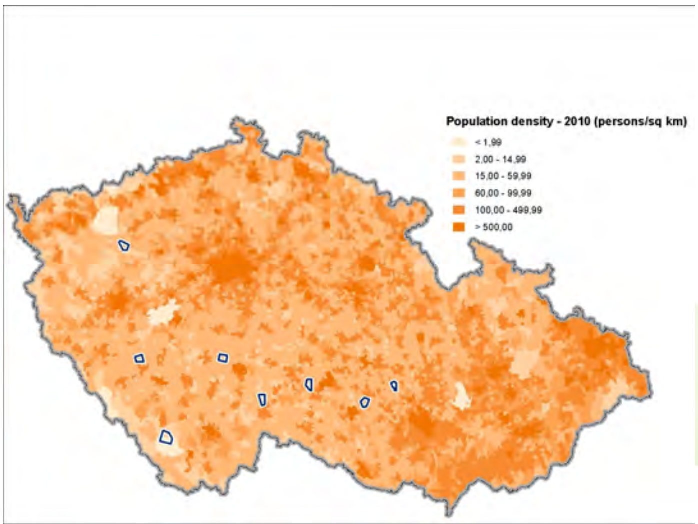
Population density

Area: 78,866 km^2
Capital: Prague – 1.18 million inhabitants

Population: 10.3 million inhabitants.
Population density: 130 inhabitants/km^2

Number of municipalities: 6 248



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Infrastructure

Necessary networks

- electric power distribution network
- gas network
- telecommunications network
- highway, road and railway networks including protected areas alongside them
- air transport routes

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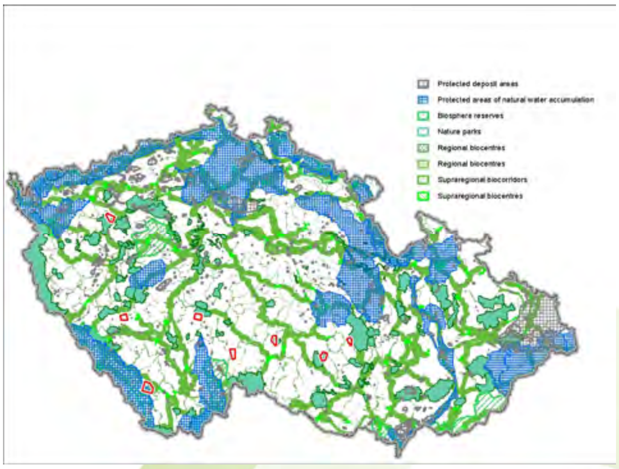
Natural and Human Environments

Environmental protection

Natural parks
Natural reserves
Biosphere reserves
Regional bio-corridors
Regional bio-centres
Natural raw deposit protected areas
Water management network
Drinking water reservoir protection
Natural water accumulation protected areas

NATURE 2000



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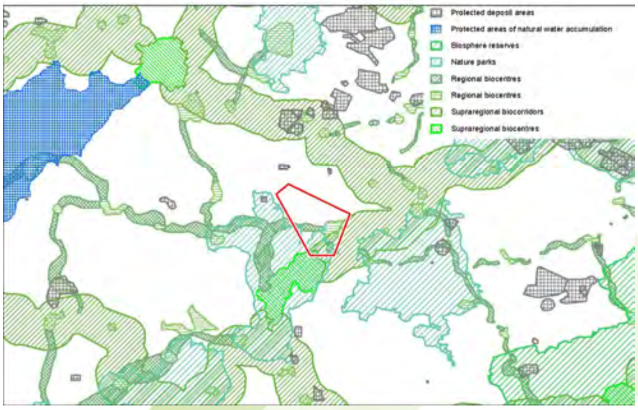
Natural and Human Environments

Environmental protection



NATURE 2000

Natural parks
Biosphere reserves
Regional bio-corridors
Regional bio-centres
Natural raw deposit protected areas
Water management network
Drinking water reservoir protection
Natural water accumulation protected areas

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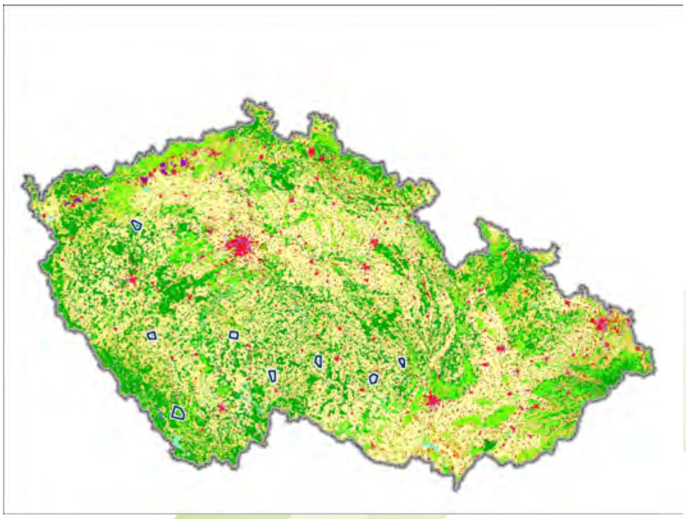
Natural and Human Environments

Land use protection
Land protection
Forest protection



Natural hazards

Flood-prone areas
Earthquakes
Landslides
Mudslides
Tsunamis

CORINE

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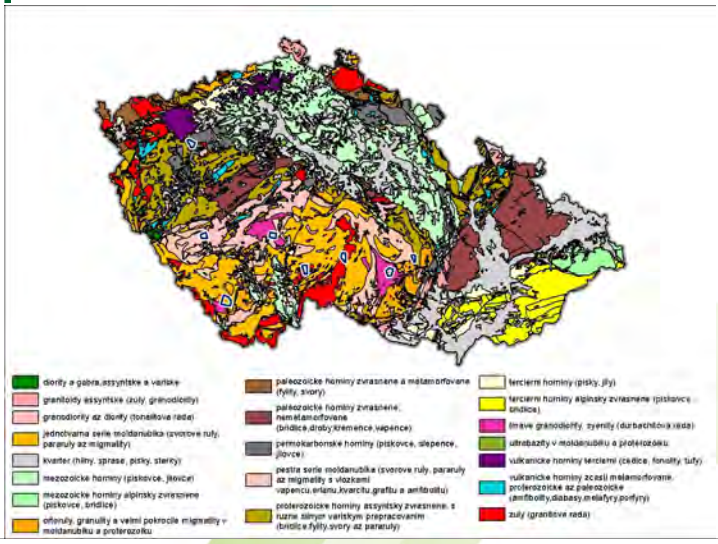
Mineral deposit protection

Geological map



Old and abandoned mines
Protected mineral deposit areas
Mining areas
Deposit reservation

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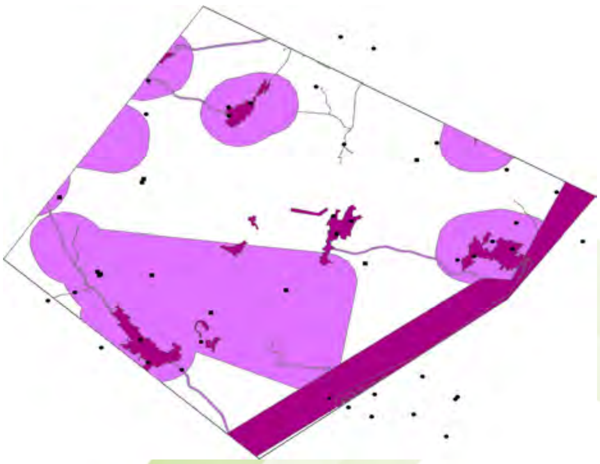
Cultural Heritage Protection

Protection of cultural monuments

Cultural heritage
Historical monuments
National monuments
Archaeological sites

Natural monuments



Recreation zone protection

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How to Solve Potential Conflicts of Interest?

To inform all stakeholders in a transparent way and well in advance on:

- Main aims of geological investigation work
- Extent of geological investigation work
- Subject of geological work
- Geological investigation techniques used on site
- How the work will be performed
- Geological work schedule and duration
- Who will be responsible
- Potential damage compensation
- Potential restrictions/limitations on land use during geological investigation work
- Impact on the environment
- Results publication in a comprehensible way
- Benefits of geological investigation

Profit → - open discussion on conflicts of interest and the best ways in which to solve them

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What is required?

to make every effort to build - win - keep trust in the necessity for geological investigation work or even better in the necessity for a radioactive waste repository

How to do it:

- To follow all legislative requirements
- To prepare alternative scenarios for geological investigation work focusing on site characterisation
- To keep to the time schedule so as not to disturb land-owners and users any longer than necessary
- To ensure responsible people fulfil their promises
- To observe and keep to agreed rules
- To inform stakeholders on any problems/issues
- To move investigation work to an alternative place if conflicts of interest are insoluble – if possible
- To document all the initial conditions before geological investigation begins – especially environmental conditions on site
- To monitor all the necessary aspects – environmental condition changes, drinking water quality, …
- To archive everything necessary in order to prevent potential problems and misunderstandings in future

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Conclusion

Basic requirements when solving potential conflicts of interest in the siting process

to promote the provision of

credible + transparent + convincing + sufficiently detailed information

→ In a timely manner

→ to all concerned

→ and that is all!

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Thank you

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Deep Geological Repository Development in the Czech Republic Technical and Safety Aspects

Radioactive Waste Repository Authority

Jiří Slovák

Deputy Managing Director

Nuclear sites in the Czech Republic

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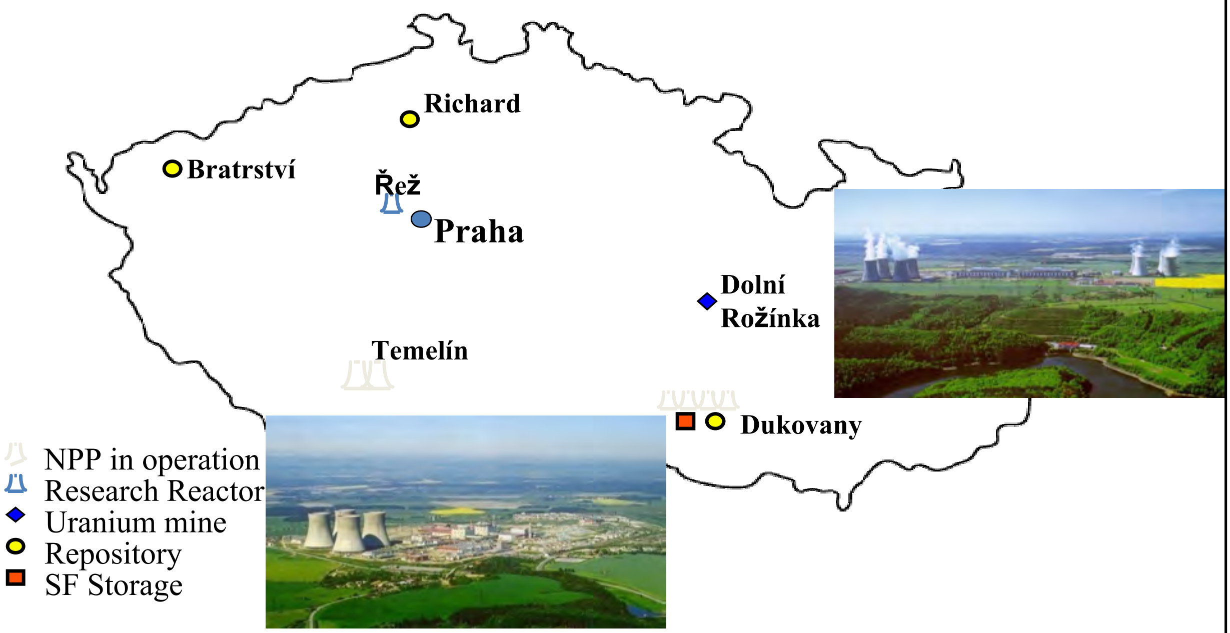

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Legislative Principles of RAWM

Act on the Peaceful Uses of Nuclear Energy and Ionizing Radiation – Atomic act, No. 18/1997

The main principles:

- **Radioactive Waste** – all wastes with contamination (content) of radionuclides (natural or artificial nuclides) but – except wastes occurring due to mining activities (including U – mining)
- **The state guarantees** the safe disposal of all radioactive waste.
- **All producers** of radioactive waste **shall bear all costs** associated with its management from the time of origin to its disposal.
- To provide for activities associated with radioactive waste disposal, the Ministry of Industry and Trade set up the **Radioactive Waste Repository Authority (RAWRA)** as a state organization - established on 1st June 1997

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Radioactive Waste Management Concept

Approved by the Government in 2002

LLW /ILW waste

- Ongoing disposal at existing repositories
  - Bratrství – institutional wastes - only natural nuclide content
  - Richard – institutional wastes – artificial nuclide content – from industry, research, medicine, …
  - Dukovany – wastes produced by NPP operation

HLW / Spent Nuclear Fuel (SNF)

- Decided future disposal in a Deep Geological Repository (DGR)
  - 2015 – Two suitable sites – main and alternative
  - 2025 – Approval of the safety of the final site
  - 2030 – Construction of Underground Research Laboratory
  - 2065 – Commissioning of the DGR
- Support for R&D of P&T
- to observe the potential for an international DGR

4

HLW and SNF Management

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Supposed waste amounts for DGR

6 reactors in operation and 3 planned

- HLW - NPPs Dukovany and Temelin — 3000 m^3
- HLW - new reactors — 2000 m^3

- SNF - EDU 1 (4 reactors) — 1940 t (est. 40 years operation)
- SNF - ETE 1 (2 reactors) — 1790 t (est. 40 years operation)
- SNF - new 3 reactors (TE 2+DU 1) up to — 5000 t (est. 60 years operation)

Space required for 5 862 disposal containers – latest estimation according Reference Design 2011

2 047 disposal containers (440 type)
1 124 disposal containers (1 000 type)
2 691 disposal containers (new type)

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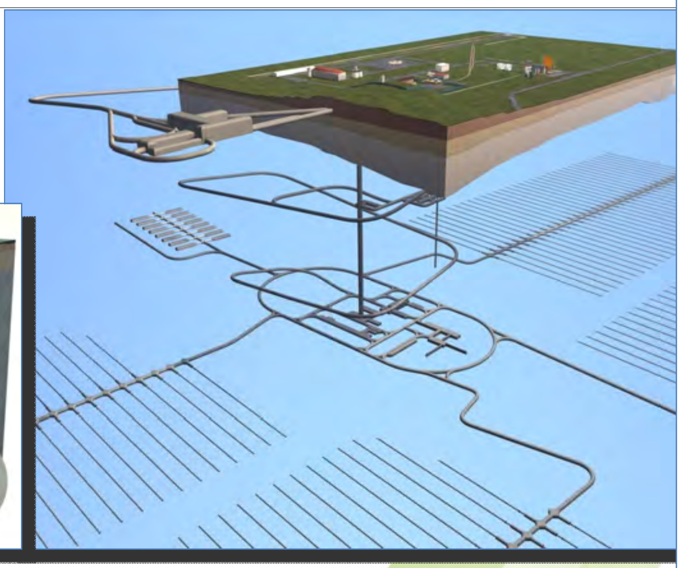
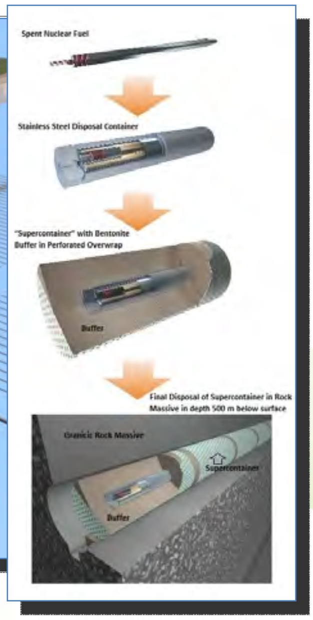
New Reference Design 2011





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DGR and RAWM concept
2018 – 2025 – 2065 – CZ approach

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DGR – three pillars as for any important construction projects

Technology <> Financial resources <> Site

Technology for application in 2065?

- YES, but today only in terms of the feasibility of a DGR at areal site under real conditions

Financial resources?

- YES –for development as well as for future construction

Site?

- IN ALL CASSES – we will construct a DGR so as to be able to prove long term safety
- site has a strong **INFLUENCE ON SAFETY** and **FUTURE TECHNOLOGY** and ..... **ON FINANCIAL SOURCES**

!! SITE 2025 !!

And next steps? – potential future optimisations

Preliminary site selection - 2002

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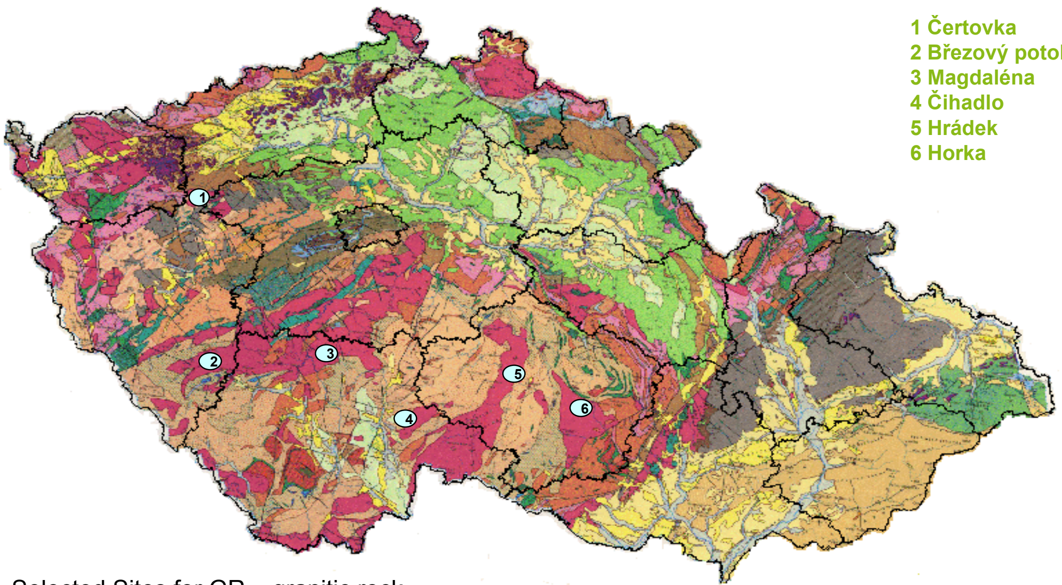

1 Čertovka
2 Březový potok
3 Magdaléna
4 Čihadlo
5 Hrádek
6 Horka

Selected Sites for GR – granitic rock

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Supposed Site Selection Process 2012 – 2018

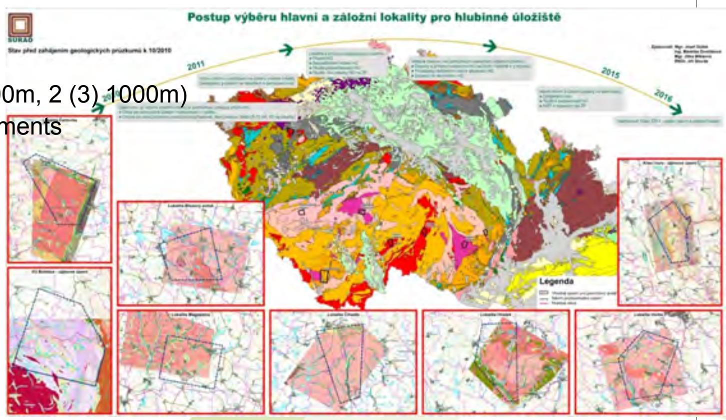
Geological survey will commence at 4 sites

Parallel geophysical and geochemical landscape survey
Drilling of boreholes (at depths of 5 – 500m, 2 (3) 1000m)
Rock characterization – in situ measurements
Laboratory research

Environmental sitespecific studies

At each site with suitable geology:

- Design of the DGR
- Feasibility Study
- Preliminary Safety Case
- Environmental Impact Assessment Study



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Site Selection Criteria

How and When? (and Who?)

Until now

- No real generic or on site data on crystalline geology from depths considered useful for DGR
  - Provision of geological survey parallel to generic research

Two options for establishing site selection criteria

- Progressively by means of geological surveys
- General criteria at the beginning of investigation work
- Step by step application of real data and comparison with the on site situation

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Necessary R&D for DGR siting

General objectives and goals

Site selection process requires

- **Understanding of data and relevant information performed at the sites**
- **Interpreting and adapting criteria for site selection**
- **adapting Reference design at the selected sites**
- **Performance of preliminary safety assessment**

= R&D supporting site selection

How to perform the necessary R&D?

- **Internal – by means of RAWRA supported R&D projects - intensive start from 2012**
- **More involvement in EU projects – RAWRA and supported CZ organisations**
- **Direct participation in international projects**

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DGR site selection and public acceptance

Role of the public in drawing up of important documentation

Concept of Radioactive Waste and Spent Nuclear Fuel Management in CR (2002)

- Connection between RAW disposal and provision of information
- Decision-making on the site of a future geological repository– **… respecting the interests of local development …**
- S.E.A. – Strategic Environmental Assessment

Regional Development Policy of the CR (2008)

- Task for MIT and RAWRA – to select final and reserve sites for future deep geological repository ensuring **public involvement**

1

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Public involvement principles

Voluntarism as a primary principle

Call to local municipalities to participate in the site selection process

Geological survey will start **only at those sites where municipalities wish to participate**

Benefits for local municipalities

Direct annual payment only to those municipalities at sites where RAWRA obtains a licence for geological survey work

9/2011 – update to Atomic act.

Annual maximum 4 MCZK (160 k€) per municipality

Fixed 600 kCZK + 0,30 CZK per m^2 of geol. survey area

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Public involvement

Step by step towards dialogue

11/2009

- **Conference „Deliberation – the way towards a deep geological repository "**

6/2010

- **„Round table discussion" with the participation of municipalities and non-governmental organisations**

11/2010

- **„Working Group for Dialogue on a DGR"**
  - **to increase the transparency of the siting process respecting public interests**
  - **to strengthen the role of municipalities in administrative processes related to site selection for a DGR**

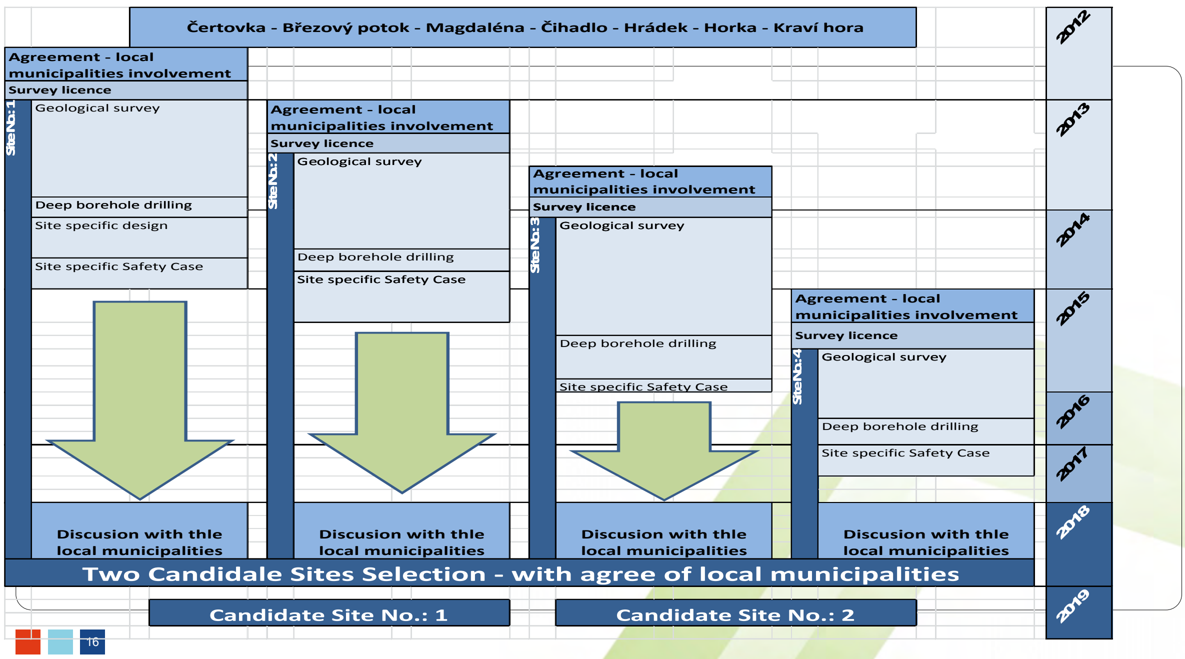
How will municipalities get involved?

Guarantees and Motivation – main issues for WG Dialogue meetings

Before start of geological survey work:

- **RAWRA invites municipalities from preselected sites to actively participate** in the candidate site selection process for a deep geological repository
- **RAWRA will sign an agreement with volunteering municipalities. Agreement will determines the conditions of municipality participation**
- RAWRA will submit an application to the Ministry of the Environment **for licence for of exploratory area** at a site at which **all municipalities** will **participate**
- **Contractual guarantees to municipalities that their participation does not mean automatic approval of repository construction - GUARANTEE**
- **Establishment of exploratory area = municipalities entitled to receive payments from the nuclear account - MOTIVATION**

How to select Candidate Sites?



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Future site for DGR – how to select it?(1)

Selection of 2 candidate sites with public participation

- **Only sites where all municipalities will become involved in the selection process**
- Application for the establishment of an exploratory area
- Geological survey with the main aim of evaluating the suitability of the host rock formation
- Fulfilment of all technical requirements related to site – DGR project
- Providing evidence that DGR on site meets all strict safety criteria
- Assessment and comparison of suitability of sites - with local public involvement
- **Selection of two candidate sites in 2018 – only with approval of all affected municipalities**

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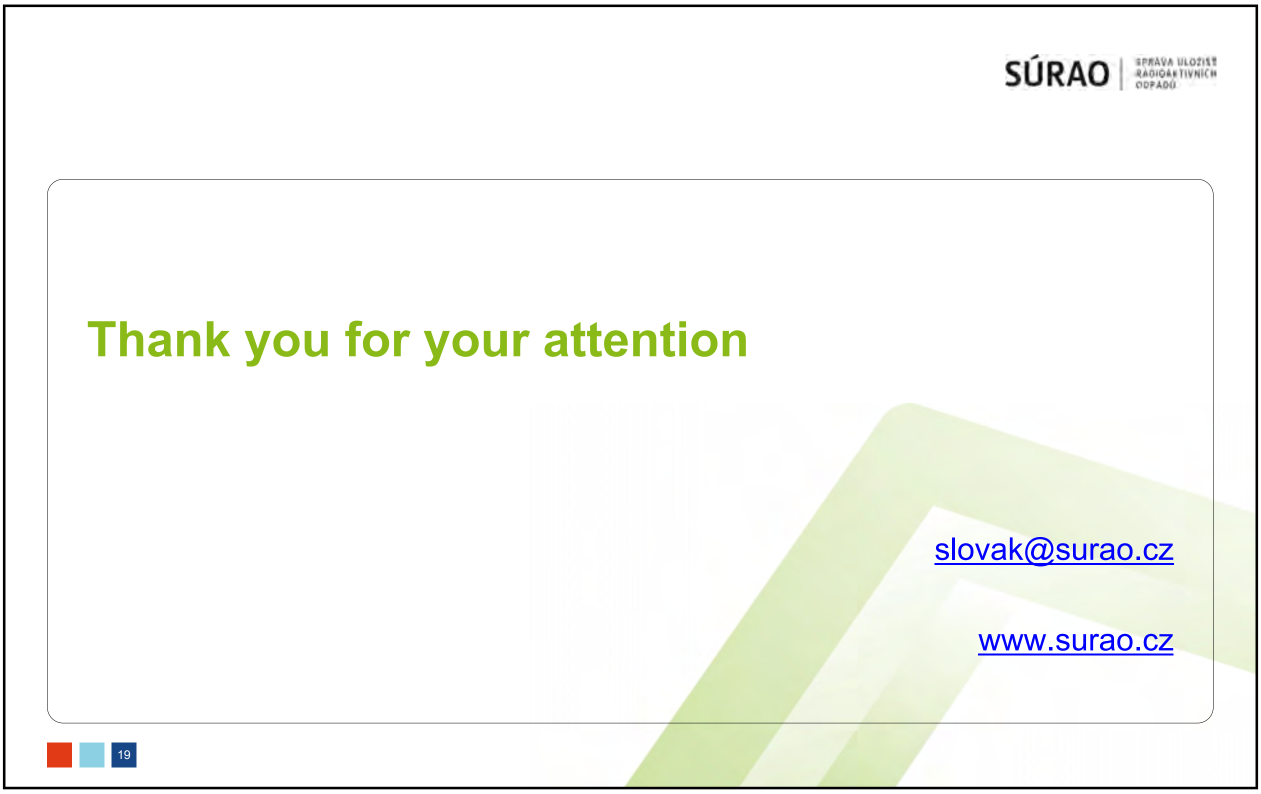
Future site for DGR – how to select it?(2)

Selection of final site – with approval of municipalities

Only with approval of affected municipalities, observing interests of the corresponding region

- Site with the highest + most robust **safety levels**
- Economic criteria – site where repository construction and operational costs are optimised to the maximum
- Socioeconomic impacts – site where DGR creates **the most impulses for regional development**



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Application of the Safety Assessment Methodology

Geoff Freeze

Scientific Visit on Crystalline Rock Repository Development

Prague, Czech Republic

September 25, 2012

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2012-7713P

Outline

- Safety Case
- Safety Assessment Methodology
  - FEP Analysis
  - Scenario Development
  - PA Model Implementation
- Application to Crystalline Rock Repositories
  - U.S. DOE Office of Used Nuclear Fuel Disposition (UFD)
  - Other National Programs

Safety Case - Definition

- "an integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility" (NEA 2004, Section 1)
  - Quantitative information – calculated values for safety indicators, including uncertainty (e.g., a safety assessment)
  - Qualitative information – supporting evidence and reasoning that gives confidence in the quality of the underlying science and conclusions (e.g., relevant literature, natural analogs)
- References – Safety Case Elements
  - NEA (1999b, 2002, 2004, 2008, 2009, *2012?*)
  - IAEA (2006, 2011)
  - Bailey et al. (2011), Van Luik et al. (2011)

Safety Case – Iterative Development

- "The safety case has to be developed progressively and elaborated as the project proceeds. ... The formality and level of technical detail of the safety case will depend on the stage of development of the project, the decision in hand, the audience to which it is addressed, and specific national requirements." (IAEA 2011, Section 4.12)
  - Early – more qualitative, generic
  - Later – more refined, site specific
- Provides a structure for
  - Identification of important subsystem components and processes
  - Evaluation of evidence and gaps – to guide research and development (R&D)
  - Discussion with stakeholders – address socio-political concerns

Safety Assessment - Definition

- "quantification of the overall level of performance, analysis of the associated uncertainties, and comparison with the relevant design requirements and safety standards" (IAEA 2011, Section 4.10)
  - Pre-Closure Safety Analysis
  - Post-Closure Safety Assessment
    - also referred to as Performance Assessment (PA)
- References – Safety Assessment Methods
  - NEA (1991, 1997)
  - Safety Case references (from slide 3)
  - Meacham et al. (2011)

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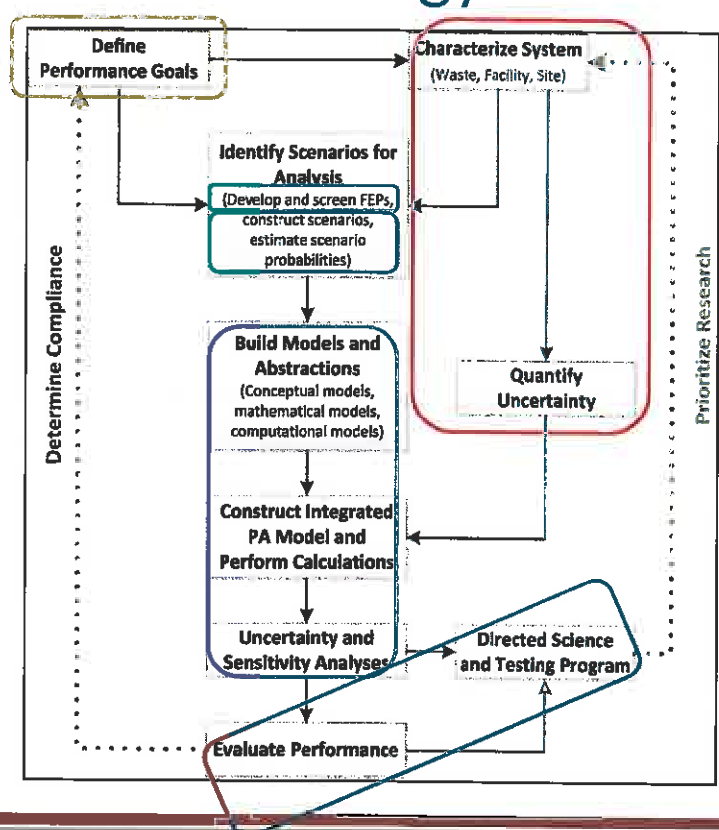
Safety Assessment Methodology

- Formal structure to guide iterative quantitative post-closure assessments
  - Application Objectives
  - Site Characterization
  - FEP Analysis
  - Scenario Development
  - PA Model Implementation
  - Assessment Results



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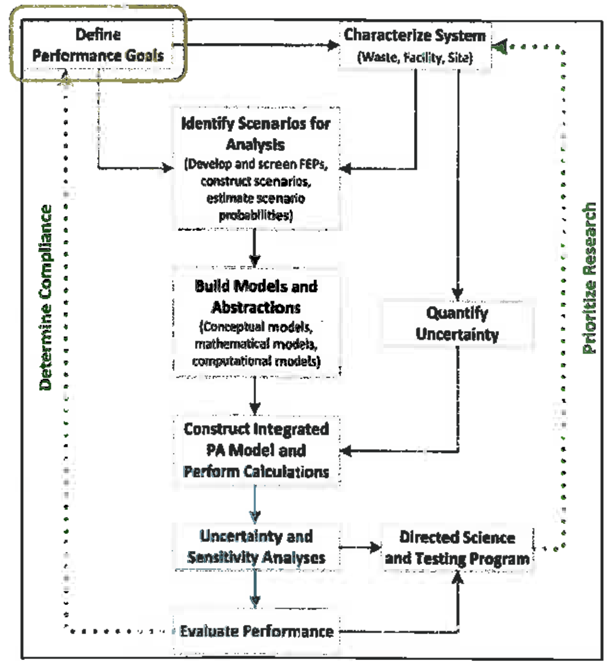
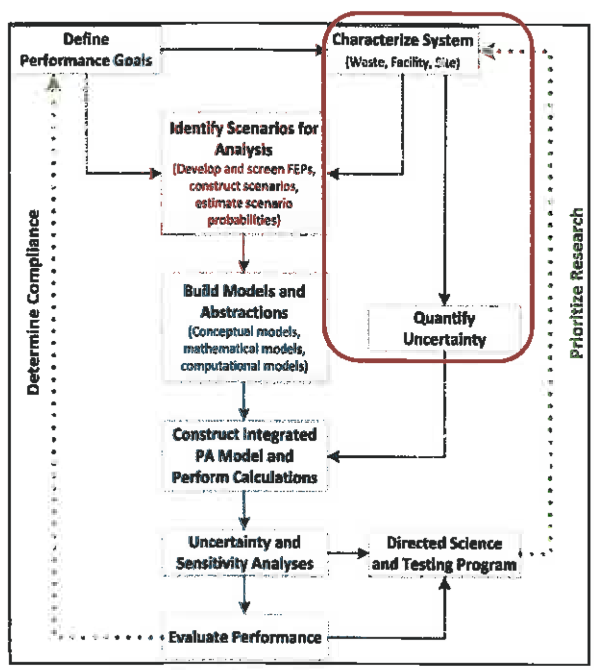
Application Objectives

- Performance goals and complexity of assessment vary to support evolving phases of repository development
  - Repository planning
  - Site screening and selection
  - Site characterization and repository design
  - Licensing
  - Construction
  - Operation
  - Closure



Site Characterization

- Supporting Pre-Closure
  - Waste Transportation to Site
  - Surface and Subsurface Facilities
    - Construction
    - Operations
    - Closure
  - Iterative with structures, systems, and components (SSC) analysis
- Supporting Post-Closure
  - Repository Design and Setting
    - Engineered Barriers
    - Natural Barriers / Geosphere
    - Biosphere
  - Iterative with features, events, and processes (FEP) analysis



Site Characterization

- Collect information to characterize:
  - spent nuclear fuel (SNF) and/or high-level waste (HLW) inventory and waste forms
  - thermal-hydrologic-chemical-mechanical-biological-radiological (THCMBR) processes and properties governing disposal system performance
  - spatial and temporal variability and uncertainty in the THCMBR properties and processes associated with the initial state of the disposal system and its evolution over 10,000 years or more

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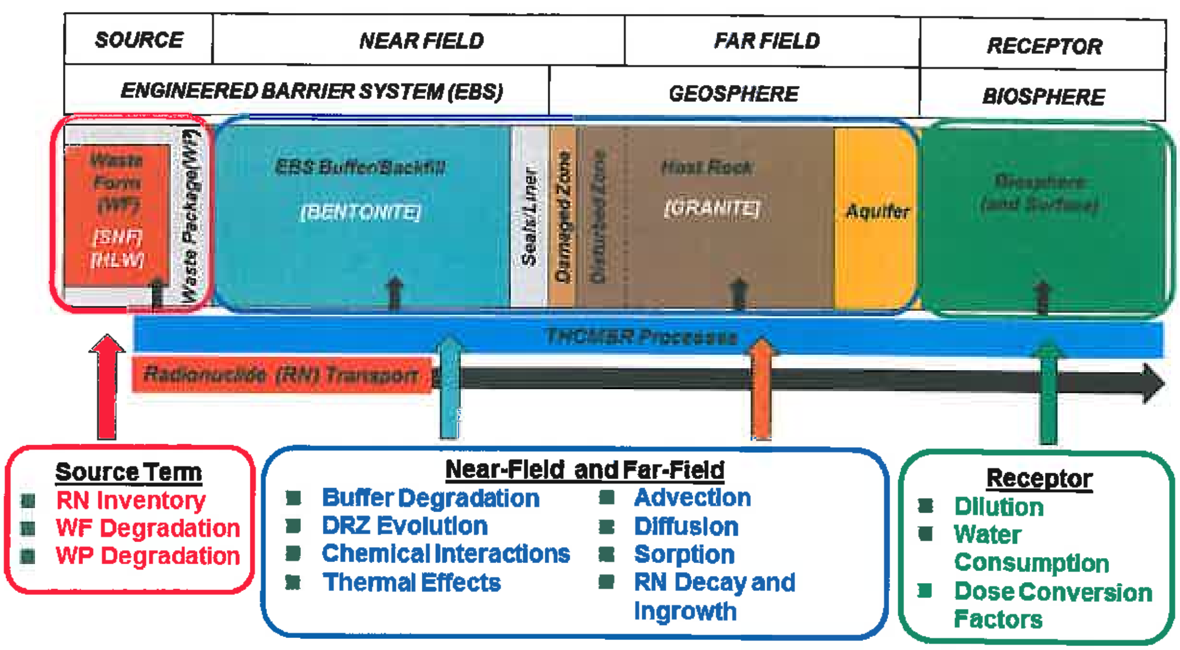
Site Characterization

- Schematic of "generic" components (features) and "nominal" processes for a crystalline rock repository



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FEP Analysis

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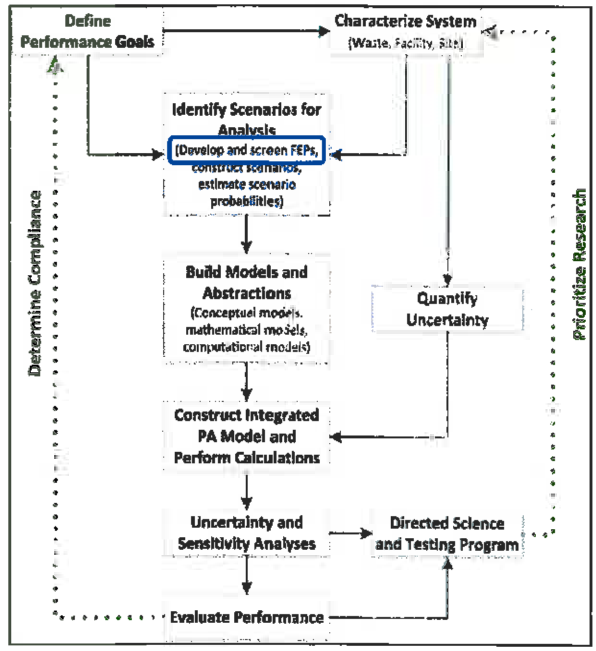
- Formal FEP Analysis for PA consists of the systematic implementation of:
  - FEP Identification
  - FEP Screening
- FEP Analysis is performed iteratively with Scenario Development and PA Model Implementation
- References – FEP Analysis
  - NEA International FEP Database - (NEA 1999a, 2006)
  - US OCRWM - BSC (2005), SNL (2008)
  - US UFD - Freeze et al. (2010, 2011), Freeze and Swift (2010)



FEP Analysis

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- Feature
  - An *object, structure, or condition* that has a potential to affect repository system performance (NRC 2003, Section 3)
- Event
  - A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs during an interval that is short compared to the period of performance (NRC 2003, Section 3)
- Process
  - A natural or human-caused *phenomenon* that has a potential to affect repository system performance and that occurs during all or a significant part of the period of performance (NRC 2003, Section 3)

- A "FEP" generally encompasses a single phenomenon
  - Typically a FEP is a *process* or *event* acting upon a *feature*

FEP Identification

- Compilation of a set of FEPs (i.e., a FEP List) that captures all of the phenomena that are potentially relevant to the long-term performance of a disposal system
  - Addresses the question of comprehensiveness
    - Have we thought of everything?
  - Comprehensiveness of a FEP list cannot be proven with absolute certainty. However, confidence can be gained through a combination of systematic reviews (both top-down and bottom-up), audits, comparisons with other FEP lists, and examination of multiple categorization schemes.
    - Formal FEP identification provides objective evidence that all potentially relevant FEPs have been considered

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FEP Identification

- Must define FEPs at a level of detail that is broad enough to produce a systematically categorized, manageable number of FEPs (a few hundred), yet specific enough to provide the complexity required for screening and/or modeling
  - There is no uniquely correct level of detail at which to define and/or aggregate FEPs. However, bounding cases can be defined:
    - "too specific" - FEPs are narrowly defined, such that there are many independent FEPs, and it is impractical to develop specific screening decisions and/or submodels for each FEP.
    - "too broad" - FEPs are coarsely defined and it is difficult to isolate important issues for each FEP. Consequently, some important issues may get overlooked.

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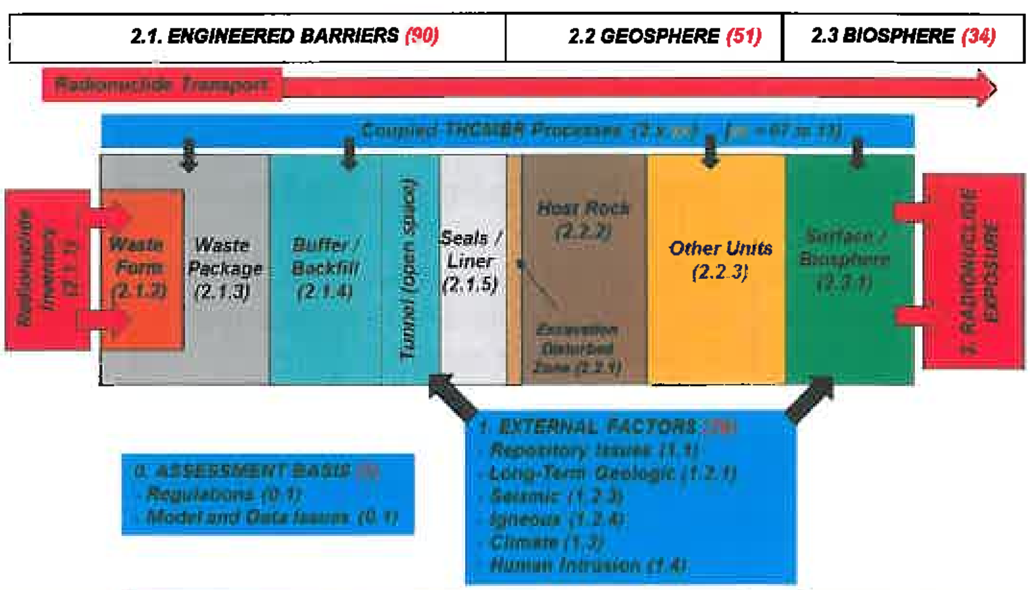
FEP Identification

- NEA FEP Database is the basis for many FEP lists
  - comprehensive NEA FEP list (NEA 1999, 2006) contains ~2000 FEPs from 10 international programs in 6 countries
- Yucca Mountain Project (YMP) list = 374 FEPs
  - ~400 site- and design-specific phenomena considered in addition to ~2000 NEA FEPs (SNL 2008)
  - NEA list contains many duplicate or redundant FEPs – e.g., same FEP listed in each of the 10 programs
  - Categorization identified additional NEA FEPs that could be combined
- Preliminary UFD FEP list = 208 FEPs
  - Site- and design-specific YMP FEP list provides initial basis for generic UFD FEP list applicable to a range of disposal options
  - Focus on generic details results in smaller number of broader FEPs (Freeze et al. 2010, 2011)

FEP Identification

- NEA hierarchical numbering system used to categorize 208 UFD FEPs by physical domains and features, THCMBR processes, and external factors/events



FEP Screening

- From the comprehensive FEP list, selection of a subset of important (included) FEPs that define the range of possible future states (i.e., scenarios) of the disposal system
  - Addresses the question of completeness
    - Are all important phenomena represented in the PA model?
  - Must demonstrate that all important FEPs are included in the PA Model
    - Formal FEP screening provides a structure to ensure that all important FEPs are captured in the PA model
      - Included FEPs: Are they appropriately included in the model?
      - Excluded FEPs: Do they have defensible rationale for exclusion?

FEP Screening

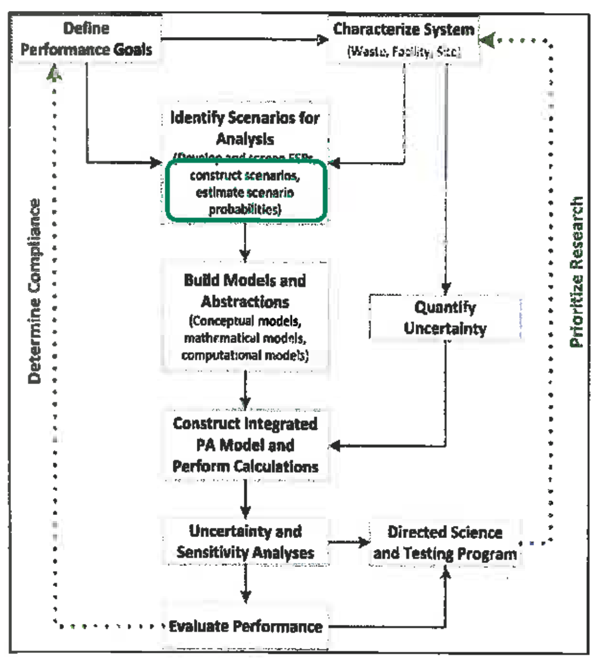
- FEPs may be screened out (excluded from the PA model) by evaluation against the following screening criteria:
  - Low probability - probability of occurrence during the time period of concern is less than an established (regulatory) threshold
  - Low consequence - effect (quantitative or qualitative) on a specified performance measure (e.g., dose, subsystem measure) is not measureable/observable/significant during the time period of concern
    - Try to avoid system-wide quantitative measures of significance (e.g., 1% change) – not all FEPs or subsystem domains affect the system equally
    - Subsystem-level effects on system-level performance may be masked by certain designs and/or combinations of input parameter values
      - A FEP may have a significant effect on subsystem performance (e.g., increased sorption of actinides) but minimal effect on system performance measure (e.g., dose dominated by ^{129}I)
  - Regulation - inconsistent or incompatible with the regulations
  - Physical reasonableness - not relevant or applicable to the specific repository design or site (variant of low probability or consequence)

FEP Screening

- Screening is site-, design-, and regulation-specific
- Each FEP should be evaluated against the screening criteria
  - Screening criteria can be considered in any order
  - Screening need not be quantitative, but should have a technical basis
    - may be more qualitative and inclusive during early iterations
  - Screening should consider interactions between FEPs
    - Avoid Risk Dilution - ensure that FEP level of detail is appropriate and does not minimize importance and/or consequence of interactions
- If a FEP cannot be excluded, then it must be included
  - Err on side of inclusion – there is no downside to including a non-important FEP in a PA Model, other than computational / implementation cost

Scenario Development

- Scenario
  - A well-defined, connected sequence of FEPs that is an outline of a possible future condition of the repository system (NRC 2003, Sec. 3)
- References – Scenario Development
  - International - (NEA 1992)
  - Safety Case References (slide 3)
  - US OCRWM - BSC (2005)



Scenario Development

- Scenario Construction
  - Form scenarios from the included FEPs
    - Undisturbed scenario – nominal, central, reference behavior
    - Disturbed scenarios – alteration of nominal conditions by disruptive events
      - e.g., seismicity, volcanism, human Intrusion
  - All included FEPs must be in at least one scenario, but some "nominal" processes may be in more than one scenario
  - Some processes and events may be treated as either part of nominal scenario or as a disruptive scenario
    - decision may depend on probability of the disruption
- Scenario Screening
  - Use similar criteria as for FEP screening to identify any scenarios that can be excluded from the PA model

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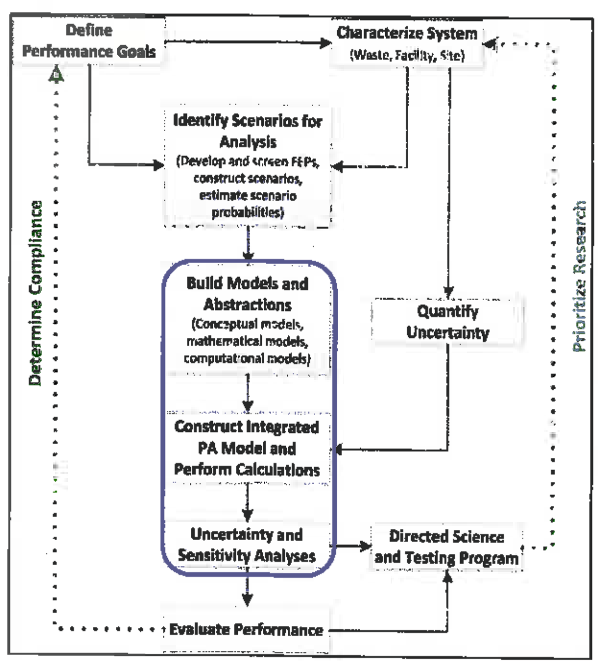
PA Model Implementation

- Disposal System Model
  - Integrated conceptual and mathematical representation of the disposal system components and scenarios (i.e., the included FEPs)
  - Numerical solution of the mathematical representation using a computer code or code suite



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PA Model Implementation

- Treatment of Uncertainty
  - Deterministic – base case results from a single realization with "best estimate" input values, sensitivity analyses based on "one-off" realizations
  - Probabilistic – base case results is a "mean" from multiple realizations of the input values (e.g., based on Monte Carlo sampling), sensitivity analyses also based on multiple realizations
- Treatment of Scenarios
  - Combined result from probability-weighted combination of individual scenario results
  - Separate scenario results (e.g., undisturbed criteria, disturbed criteria)
- Model Complexity
  - Simplified system model of "linked" subsystem physics with some submodel abstractions
  - Highly-integrated system model with coupled multi-physics (e.g., THC) in an advanced high-performance computing (HPC) framework

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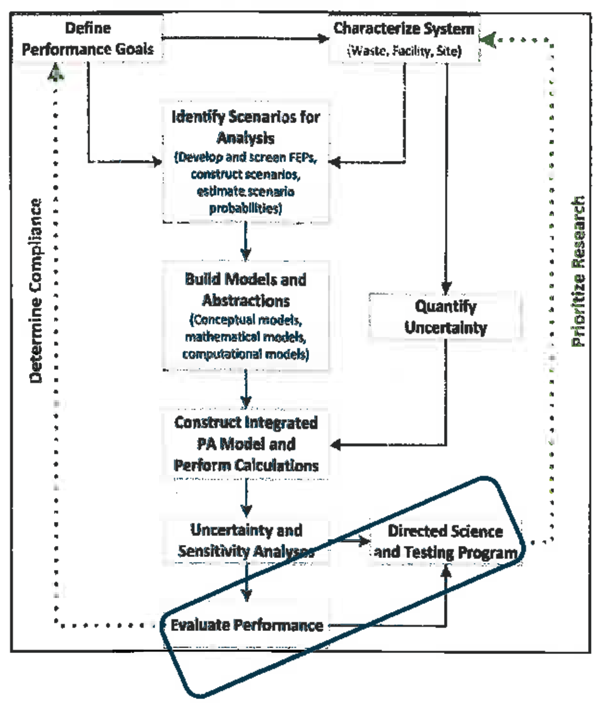
Assessment Results

- Model performance measures include:
  - System (e.g., dose)
  - Subsystem (e.g., fluxes, radionuclide masses)
- Model results and sensitivity analyses provide:
  - Quantitative input to the safety case
  - Guidance to science and testing programs (R&D)



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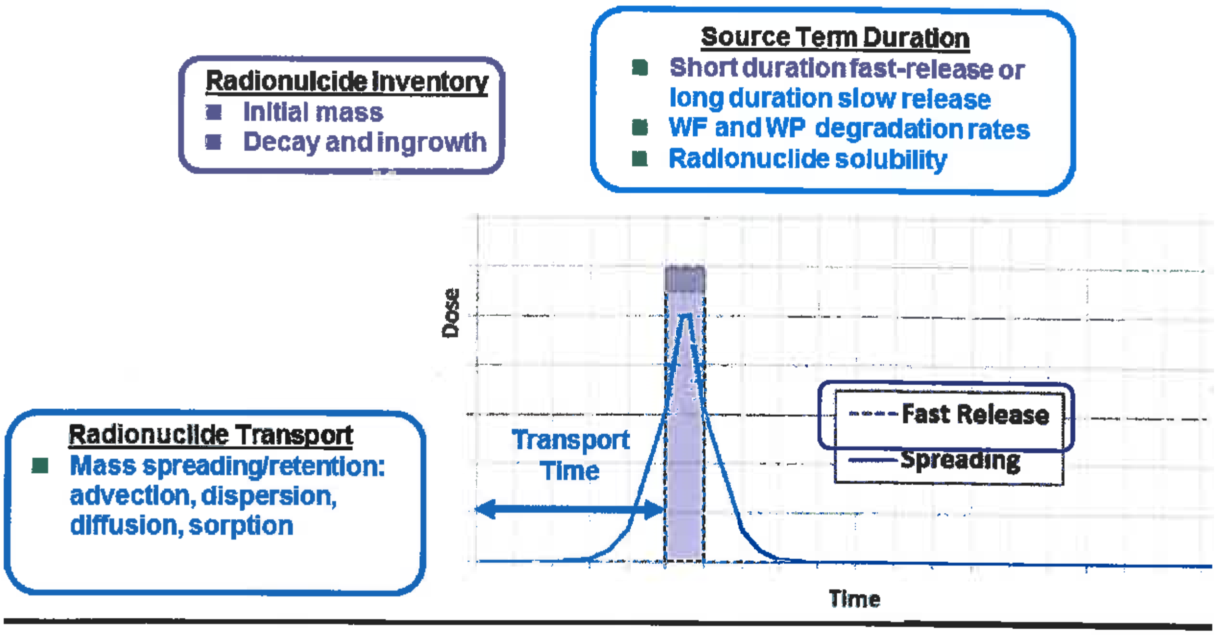
Assessment Results

- Dose estimates in most geologic disposal system models are controlled by a few key processes/parameters



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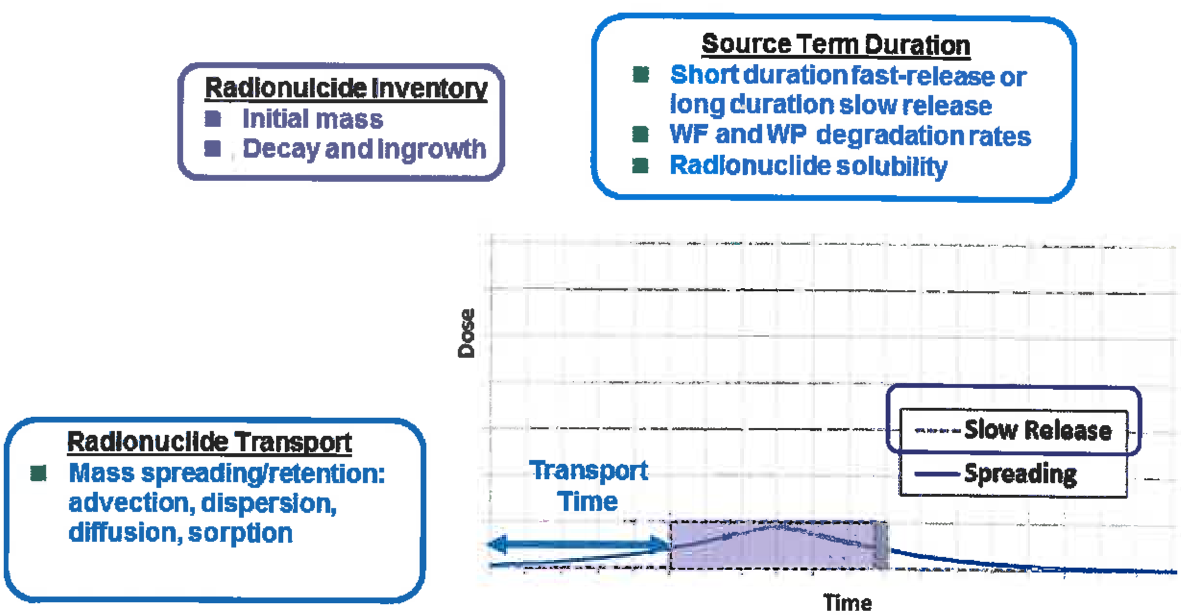
Assessment Results



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Application

- Crystalline Rock Safety Assessments
  - USA
    - Mariner et al. (2011), Clayton et al. (2011)
  - Finland, Sweden, Canada, Japan, Switzerland, France, Korea
    - References provided in P. Mariner presentation

References

- BSC (Bechtel SAIC Company) 2005. *The Development of the Total System Performance Assessment-License Application Features, Events, and Processes.* TDR-WIS-MD-000003 REV 02. Las Vegas, Nevada: Bechtel SAIC Company.
- Bailey, L.E.F.; Billington, D.E.; Hickford, G.E.; Kelly, M.; Lever, D.A.; Locke, J.; and Thorne, M.C. 1998. *Overview of the FEP Analysis Approach to Model Development.* Nirex Science Report S/98/009. Harwell, Oxfordshire, England: United Kingdom Nirex Limited.
- Clayton, D., G. Freeze, T. Hadgu, E. Hardin, J. Lee, J. Prouty, R. Rogers, W.M. Nutt, J. Birkholzer, H.H. Liu, L. Zheng, and S. Chu 2011. *Generic Disposal System Modeling – Fiscal Year 2011 Progress Report.* FCRD-USED-2011-000184, SAND2011-5828P. U.S. Department of Energy, Office of Nuclear Energy, Used Fuel Disposition Campaign, Washington, D.C.
- Freeze, G., Mariner, P., Houseworth, J.E., and Cunnane, J.C. 2010. *Used Fuel Disposition Campaign Features, Events, and Processes (FEPs): FY10 Progress Report.* SAND2010-5902, Sandia National Laboratories, Albuquerque, New Mexico.
- Freeze, G.; and Swift, P. 2010. *Comprehensive Consideration of Features, Events, and Processes (FEPs) for Repository Performance Assessments.* PSAM 10 Conference Proceedings. Seattle, Washington: International Association for Probabilistic Safety Assessment and Management.
- Freeze, G., P. Mariner, J.A. Blink, F.A. Caporuscio, J.E. Houseworth, and J.C. Cunnane 2011. *Disposal System Features, Events, and Processes: FY11 Progress Report.* FCRD-USED-2011-000254. SAND2011-6059P. Sandia National Laboratories, Albuquerque, New Mexico.
- IAEA (International Atomic Energy Agency) 2006. *Geologic Disposal of Radioactive Waste, Safety Requirements.* IAEA Safety Standards Series No. WS-R-4, IAEA, Vienna, Austria.
- IAEA (International Atomic Energy Agency) 2011. *Disposal of Radioactive Waste, Specific Safety Requirements.* IAEA Safety Standards Series No. SSR-5, IAEA, Vienna, Austria.
- Mariner, P.E., J.H. Lee, E.L. Hardin, F.D. Hansen, G.A. Freeze, A.S. Lord, B. Goldstein, and R.H. Price 2011. *Granite Disposal of U.S. High-Level Radioactive Waste.* Sandia National Laboratories, Albuquerque, New Mexico
- NEA (Nuclear Energy Agency) 1991. *Disposal of Radioactive Waste: Review of Safety Assessment Methods.* Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.

References (cont.)

- NEA (Nuclear Energy Agency) 1992. *Systematic Approaches to Scenario Development: A Report of the NEA Working Group on Identification and Selection of Scenarios for Performance Assessment of Radioactive Waste Disposal.* Paris, France: Nuclear Energy Agency, Organisation for Economic Co-operation and Development.
- NEA (Nuclear Energy Agency) 1997. *Lessons Learnt from Ten Performance Assessment Studies.* Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- NEA (Nuclear Energy Agency) 1999a. *An International Database of Features, Events and Processes.* Paris, France: Organisation for Economic Co-operation and Development.
- NEA (Nuclear Energy Agency) 1999b. *Confidence in the Long-term Safety of Deep Geological Repositories: Its Development and Communication.* Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- NEA (Nuclear Energy Agency) 2002. *Establishing and Communicating Confidence in the Safety of Deep Geologic Disposal: Approaches and Arguments.* Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- NEA (Nuclear Energy Agency) 2004. *Post-Closure Safety Case for Geological Repositories, Nature and Purpose,* NEA Report No. 3679, Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- NEA (Nuclear Energy Agency) 2006. *The NEA International FEP Database: Version 2.1.* Paris, France: Nuclear Energy Agency.
- NEA (Nuclear Energy Agency) 2008. *Safety Cases for Deep Geological Disposal of Radioactive Waste: Where Do We Stand? Symposium Proceedings Paris, France, 23-25 January 2007,* NEA Report No. 6319, Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- NEA (Nuclear Energy Agency) 2009. *International Experiences in Safety Case for Geological Repositories (INTESC),* NEA Report No. 6251, Organisation for Economic Co-operation and Development (OECD) NEA, Paris, France.
- Meacham, P.G., D.R. Anderson, E.J. Bonano, and M.G. Marietta 2011. *Sandia National Laboratories Performance Assessment Methodology for Long-Term Environmental Programs: The History of Nuclear Waste Management.* SAND2011-8270. Sandia National Laboratories, Albuquerque, New Mexico.
- SNL (Sandia National Laboratories) 2008. *Features, Events, and Processes for the Total System Performance Assessment: Methods.* ANL-WIS-MD-000026 REV 00. Las Vegas, Nevada: Sandia National Laboratories.

29

References (cont.)

- U.S. Nuclear Regulatory Commission (NRC) 2003. *Yucca Mountain Review Plan.* NUREG-1804, Revision 2. Office of Nuclear Material and Safeguards, Washington, DC.
- Van Luik, A., E. Forinash, and N. Marcos 2011. "Safety Assessment in the Context of the Safety Case," OECD/NEA Project on the Methods of Safety Assessment (MeSA), MeSA Issue Paper # 1 Final, May 2011.

30

Other Informative Reports

- Bronders, J.; Patyn, J.; Wemaere, I.; and Marivoet, J. 1994. *Long term Performance Studies, Catalogue of Events, Features and Processes Potentially Relevant to Radioactive Waste Disposal in the Boom Clay Layer at the Mol Site*. SCK-CEN Report R-2987 Annex. Mol, Belgium
- Chapman, N.A.; Andersson, J.; Robinson, P.; Skagius, K.; Wene, C-O.; Wiborgh, M.; and Wingefors, S. 1995. *Systems Analysis, Scenario Construction and Consequence Analysis Definition for SITE-94*. SKI Report 95:26. Stockholm, Sweden: Swedish Nuclear Power Inspectorate.
- Cranwell, R.M.; Guzowski, R.V.; Campbell, J.E.; and Ortiz, N.R. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste, Scenario Selection Procedure*. NUREG/CR-1667. Washington, D.C.: U.S. Nuclear Regulatory Commission.
- DOE (U.S. Department of Energy) 1996. *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant*. DOE/CAO-1996-2184. Twenty-one volumes. Carlsbad, New Mexico: U.S. Department of Energy, Carlsbad Area Office.
- ENRESA (Empresa Nacional de Residuos Radioactivos SA) 1995. Evaluacion del Comportamiento Opcion Granito. Identificacion de Factores. Proyecto AGP, Fase II, 48-1p-I-00G-03
- Garisto, N.; Avis, J.; Fernandes, S.; Jackson, R.; Little, R.; Rees, J.; Towler, G. and Walke, R., July 2009, *Deep Geologic Repository for OPG's Low and Intermediate Level Waste, Postclosure Safety Assessment (V1): Features, Events and Processes*, NWMO DGR-TR-2009-05
- Goodwin, B.W.; Stephens, M.E.; Davison, C.C.; Johnson, L.H.; and Zach, R. 1994. *Scenario Analysis for the Postclosure Assessment of the Canadian Concept for Nuclear Fuel Waste Disposal*. AECL-10969. Pinawa, Manitoba, Canada: AECL Research, Whiteshell Laboratories.
- Guzowski, R. V. and Newman, G., December 1993, *Preliminary Identification of Potentially Disruptive Scenarios at the Greater Confinement Disposal Facility, Area 5 of the Nevada Test Site*, SAND93-7100
- Hwang, Y.S; Kang, C.H.; and Soo, E.J. 2006. *Development of the KAERI FEP, Scenario, and Assessment Method Database for Permanent Disposal of HLW in Korea*. Progress in Nuclear Energy Volume 48, Issue 2 pp 165-172. Daejeon, South Korea: Korea Atomic Energy Research Institute.

Other Informative Reports (cont.)

- Mazurek, M.; Pearson, J.F.; Volckaert, G.; and Bock, H. 2003. *Features, Events and Processes Evaluation Catalogue for Argillaceous Media*. Paris, France: Organisation for Economic Co-Operation and Development, Nuclear Energy Agency.
- Miller, B.; Savage, D.; McEwen, T.; and White, M. 2002. *Encyclopaedia of Features, Events and Processes (FEPs) for the Swedish SFR and Spent Fuel Repositories, Preliminary Version*. SKI Report 02:35.
- Miller, W.M. and Chapman, N.A. 1993. *HMIP Assessment of Nirex Proposals, Identification of Relevant Processes (System Concept Group Report)*. Technical Report IZ3185-TR1 (Edition 1). [London], United Kingdom: Her Majesty's Inspectorate of Pollution (HMIP), Department of the Environment.
- NAGRA (Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle) 1994. *Kristallin-I, Safety Assessment Report*. NAGRA Technical Report 93-22. Wettingen, Switzerland: National Cooperative for the Disposal of Radioactive Waste.
- Prij, J. (editor) 1993. *PROSA – Probabilistic Safety Assessment – Final Report*. ECN, RIVM, RGD Report OPLA-1A. Petten, Netherlands
- SNL (Sandia National Laboratories) 2008b. *Features, Events, and Processes for the Total System Performance Assessment: Analysis*. ANL-WIS-MD-000027 REV 01. Las Vegas, Nevada: Sandia National Laboratories.
- SNL (Sandia National Laboratories) 2008c. *Total System Performance Assessment Model/Analysis for the License Application*. MDL-WIS-PA-000005 Rev 00. Las Vegas, NV: Sandia National Laboratories.

Exceptional service in the national interest

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Insights from Safety Assessments for Mined Repositories in Crystalline Rock

Peter Swift
Senior Scientist
Sandia National Laboratories

Presented to the Scientific Visit on Crystalline Rock Repository Development, Prague, Czech Republic
25 September 2012

U.S. DEPARTMENT OF ENERGY NNSA

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Outline

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- Goals of the discussion
  - First order insights into what factors may influence crystalline repository performance
  - Integrating safety assessment results with the R&D programme
- Examples of Safety Assessment Results
  - Preliminary US modeling of a generic crystalline repository
  - Canadian generic safety assessment
  - Swedish Forsmark Safety Assessment
- Observations about potentially important components and processes
- Integrating Iterative Safety Assessments with R&D
- Discussion

2

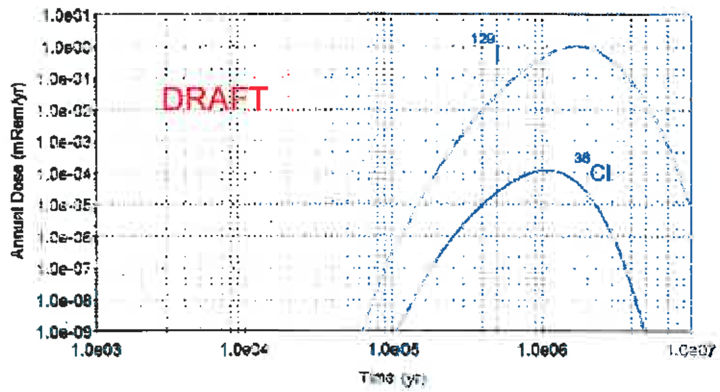
Generic Crystalline Repository Performance

Example from Current US DOE Analyses

Key assumptions in this analysis

- Uncertainties treated deterministically for simplicity
- Waste packages and cladding fail immediately
- Used fuel degrades relatively rapidly (fractional degradation rate = 2×10^{-5}/yr)
- Bentonite buffer remains intact (0.36 m thick)
- 1 % of radionuclides released from the waste form pass through the buffer and enter a fracture network
- Early releases from gap and grain boundaries are not modeled
- No disruptive events or human intrusion

Nominal Performance



Estimated peak dose is 0.0095 mSv/yr at 1.7 Myr, from I-129

3

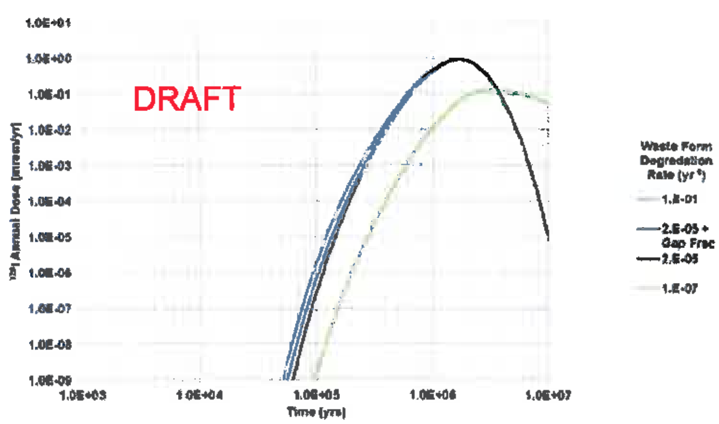
Generic Crystalline Repository Performance

Example from Current US DOE Analyses (cont.)

Key observations from this analysis

- Because base case was run with relatively rapid degradation, faster waste form degradation has little effect on performance
- Effects of early release fraction are not significant when compared to the base case
- Significantly slower waste form degradation rates result in smaller doses occurring at later times

Sensitivity to Waste Form Degradation Rate



4

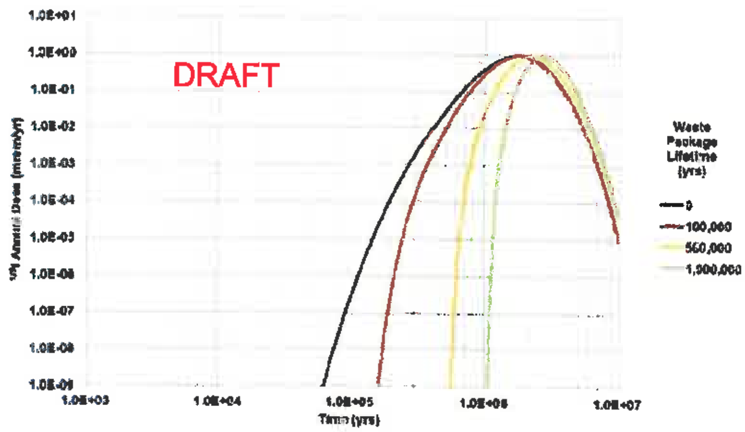
Generic Crystalline Repository Performance

Example from Current US DOE Analyses (cont.)

Key observations from this analysis

- Longer waste package lifetime results in doses occurring later in time.
- Because of the long half-life of I-129, there is no perceptible impact on the magnitude of the estimated dose

Sensitivity to Waste Package Lifetime



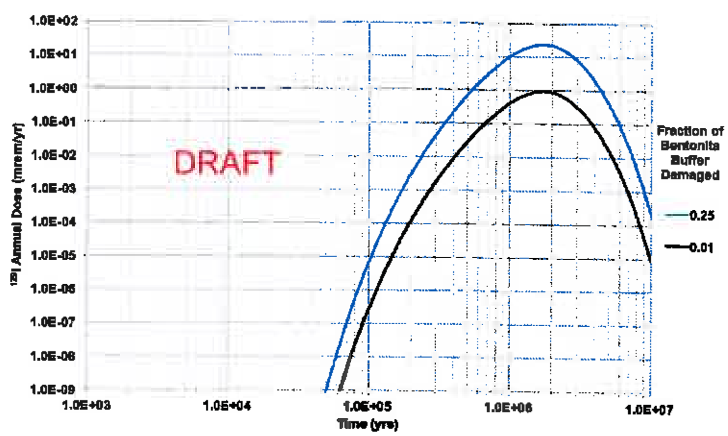
Generic Crystalline Repository Performance

Example from Current US DOE Analyses (cont.)

Key observation from this analysis

- For the assumptions used here, the magnitude of the estimated dose increases linearly with the increase in the fraction of radionuclides passing through the bentonite buffer and entering fractures in the granite

Sensitivity to Buffer Integrity

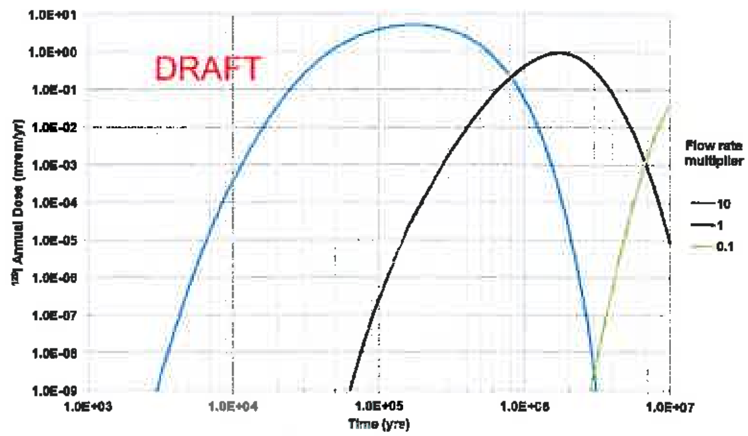


Generic Crystalline Repository Performance
Example from Current US DOE Analyses (cont.)

Key observation from this analysis

- For the assumptions used here, the time of peak dose is strongly sensitive to the flow rate in fractures
- Magnitude of estimated dose is less sensitive to fracture flow rate

Sensitivity to Fracture Flow Rate



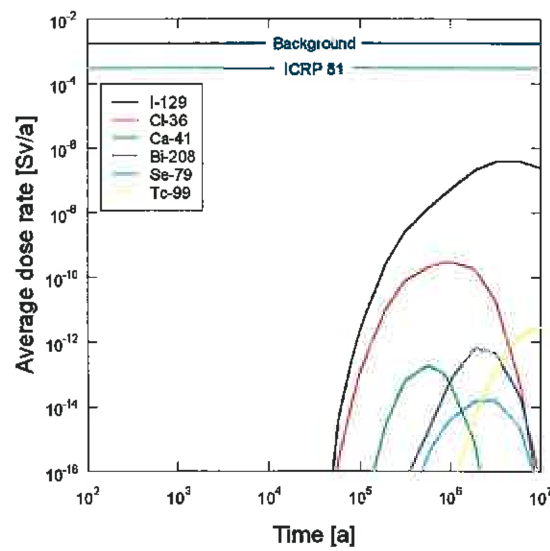
7

Generic Crystalline Repository Performance
Example from the Canadian Fourth Case Study

Key assumptions for this analysis

- Waste package failures treated probabilistically, expected value of 2 failures per repository
- Very low permeability for unfractured granite ($8.3\times10^{-20}m^2$)
- Relatively high permeability in fractures ($4.1\times10^{-14}m^2$), but fractures do not directly intersect the disposal region
- Slow degradation of the uranium oxide spent fuel in a reducing environment

Average Dose Rates



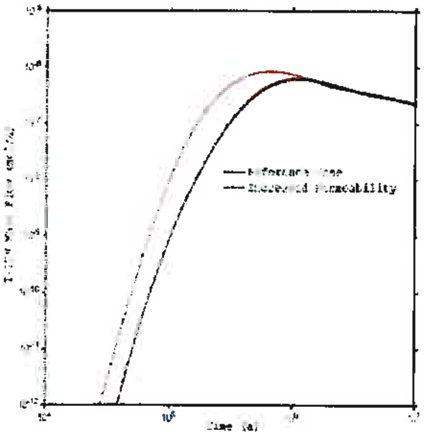
Source: Kremer et al., 2011, "Postclosure Safety Assessment of a Deep Geological Repository for Canada's Used Nuclear Fuel", Proceedings of the International High-Level Radioactive Waste Management Conference 2011, Albuquerque, NM USA, April 10 -14, 2011.

8

Generic Crystalline Repository Performance

Example from the Canadian Fourth Case Study (cont.)

Deterministic sensitivity analyses



5-fold increase in geosphere permeability causes earlier I-129 release to biosphere

TABLE I. Comparison of dose rate sensitivities

Case Description	Peak Dose (Sv/a)	Peak Time (a)
Reference Case	9.7×10^{-8}	1.1×10^{6}
10 × Fuel Dissolution Rate	5.5×10^{-7}	8.6×10^{5}
10 × Container Defect Radius	1.4×10^{-7}	5.8×10^{5}
Geosphere Sorption set to zero	1.0×10^{-7}	1.1×10^{6}
All Containers Fail after 100.000 years	9.4×10^{-5}	3.4×10^{5}

Source: Kremer et al., 2011, "Postclosure Safety Assessment of a Deep Geological Repository for Canada's Used Nuclear Fuel", Proceedings of the International High-Level Radioactive Waste Management Conference 2011, Albuquerque, NM USA, April 10 -14, 2011.

Generic Crystalline Repository Performance

Example from the Swedish Forsmark SR-Site (2011)

Probabilistic Calculation of the "Central Corrosion Case"

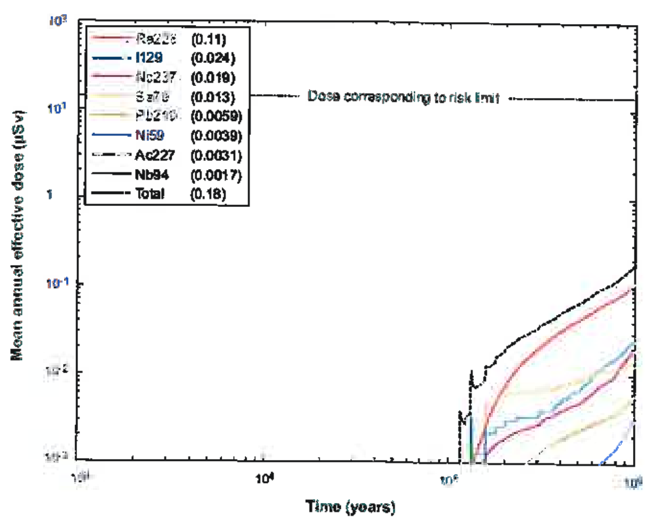
Key assumptions:

- Waste package failures treated probabilistically, expected value of 0.12 failures per repository, first failures occur at 114,000 years
- Failed waste packages assumed to be intersected by highly transmissive fractures
- Slow degradation of the uranium oxide spent fuel in a reducing environment

Key Observation

- Total dose is dominated by Ra-226, due to relatively rapid transport in fractures
- Ra-226 $t_{1/2}$ = 1601 yr

Mean Dose Rates
peak values shown in μSv



Source: SKB Technical Report TR-11-01, Figure 13-18

Generic Crystalline Repository Performance

Example from the Swedish Forsmark SR-Site (2011)

Hypothetical Deterministic Failure of Waste Packages

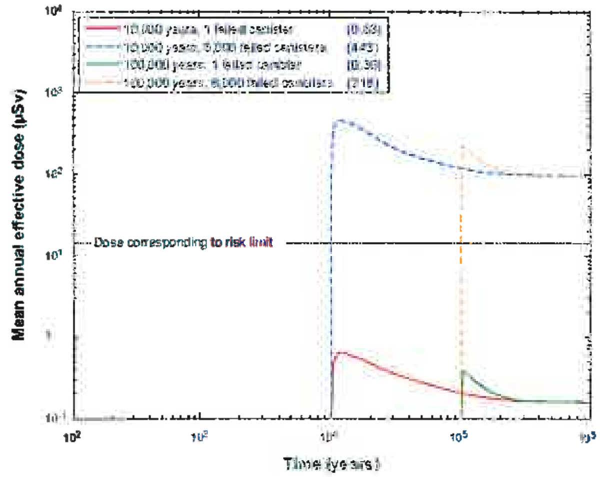
Key assumptions:

- Waste packages assumed to fail by unspecified mechanism, and to provide no further waste isolation capacity
- Geosphere functions as expected

Key Observation

- Total estimated dose varies linearly with the number of failed waste packages

Mean Dose Rates
peak values shown in μSv



Source: SKB Technical Report TR-11-01, Figure 13-53

11

Generic Crystalline Repository Performance

Example from the Swedish Forsmark SR-Can (2006)

Sensitivity to spent fuel degradation rate

- Fractional dissolution rate range 10^{-6}/yr to 10^{-8}/yr
  - Corresponding fuel lifetimes: ~ 1 Myr to 100 Myr
  - Dissolution rates for oxidizing conditions (not anticipated) up to 10^{-4}/yr (corresponds to 10,000 yr)
- Uncertainty in fuel dissolution rate is potentially an important contributor to overall uncertainty in modeled total dose estimates

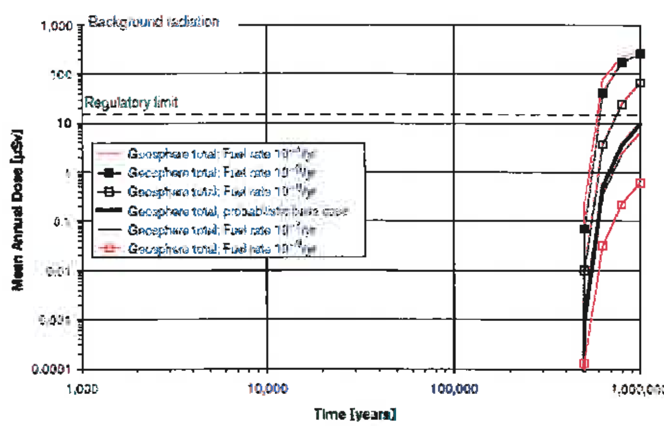


Figure 10-44. Sensitivity of the base case result to the fuel dissolution rate. Semi-correlated hydro-geological DFN model for Forsmark. 1,000 realisations of the analytic model for each case.

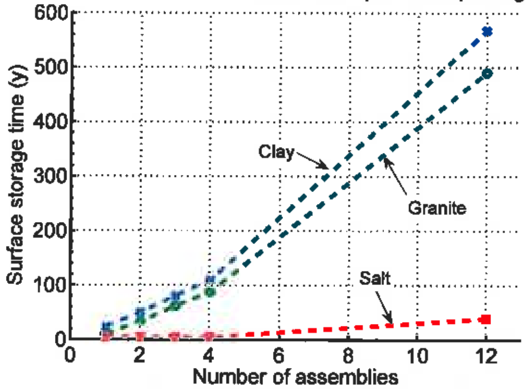
Source: SKB 2006, *Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar—a First Evaluation,* TR-06-09, section 10.6.5

Also, SKB 2006, *Fuel and Canister Process Report for the Safety Assessment SR-Can*, TR-06-22, section 2.5.5

12

Thermal Constraints for Representative Disposal Concepts

Storage time required to comply with temperature limits as a function of UOX assemblies per waste package



Notes:
1. *These results are based on assumed temperature limits on the waste package surface of 100°C in clay and granite and 200°C in salt*
2. *Thermal constraints are one of many considerations for waste packaging, storage and disposal.*

Source: Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143

Options for Meeting Thermal Constraints Include:

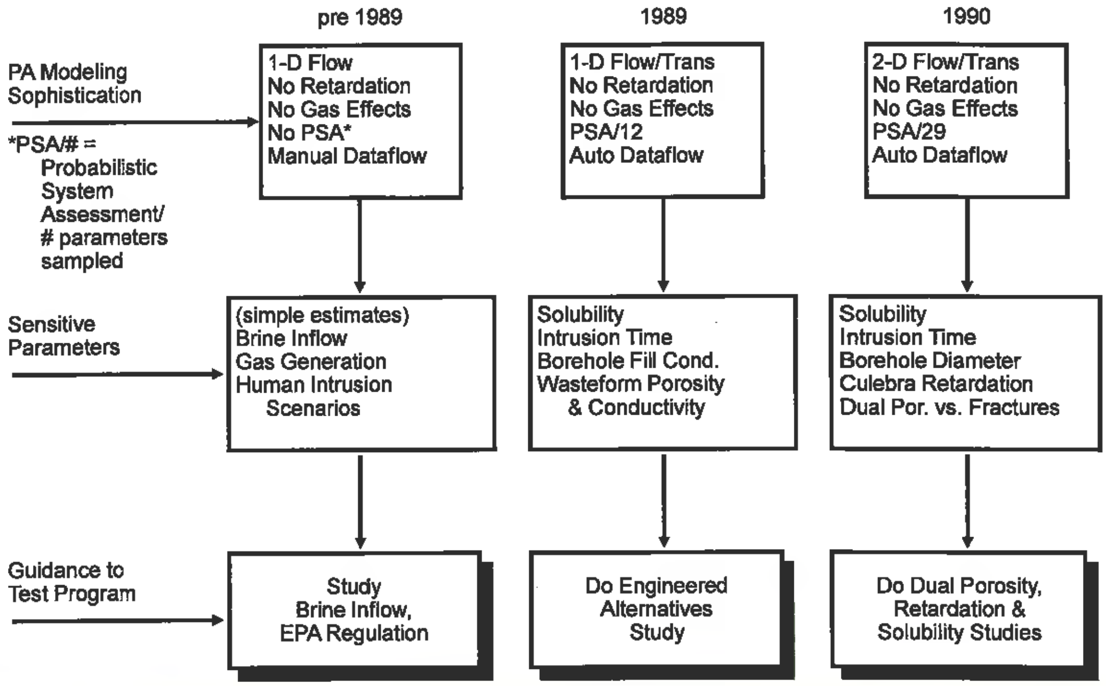
- Repository Design
  - Size of waste packages
  - Spacing between packages
  - Thermal properties of engineered materials
- Operational Options
  - Aging
  - Ventilation
  - Load management
- Modifications to Waste Forms
  - Decreasing density of fission-product and actinide loading
  - Separation of heat-generating isotopes

Summary of First Order Observations from Existing Crystalline Repository Safety Assessments

- Crystalline repositories have the potential to provide excellent long-term isolation for used nuclear fuel and high-level radioactive waste
- Components (or parameters) important to building confidence in performance estimates are likely to include
  - Waste package lifetime
  - Waste form lifetime ($U0_2$ dissolution rate)
  - Connection to transmissive fractures (including rock properties and buffer integrity)
  - Rate of advective transport in the geosphere
- Thermal load management issues are likely to favor relatively smaller waste packages in crystalline repositories

Integrating Iterative Safety Assessments with Research and Development

An Example from the Waste Isolation Pilot Plant (page 1)



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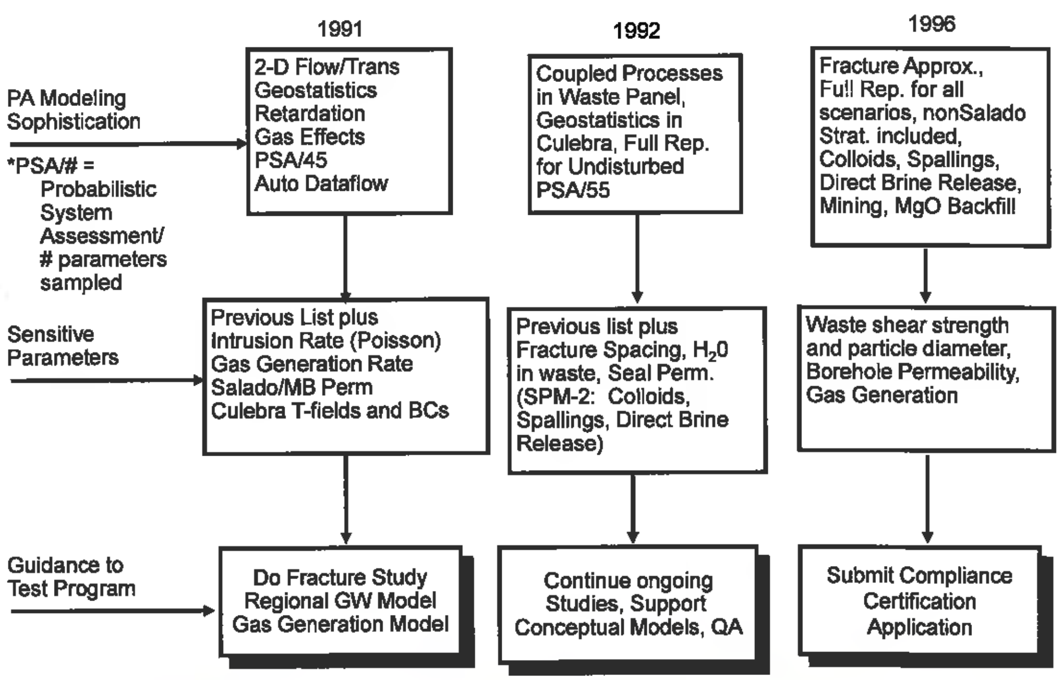
Integrating Iterative Safety Assessments with Research and Development (cont.)

An Example from the Waste Isolation Pilot Plant (page 2)



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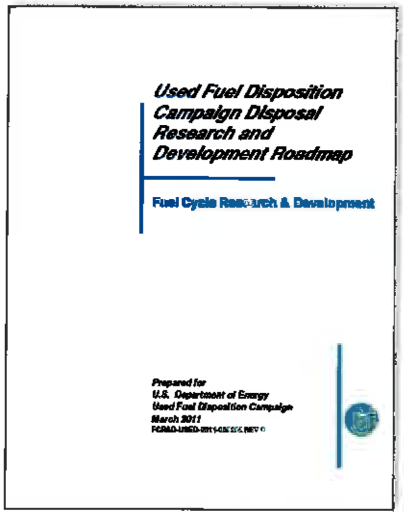
Integrating Iterative Safety Assessments with Research and Development

An Example from the Current US Program


Used Fuel Disposition Campaign Disposal Research and Development Roadmap

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
March 2011
[illegible]

- *Used Fuel Disposition Campaign Disposal Research and Development Roadmap*
  - "an initial evaluation of prioritization of R&D opportunities that could be pursued by the campaign"
  - Completed March 2011
  - Used to inform prioritization decisions for disposal research in FY12 and beyond
- Update in progress

http://www.ne.doe.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

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Used Fuel Disposition Campaign R&D Roadmap

- Objective: identify and prioritize disposal R&D opportunities to inform allocation of limited resources
- Approach
  - Engage technical staff in the evaluation
  - Use the catalog of Features, Events, and Processes to identify potentially relevant issues
  - Recognition that evaluations will be subjective and scores will be qualitative
  - Consider timeliness of the R&D:
    - Does it support generic concept evaluations?
    - Does it support site screening or selection?
    - Does it support site-specific design or licensing decisions?
  - Evaluate issues based on
    - Importance to the safety assessment
    - Importance to design/construction/operation of a facility
    - Importance overall confidence in the safety case
  - Take existing state of knowledge into account
    - i.e., something may be both very important and sufficiently well understood

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Used Fuel Disposition Campaign R&D Roadmap (cont.)

- Categories used in scoring state of knowledge
  - Well Understood: representation well developed, has a strong technical basis, and is defensible. Additional R&D would add little to the current understanding
  - Fundamental Gaps in Method: the representation of an issue (conceptual and/or mathematical, experimental) is lacking
  - Fundamental Data Needs: the data or parameters used to represent an issue (process) is lacking
  - Fundamental Gaps in Method, Fundamental Data Needs: Both
  - Improved Representation: The representation of an issue may be technically defensible, but improved representation would be beneficial (i.e., lead to more realistic representation).
  - Improved Confidence: Methods and data exist, and the representation is technically defensible but there is not widely-agreed upon confidence in the representation (scientific community and other stakeholders).
  - Improved Defensibility: Related to confidence, but focuses on improving the technical basis, and defensibility, of how an issue (process) is represented
- Importance and adequacy with respect to decision points: how much do we need to know and when?
  - Importance—additional information may be essential for a given decision, supportive, or useful but not needed
  - Adequacy—existing information may be adequate for a given decision, partially sufficient, or insufficient

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Used Fuel Disposition Campaign R&D Roadmap (cont.)

- For R&D activities proposed for each topic, additional information is needed to support prioritization
  - Decision point supported by the R&D: i.e., generic concept evaluations, site selection, site characterization and repository design, licensing
  - Time required to complete the R&D
  - Cost
- Evaluation results compiled and organized using the structure of the FEP catalog

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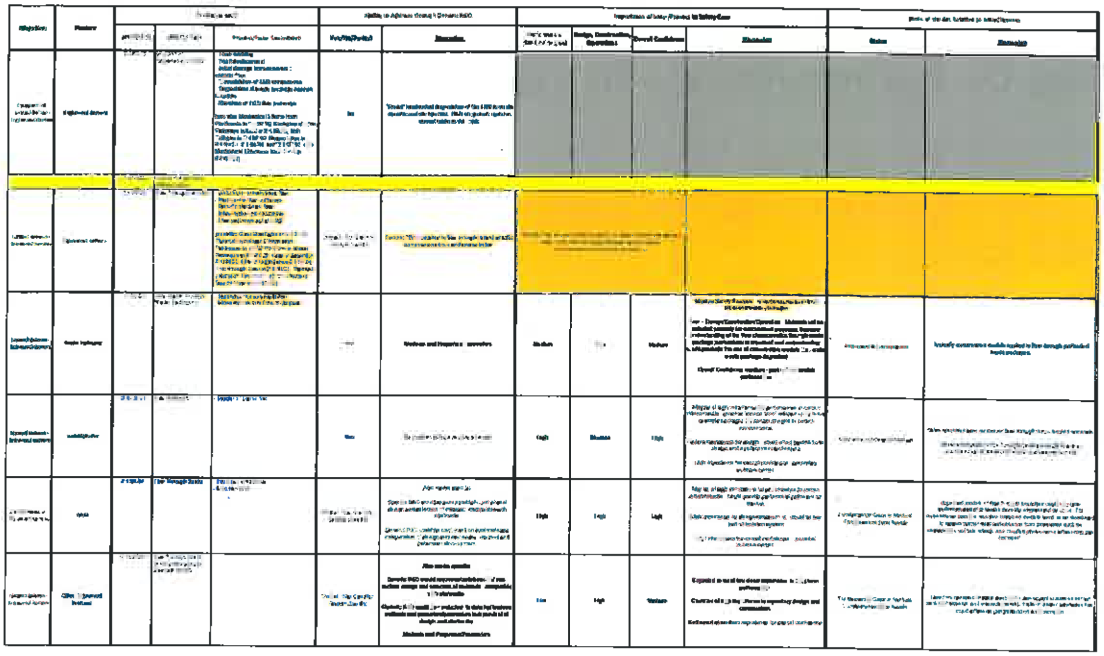
Example of the Prioritization Information Matrix



From Appendix A of the UFD Disposal R&D Roadmap:
www.nuclear.energy.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

Example of the Prioritization Information Matrix

2.1.08.03	Flow in Backfill	- Fracture / Matrix flow	May be of high importance for performance in certain environments - governs "source term" release upon failure of waste packages for certain designs in certain environments. Medium importance for design - could effect backfill/buffer design and emplacement techniques High importance for overall confidence - secondary isolation barrier.	Fundamental Gaps in Method	Other countries have evaluated flow through buffer/backfill materials. Improved models of flow through breaches could increase understanding of releases from the engineered barriers.
2.1.08.04	Flow Through Seals	- Fractu[...] - Gas tr[...]	May be of high importance for performance in certain environments - Could provide preferential pathways for release. High importance for design/construction - could be key part of isolation system High importance for overall confidence - potential isolation barrier.	Fundamental Gaps in Method, Fundamental Data Needs	Improved models of flow through breaches could increase understanding of releases from the engineered barriers. For cementitious barriers, reactive transport models need to be developed to assess barrier seal performance from processes such as carbonation, sulfate attack, and coupled phenomena influencing gas transport.

Enlargements of portions of the previous page
Full table is 56 pages long

From Appendix A of the UFD Disposal R&D Roadmap:
www.nuclear.energy.gov/FuelCycle/neFuelCycle_UsedNuclearFuelDispositionReports.html

Used Fuel Disposition Campaign R&D Roadmap (cont.)

Using Evaluation Results to Support Prioritization

- Scores and weights assigned by program management for each issue and R&D topic
- Basic principles applied in scoring
  - Overall priority is a function of
    - Importance to safety case
    - Importance at each programmatic decision point
    - Adequacy of existing information
  - Importance to the safety case is relevant at all decision points
  - Importance to near-term decisions is of higher priority
  - Where current information is adequate, priority for R&D is lower
  - Where scores differ for different concepts or media, priorities are media-specific

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Used Fuel Disposition Campaign R&D Roadmap (cont.)

Summary of Natural System Results

- **Highest ranked issues**
  - Flow and transport pathways in crystalline media
  - Excavation disturbed zone for borehole disposal and shale media
  - Hydrologic processes for salt media
  - Chemical processes for shale media
  - Thermal processes for shale

GEOSPHERE →	Crystalline	Borehole	Salt	Shale
1.2.01. LONG-TERM PROCESSES (tectonic activity)	Low	Low	Low	Low
1.2.03. SEISMIC ACTIVITY				
- Effects on EBS	High	High	High	High
- Effects on NS	Low	Low	Low	Low
1.3.01. CLIMATIC PROCESSES AND EFFECTS	Low	Low	Low	Low
2.2.01. EXCAVATION DISTURBED ZONE (EDZ)	Medium	High	Medium	High
2.2.02 HOST ROCK (properties)	High	High	High	High
2.2.03 OTHER GEOLOGIC UNITS (properties)	Medium	Medium	Medium	Medium
2.2.05. FLOW AND TRANSPORT PATHWAYS	Medium	Medium	Medium	Medium
2.2.07. MECHANICAL PROCESSES	Low	Low	Medium	Medium
2.2.08. HYDROLOGIC PROCESSES	Low	Medium	High	Medium
2.2.09. CHEMICAL PROCESSES - CHEMISTRY	Low	Medium - High	Low - Medium	Medium - High
2.2.09. CHEMICAL PROCESSES - TRANSPORT	Medium	Medium - High	Medium - High	Medium
2.2.10. BIOLOGICAL PROCESSES	Low	Low	Low	Low
2.2.11. THERMAL PROCESSES	Low	Medium	Low	Medium
2.2.12. GAS SOURCES AND EFFECTS	Low	Low	Low	Low
2.2.14. NUCLEAR CRITICALITY	Low	Low	Low	Low

Notes:
1. Shading indicates that research has been undertaken in other geologic disposal programs
2. FEP numbers lists include all FEPs beneath the 3rd level

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Used Fuel Disposition Campaign R&D Roadmap (cont.)

Sandia National Laboratories

Summary of Engineered System Results

- **Highest ranked issues: Overall higher ranking for Waste Form, Waste Package, and Buffer/Backfill materials**
  - Waste Materials: Waste form issues ranked higher than those for inventory
  - Waste Package Materials: Waste container issues and chemical processes generally ranked higher than those for specific processes such as hydrologic and biologic.
  - Buffer and Backfill Materials: Issues related to chemical processes generally ranked higher than others.
  - Seal and Liner Materials: Issues related to chemical, mechanical, and thermal processes generally ranked higher than those for radiation or nuclear criticality effects.
  - Other Engineered Barrier Materials: Issues related to chemical processes and radionuclide speciation / solubility ranked slightly higher than issues related to thermal, mechanical, and hydrological processes.
  - Overall, chemical processes in the considered EBS components ranked higher than others but these are strongly coupled to thermal, hydrological, and even mechanical processes within the EBS

Observations Regarding the Integration of Safety Assessments and Design of an R&D Program

Sandia National Laboratories

- Safety assessments provide a primary source of information about the importance of R&D topics
  - Safety assessments provide the best means of identifying those topics for which uncertainty has a large impact on estimates of long-term performance
- Safety assessments mature throughout the life of a project, and help inform R&D choices at each step of the way
- R&D decisions also take into account a broad range of qualitative programmatic considerations
  - Overall confidence in the safety case
  - State of knowledge in the international community
  - Cost, schedule, and integration with phased decision-making

Discussion

27

Nuclear Spent Fuel Management in Spain

Jorge Molinero

Introduction

- Ministry of Industry, Tourism and Commerce
  - Radioactive waste, decommissioning and NSF management policy
    - *Cabinet approved " 6th Radioactive Waste General Plan" 2006*
  - Grants Licenses of Nuclear Installations
- Nuclear Safety Council
  - Independent from the Government
    - *Nuclear safety and radiological protection regulation and guidance*
    - *Evaluation and reporting previously to Licenses*
    - *Inspection and enforcement*
- ENRESA
  - Management of spent fuel and radioactive waste
  - Nuclear installations decommissioning as well
- NPP / Utilities
  - Operate on site storage
  - Deliver the SF and waste packages in accordance to WAC
  - Pay the costs through fees on nuclear energy generation

NPP location and NSF situation

- **10 Nuclear Power Reactors**
- **8 reactors in operation in 6 sites**
  - 7.8 GWe
  - 19% of country's electricity generation
- **2 NPP closed down, being decommissioned**

NSF and HLW-MLW Inventory and estimates

- **Present Inventory**
  - 4000 tU SF in storage (December 2009)
    - Most of it in pools
    - 2 ISFSI in operation
      - Trillo NPP
      - Jose Cabrera NPP
      - Ascó NPP is in the licensing process for another ISFSI
- **Total amount of Spent fuel considered**
  - 20000 Fuel elements
  - 6700 tU
- **HLW and MLW management**
  - HLW (vitrified waste 1.17 m3 canisters)
    - 84 canisters
  - Medium Level (long-lived) waste packages
    - Around 650 m3 from reprocessing
    - Around 1000 m3 to be generated in decommissioning reactor internals

General aspects of NSF management

- **The priority is the Centralized Interim Storage Facility (ATC)**
  - Complemented by In situ Increased Storage capacity when required
- **Deep Geological Disposal studies continuation to support decision making about management options**
- **Other options also studied: advanced cycles**
- **R&D Plan 2009-2013**
- **Costs supported by the NPPs as a fee on nuclear electricity gross production**
- **Direct disposal considered as an assumption for financing the waste management fund**

Independent SF storage Facility at Trillo NPP

- **Agreement between ENRESA and Utility**
  - ENRESA licensed the system
  - Trillo NPP licensed the facility as part of the NPP
- **Storage Casks System**
  - Dual purpose metal casks. ENSA DPT
  - 21 fuel elements per cask
  - Non encapsulated
  - Re-licensed from 45 to 49 GWd/tU
- **ISFSI Commissioned in 2002**
  - Dedicated building to meet NPP dose rate design criteria
    - Capacity for 80 casks
  - 18 casks stored
    - 378 fuel assemblies



Independent SF storage facility at Jose Cabrera NPP

- **Similar scheme as in Trillo NPP**
  - Agreement ENRESA-Utility
- **HI STORM system**
  - MPC Multipurpose canisters
  - Shielding modules HI STORM
  - Transfer cask HI TRAC
  - Transport cask HI STAR
  - Auxiliary systems including Helium recirculation dehydrating system
- **Storage pad for 12 modules + 4 modules for GTCC waste**
- **100% fuel inventory transferred**
  - 377 fuel assemblies (100.5 tU)
  - Very limited place in the reactor building
  - Late fuel characterization that required adaptation of the loading plans

AMPHOS[21]

ATC. The Centralized NSF and HLW storage facility project

- **Defined as a priority in the 6th General radioactive Waste Plan**
- **Parliament supported:**
  - In 2004, Industry Commission of the Parliament unanimously asked to the Government to develop such a facility
  - In 2006, the Parliament urged the Government to set an Inter-Ministerial Commission to lead the site selection process
- **Site selected recently → Villar de Cañas (Cuenca)**

AMPHOS[21]

ATC. The Centralized NSF and HLW storage facility project

- **Advantages:**
  - Unification of SF management
  - Independence between short-term and long-term management
  - Flexibility in front of options development
  - Minimization of the total numbers of nuclear installations
  - Efficiency for reaching safety and security levels
  - Possibility to release decommissioned nuclear sites
  - Respect of international engagements
  - Cost reduction
  - Optimization of support services and operations

AMPHOS 21

ATC. The Centralized NSF and HLW storage facility. Main parts

Three main parts:

- **The Centralized Interim Storage Facility** (ATC) **itself**
  - Unloading, and encapsulation
  - SF/HLW storage
  - MLW storage
- **A Research Center**
  - Spent fuel and waste laboratory
  - Other laboratories (chemistry and environment, materials, prototypes…)
- **A Business park**
  - Regional development project
  - Infrastructure for companies settlement in the area

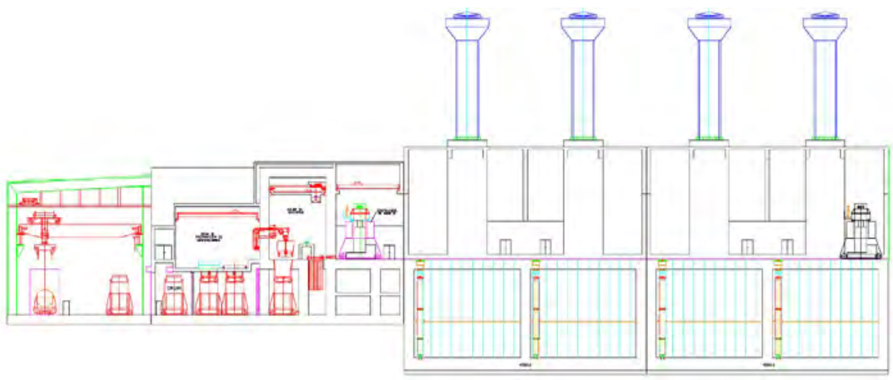
ATC. The Centralized NSF and HLW storage facility. Site selection process

- **Siting based on volunteer candidate municipalities:**
  - Principles of publicity, participation and transparency.
  - Volunteer municipalities: candidature approved by the Local Council
- **Creation of an inter-ministerial Commission to:**
  - Defining the technical and social criteria for municipalities candidate to host the facility
  - Supervising the respect to the siting process criteria
  - Managing the information and candidatures reception
  - Assessing and Proposing to the Government suitable sites in candidate municipalities
- **Information campaign 2006-2008**
- **Call for candidate municipalities in December 2009**
  - Excluded areas report published in April 2009. Site proposal
  - Potential sites in eight municipalities are being studied
- **The Government will decide the site**
  - Dialog with the suitable candidate local councils
  - Dialog with Region Government

AMPHOS 21

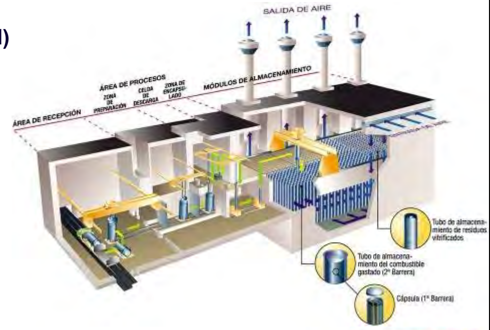
ATC. The Centralized NSF and HLW storage facility. Functions

- **The ATC facility is designed for the following functions:**
  - Reception and unloading.
  - Encapsulation of fuel assemblies.
  - Long-term Storage of NSF and waste packages
  - Retrieval of waste packages for future management options.



ATC. The Centralized NSF and HLW storage facility. Conceptual design

- **Vault type:**
  - Spent Fuel and HLW encapsulated in canisters
  - Canisters placed in storage dry wells
    - Double barrier
    - Inert atmosphere
  - Cooling by natural draft
- **Storage bunker for MLW (long lived)**



AMPHOS 21

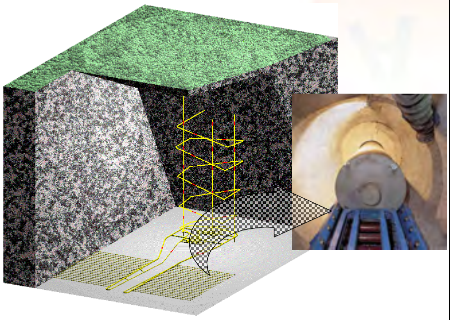
ATC. The Centralized NSF and HLW storage facility. Focus

- **Previously encapsulated spent fuel**
  - Storage in their canisters with no need for re-encapsulation?
- **Detailed revision of expected inventories and acceptance criteria, with particular attention to**
  - Trend to higher burn-ups
  - Final cycles with relatively low cooling periods
  - Fuel characterization status and requirements
- **SF and waste laboratory**
  - SF characterization and behaviour
    - Extended storage
    - Disposal
    - Mechanical, chemical, and radiological characterization and behaviour of Rods, samples, irradiated materials
- **Site characterization and licensing work ongoing after site designation**

AMPHOS 21

Deep Geological Disposal. Previous works

- **Site identification Program: 1986-1996**
- **Deep Geological Repository design and associated Performance assessment (1990-2004) in three steps:**
  - Disposal concept and basic design
    - Carbon steel canisters placed horizontally in parallel galleries, with Calcium-Bentonite seal
  - Strengthening the bases of the concept
    - Flexibility and Robustness (better justification of decisions, alternatives analysis)
    - Convergence: Package definition common for the three host rocks in consideration (salt, clay and granite)
  - Optimization through requirements review



Deep Geological Disposal. Supporting Research

- **Priority of HLW/SNF management is interim storage**
- **DGR in 2050 for planning and financial purposes**
- **R&D supporting Deep Geological Repository development adapted to planning.**
- **Main objectives:**
  - Respect of International Commitments and Co-operation
  - Maintenance of Capabilities of research groups
  - Follow-up of state of the art
  - Support future decisions
  - Focus on techniques and basic aspects
  - Consideration of alternatives (i.e. separation and transmutation) and their influence in DGR concept

Conclusions

- **ATC. The priority**
  - Gives time for decision making depending on trends and technological and social advances
  - The Government has launched the call for candidate municipalities to host the Central SNF/HLW Interim Storages in December 2009.
  - Site analysis to be completed in June
  - The Ad-hoc Inter-ministerial Commission will pass a report with site proposals
  - The CSN approved the generic design of such facility
- **NPP on site storage capacity increase as needed**
- **Research includes extended storage conditions. Research on geological disposal and on advanced recycling options continue in a scale adapted to the general waste management plan time frame.**
- **Reports to the Government on**
  - Generic Design of Deep Geological Disposal,
  - Management options and
  - Feasibility of advanced separation and transmutation

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Simulating Flow and Transport in Fractured Media

A. Püschel, U. Noseck, J. Flügge, J. Wolf
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, Germany

26.09.2012

A Scientific Visit on Crystalline Rock Repository Development, Prague

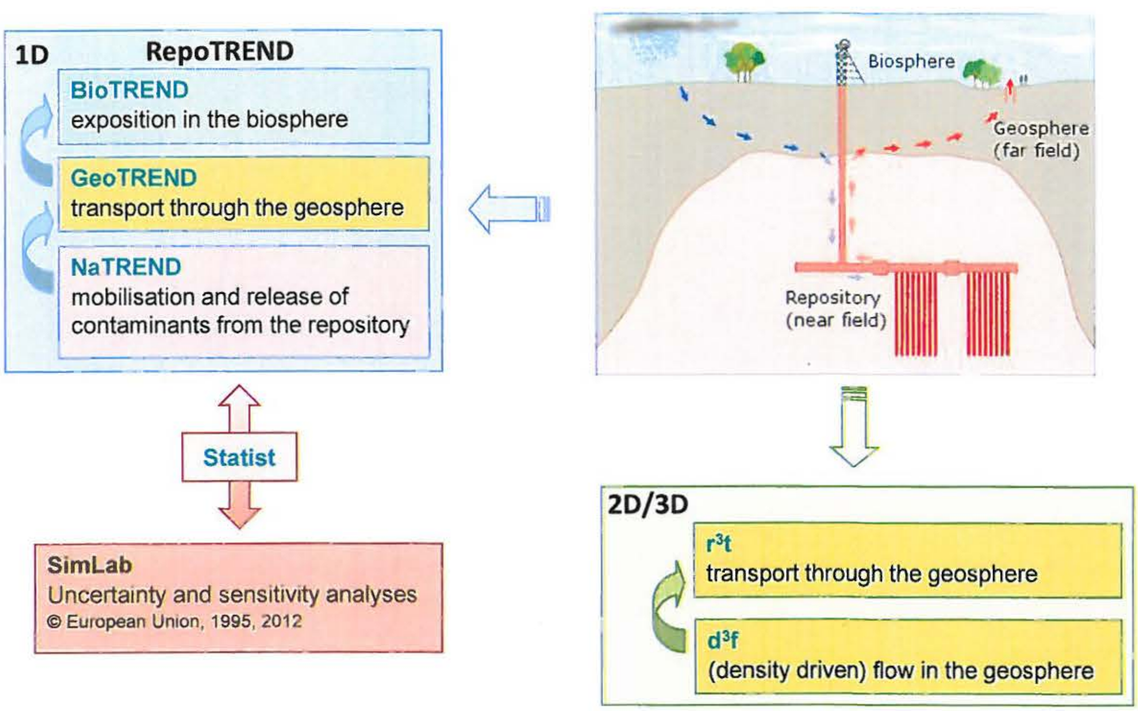
Contents

- Introduction
- Example 1: 1D transport simulations for a generic repository in Russia
- Example 2: 2D radionuclide-colloid associated transport within a fracture
- Example 3: 2D flow and transport in a fractured medium
- Conclusions

Introduction: Profile of the GRS

- GRS is Germany's central expert organisation in the field of nuclear safety and radioactive waste management
- GRS is a non-profit and independent organisation
- Its statements are only bound by technical/scientific principles
- The department "Repository Safety Research" develops tools for long-term safety analyses

Introduction: Tools of the GRS for long-term safety analyses



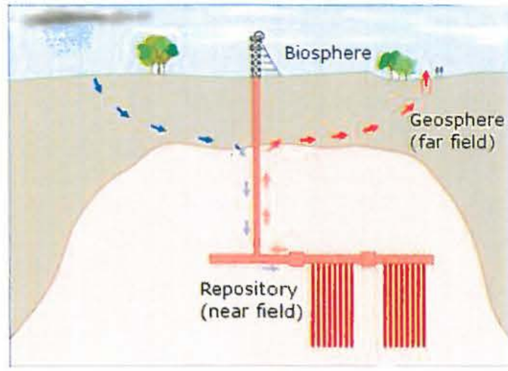
Tools of the GRS for long-term safety analyses

1D RepoTREND

- **BioTREND** exposition in the biosphere
- **GeoTREND** transport through the geosphere
- **NaTREND** mobilisation and release of contaminants from the repository

Statist

SimLab
Uncertainty and sensitivity analyses
© European Union, 1995, 2012

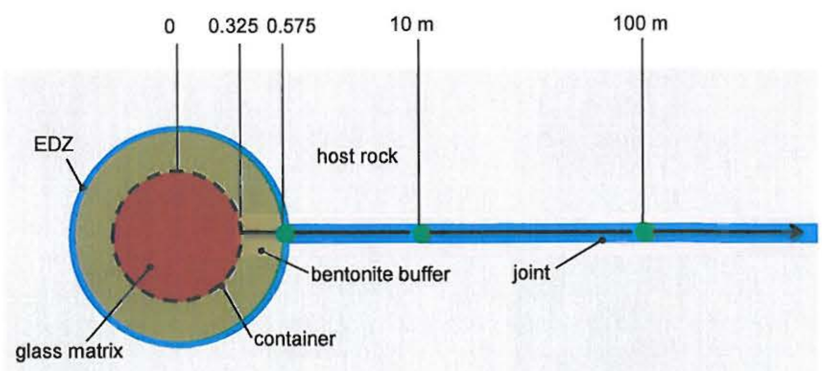


2D/3D

- **r³t** transport through the geosphere
- **d³f** (density driven) flow in the geosphere

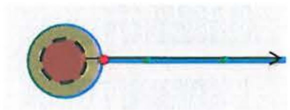
Example 1: 1D transport simulations for a generic repository in Russia

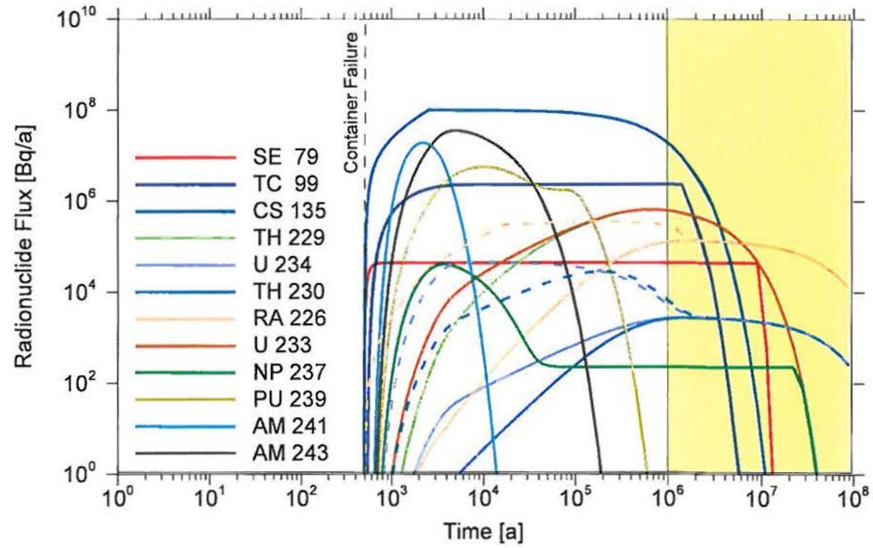
- 1D simulations for a representative fracture
- Modelling advective transport and matrix diffusion



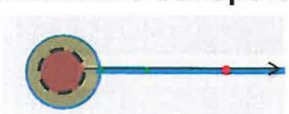
● observation points for the assessment of radionuclide migration

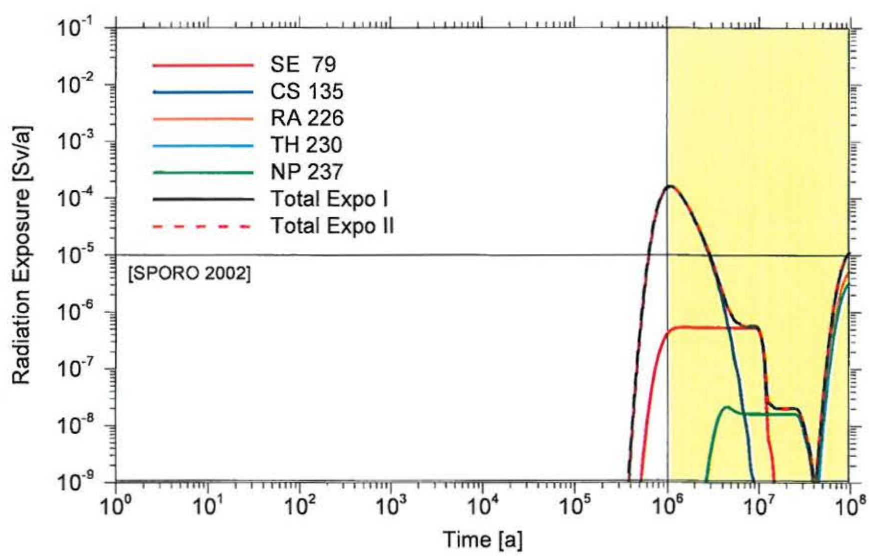
Example 1: Radionuclide fluxes from the near-field (buffer)





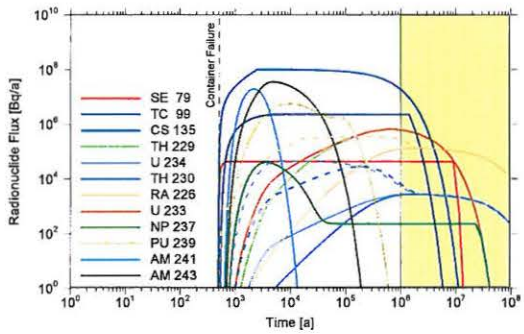
Example 1: Indicator „annual radiation exposure“ Advective transport with matrix diffusion, transport distance: 100 m

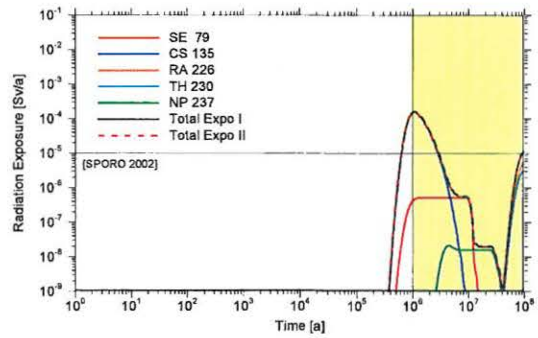




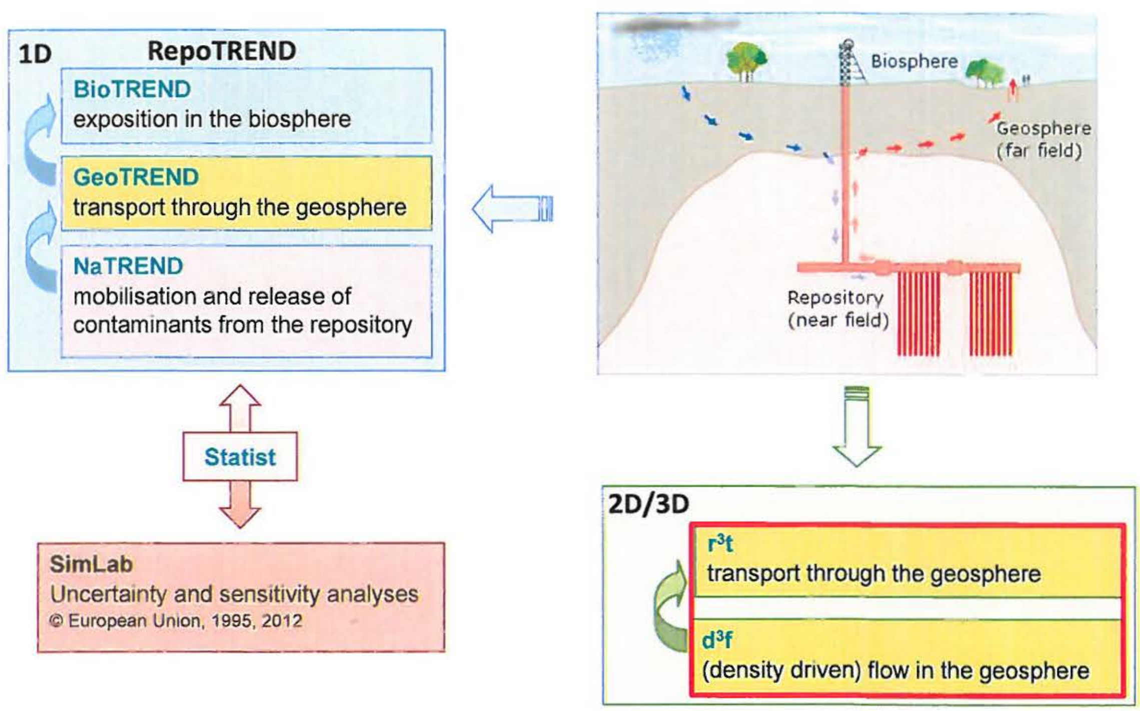
Example 1: 1D transport simulations for a generic repository in Russia Summary

- GeoTREND used to assess radionuclide fluxes and radiation exposure for a generic radioactive waste repository (transport path 100 m)
- Cs-135, and Se-79 are the dominating radionuclides (Ra-266, Th-230, Np-237 after about 10 million years)
- Outlook: uncertainty and sensitivity analyses will be performed soon





Tools of the GRS for long-term safety analyses



Processes and dependencies

d³f

- advection, diffusion, dispersion
- fluid density and viscosity depending on concentration and temperature
- completely coupled equations (no Boussinesq approximation)
- permeability: constant, function, or stochastic
- user-defined functions (initial and boundary conditions, parameters)

r³t

- sorption
  - equilibrium
  - kinetically controlled sorption (linear and non-linear)
- complexation
- precipitation
- immobile pore water
- element-dependent porosities
- element-dependent diffusion
- anisotropic diffusion
- contaminant-dependent decay
- colloid-borne transport
- coupling with PHREEQC
- smart K_d-concept

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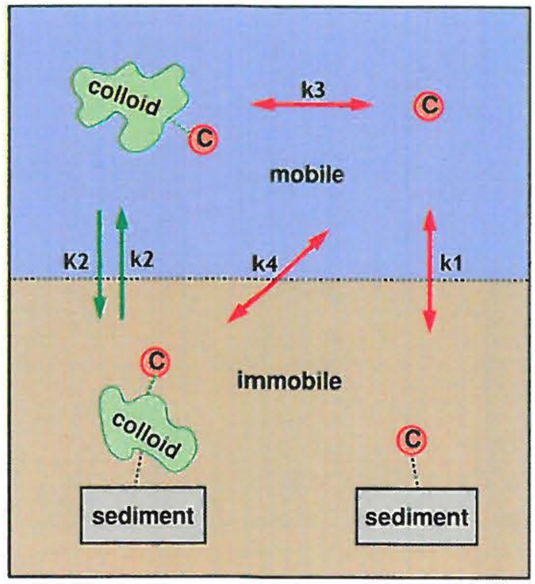
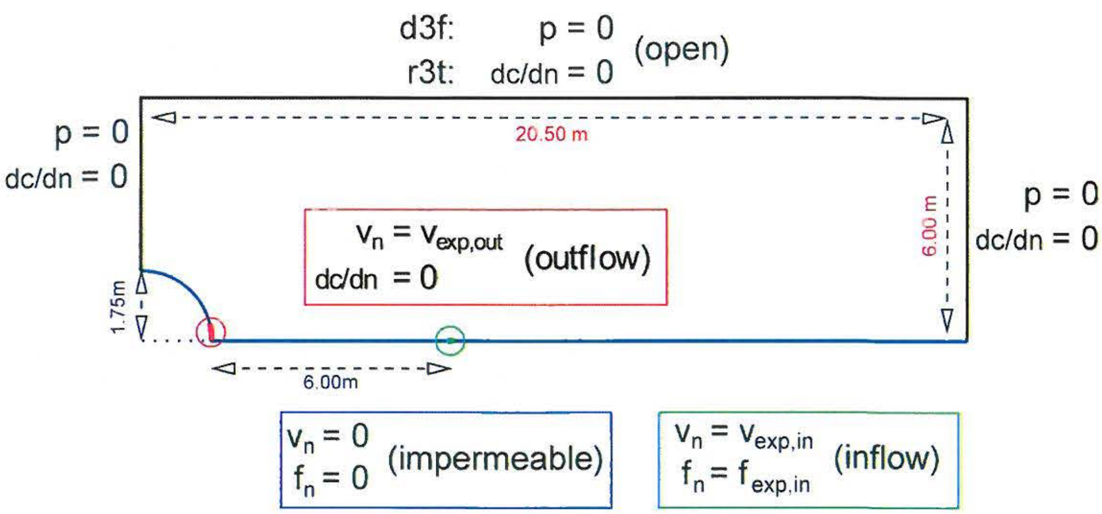
Example 2: 2D radionuclide-colloid associated transport within a fracture

Interaction rates:

- k_1: free radionuclide (RN) - sediment
- k_2: colloid – sediment (detachment)
- K_2: colloid – sediment (attachment)
- k_3: free RN – mobile colloid
- k_4: free RN – immobile colloid



Example 2: 2D radionuclide-colloid associated transport Model setup



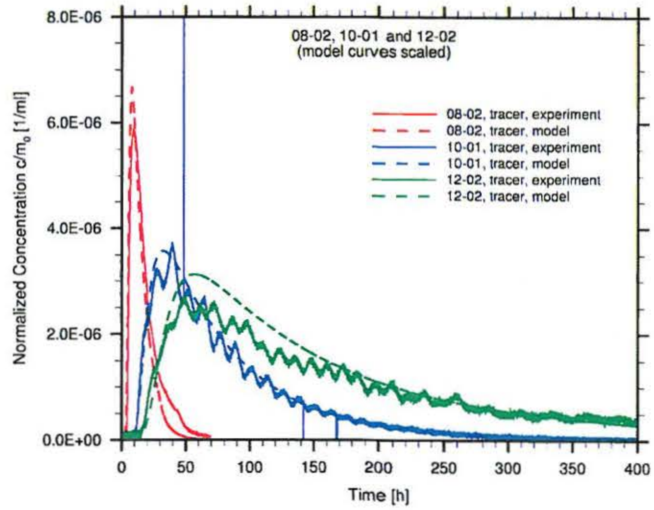
p = pressure [Pa]
dc/dn = diffusive/dispersive flux

v = velocity [m s^{-1}]
f = flux [m^3 s^{-1}]

Example 2: 2D radionuclide-colloid associated transport
Predictive calculations

Calculations for ideal tracer show quite good agreement with experiment

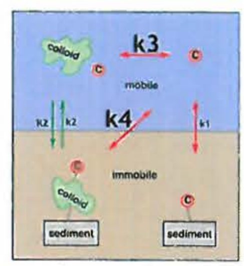
Test run	08-02	10-01	12-02
Inflow Q [ml/min]	10	ca. 0.55	0.33
Outflow Q [ml/min]	165	47.2	25
Injected tracer mass m_0[mg]	15.4	5	4.5
Test run period t [s]	$2.5 \cdot 10^5$	$2 \cdot 10^6$	$4 \cdot 10^6$

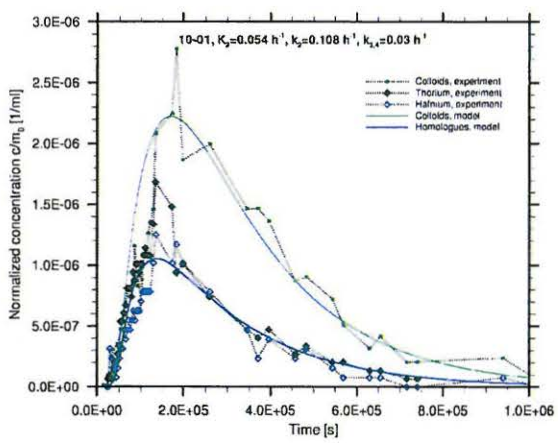


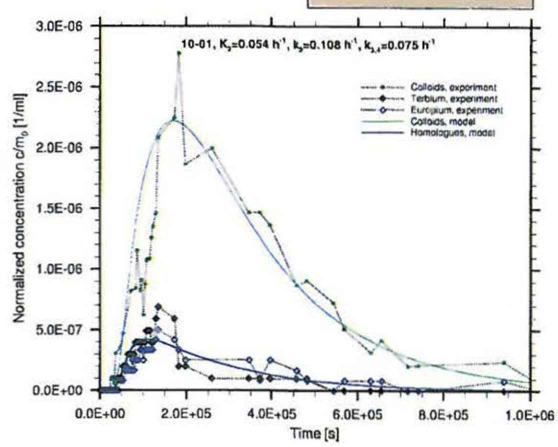
Example 2: Experimental and simulated breakthrough curves for run 10-01: Homologues

Desorption rates from colloids

- tetravalent (Hf, Th): $k_{3,4} = 0.03\ h^{-1}$
- trivalent (Eu, Tb): $k_{3,4} = 0.075\ h^{-1}$

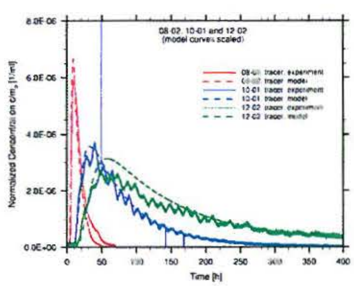


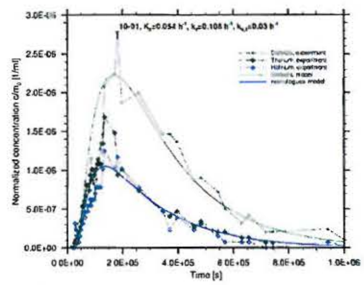


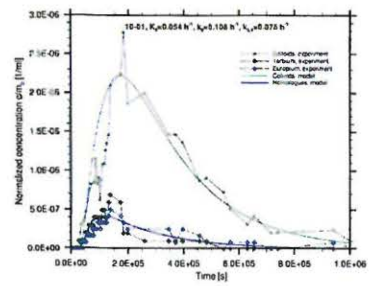


Example 2: Summary

- Modelled breakthrough curves for tracer, colloids and nuclides agree quite well with experimental data
- Desorption is stronger for trivalent than for tetravalent nuclides
- Outlook: experiment with colloid-bound radionuclides was performed
  → comparison with simulation results when data analyses are completed







Processes and dependencies

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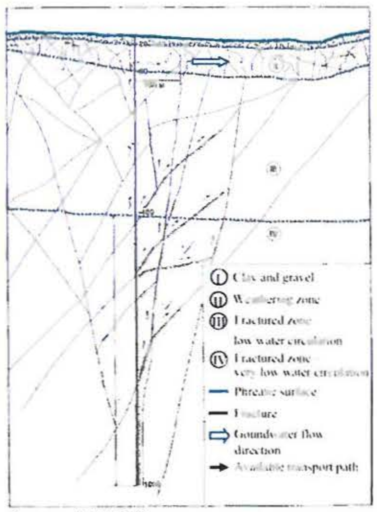
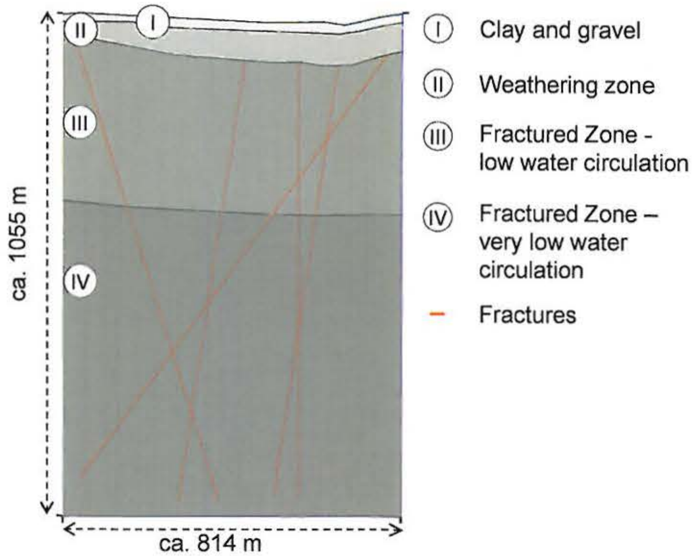
Example 3: 2D flow and transport in fractured media

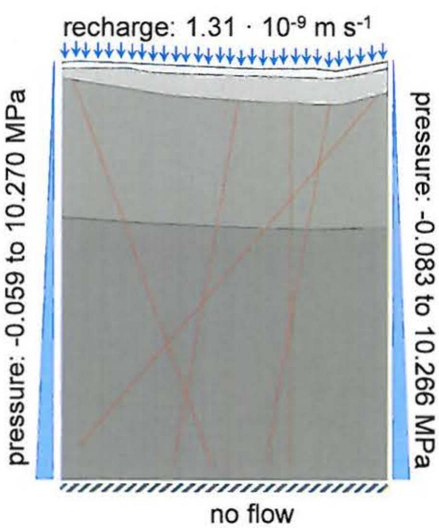
- Vertical 2D model for an area near Majak, Russia
- Four hydrogeological units, five representative fractures
- Comparison of model results of d³f and FEFLOW /DHI 2010/



Source: /WAL 05/



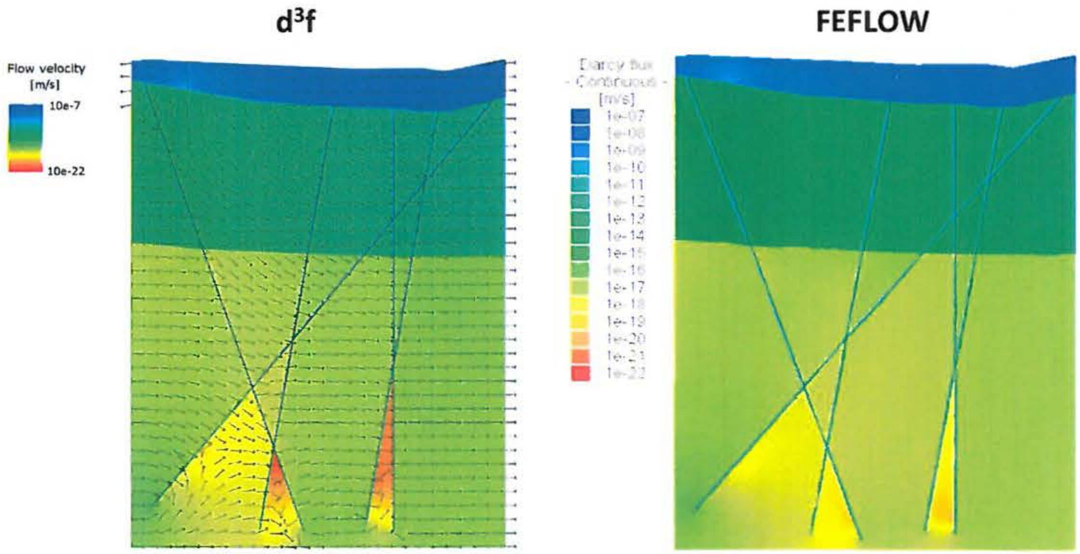
Example 3: Flow simulations
Parameters and boundary conditions



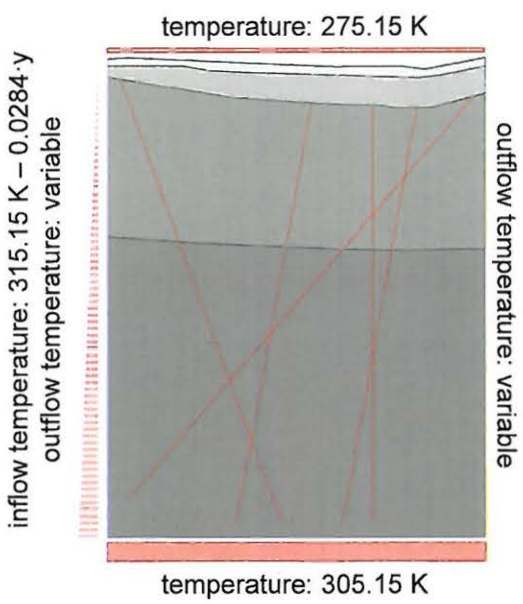
Geological unit	Permeability [m²]
I: Clay and gravel	$2.08 \cdot 10^{-12}$
II: Weathering zone	$5.79 \cdot 10^{-13}$
III: Fractured zone	$1.16 \cdot 10^{-17}$
IV: Fractured zone	$1.16 \cdot 10^{-21}$

	Fractures
Aperture [m]	$1.0 \cdot 10^{-2}$
Permeability [m²]	$7.52 \cdot 10^{-13}$

Example 3: Flow simulations
Results

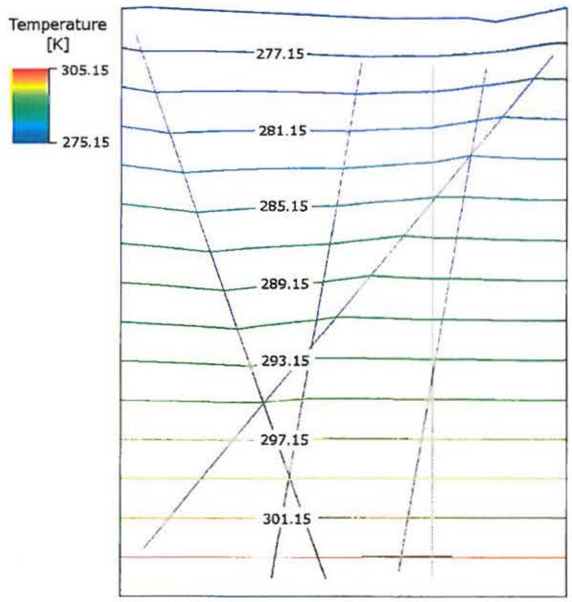


Example 3: Heat transport simulations
Parameters and boundary conditions



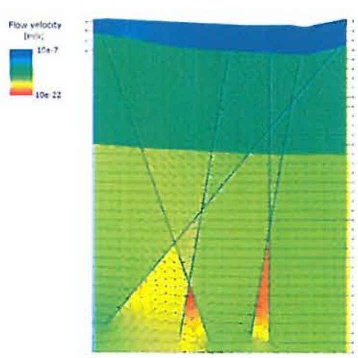
	Matrix	Fractures
Heat capacity of the fluid [J kg^{-1} K^{-1}]	4.170	4.170
Heat capacity of the solid [J kg^{-1} K^{-1}]	2.199	2.199
Heat conductivity of the fluid [J s^{-1} m^{-1} K^{-1}]	$5.97 \cdot 10^{-1}$	$5.97 \cdot 10^{-1}$
Heat conductivity of the fluid [J s^{-1} m^{-1} K^{-1}]	2.66	2.66
Mass-density of the solid phase (rock) [kg m^{-3}]	$3.0 \cdot 10^{3}$	$3.0 \cdot 10^{3}$

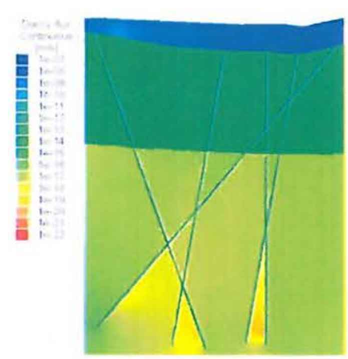
Example 3: Heat transport simulations
Results

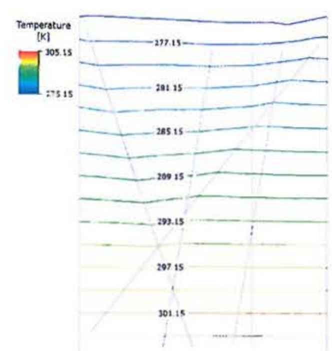


Example 3: 2D flow and transport in fractured media
Summary

- Simulations of flow and heat transport in a fractured area
- Flow fields and temperature isolines from d^3f and FEFLOW simulations show a good agreement
- Also tracer transport was simulated within the project /SCH 12/







Conclusions

- A variety of tools for long-term safety analyses is available at the GRS
  - RepoTREND system: 1D simulations of processes in the near field, far field and biosphere, coupling with uncertainty and sensitivity analyses
  - d^3f/r^3t: 2D and 3D flow and transport simulations in the far field
- The tools are constantly improved. Comparisons with other codes and experimental data are performed

Thank you for your attention!

Acknowledgements:

K.-P. Kröhn, GRS

This work was financed by the German Federal Ministry of Economics and Technology (BMWi) under Contract Nos. 02 E 10750, 02 E 10669, and 02 E 10336.

References

/DHI 10/ DHI-WASY Software: FEFLOW 6. Finite Element Subsurface Flow & Transport Simulation System. User Manual, Berlin, 2010.

/SCH 12/ Schneider, A. (ed.): Enhancement of the Codes d³f and r³t, Final report, FKZ 02 E 10336, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, GRS – 292, Köln, 2012.

/WAL 05/ Wallner, M., Mrugalla, S., Hammer, J., Brewitz, W., Fahrenholz, C., Fein, E., Filber, W., Haverkamp, B., Jobmann, M., Krone, J., Lerch, C., Ward, P., Weiß, E., Ziegenhagen, J., Gupalo, T., Kamnev, E., Konovalov, V., Lopatin, V., Milovidov, V., Prokopova, O.: Anforderungen an die Standort-erkundung für HAW-Endlager im Hartgestein (ASTER), Final report, FKZ 02 E 9612 and FKZ 02 E 9622, 2005.

Geological mapping and structural research: implication for High Level Waste Disposal

Jaroslava Pertoldová, Kryštof Verner, Jan Franěk

Czech Geological Survey

- Historical development of geological mapping in the Czech Republic
- Current stage of geological mapping in the CGS
- Significance and practical utilization of geological mapping
- Structural research foccused on HLWD

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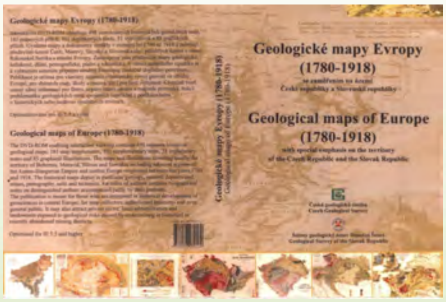
Historical development of geological mapping in the Czech Republic



Systematic mapping of the territory of the country was first carried out in the 1960´s and 1970´s in the number of areas and covered the territory of Czechoslovakia at that time with bedrock geological mapping at a scale of 1:200 000.

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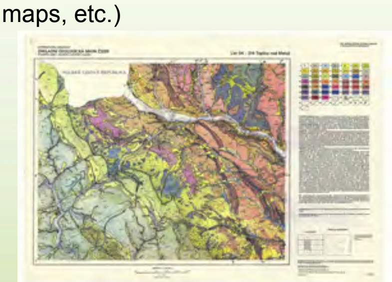
Geological mapping at a scale of 1:50 000

The economic requirements of the state and expanding requirements for more detailed information led in 1987-2000 to increased mapping at a scale of 1:50 000.

221 Geological and special-purpose maps (maps of mineral resources, hydrogeological maps, etc.)



These maps are also available in the digital form on the web site of the Czech Geological Survey – www.geology.cz

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Geological mapping at a scale of 1:25 000 since 1990´s and the current stage of geological mapping in the Czech Republic

Geological mapping programme is planned for 7 years (2008-2014) and takes place in ten areas.

CGS´Directive for the compilation of the Map of the Czech Republic at a scale of 1:25 000.

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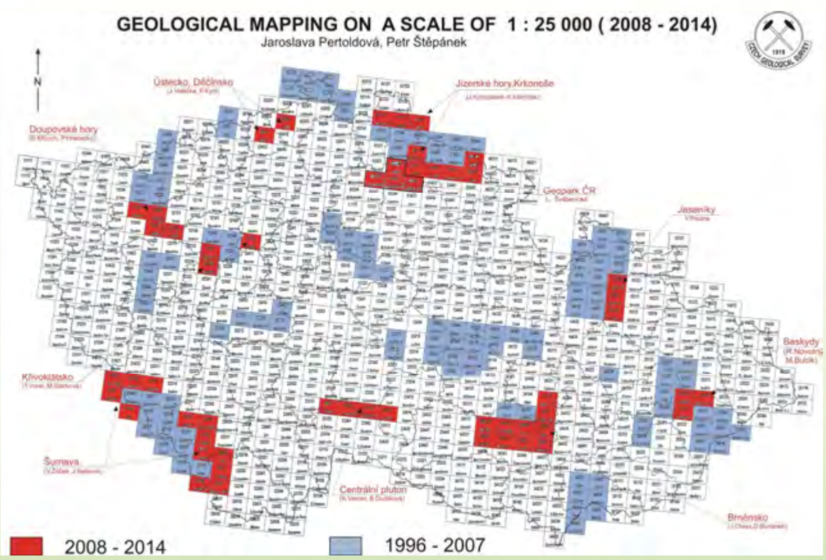

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Geological Map of the Czech Republic at a scale of 1:25 000 and its integral parts

- map part: **Geological map with graphic appendices and special purpose (thematic) maps,**
- text part: **Explanatory notes to the Geological Map of the Czech Republic,**
- documentary part: **Documentation and data to the Geological Map of the Czech Republic.**

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Geological map

Geological map comprises geological map as such, which is compiled as a map with overlying Quaternary deposits and supplemented with obligatory information which will be finally placed on the map margin, which include:

number and name of map sheet,

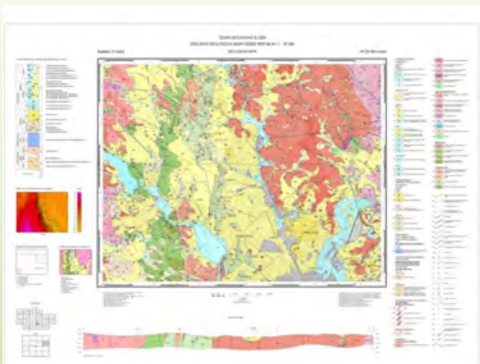
legend to geological map

lithostratigraphic scheme

geological cross-section

summary of geological mapping

summary description of regional geological units



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Explanatory notes to the Geological Map

All the important geological features identified during geological mapping are summarized in the explanation text with following parts and chapters:

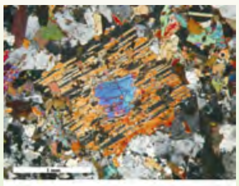
Abstract
1. Introduction
2. Geology
3. Geophysics
4. Geochemistry
5. Mineral resources
6. Hydrogeology
7. Engineering-geological pattern
8. Environmental geofactors
9. Important geological localities
10. Geological development
11. List of references and maps used

Special supplements

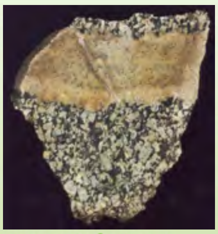
Česká geologická služba | Czech Geological Survey

Documentation used in the compilation of the Geological Map

The term documentation is understood to include all materials that were acquired and used in the compilation of the Geological Map.



The documentation is divided into:
- graphic illustrations
- written documentation
- rock specimens, minerals, fossils, thin and polished sections



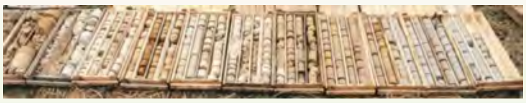
(text and numerical information are stored in databases)

Significance and practical utilization of geological mapping

The results of mapping provide modern, up-to-date information on geological phenomena of the state territory of the Czech Republic, which is part of international scientific research and is employed for comparative studies of geological developments on the surface of the planet Earth.

Česká geologická služba | Czech Geological Survey

- **Direct economic benefits** include important data of new indications of mineral resources, re-evaluation and protection of energy sources (coal, geothermal energy), industrial minerals and **proposal of potential sites for storage of hazardous waste.**

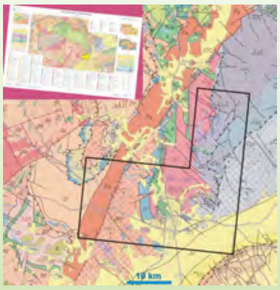


Water tunnels in granites of the Jizera Mts - the antropogenous analogue of the underground waste depository

Česká geologická služba | Czech Geological Survey

- Records of the extent and thickness of Quaternary sediments, tectonic analysis, and hydrogeological conditions are amongst important, **indirect social-economic benefits**, that are broadly utilized **in land-use planning**, environmental decision-making and evaluation of natural risks.

Brno town agglomeration



Geological mapping provide new information relevant to the geochemistry, geologic history, landscape planning of the Brno town agglomeration

and ecology of the Moravian Karst and other protected areas near Brno

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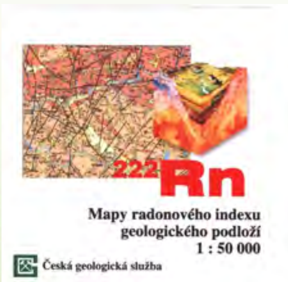
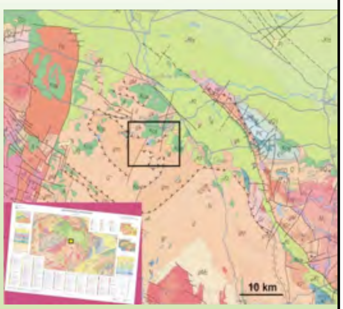
- Evaluation of the current state of anomalous values of the concentrations of **heavy metals and toxic and radioactive elements** in rocks, river and lake sediments, ground and surface waters, and of the risk of radon radiation.



Kutná Hora region



Mapping is important especially in context with a large-scale undermining of the historical silver-bearing Kutná Hora district. The mine system is situated directly underneath the centre of the UNESCO-protected medieval town of Kutná Hora. Polluted anthropogenic mining waste deposits may cause environmental problems.

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- Evaluation of **rock falls**, and **landslides.**

Beskydy Mts.

The Carpatian flysh rocks are represented by layers of claystones, siltstones and sandstones. These rocks are not well permeable when speaking about the precipitation and it comes to a very quick saturation in their surface layers.

The petrological and tectonic predisposition of the area result in instability, which led to numerous land slides in the past.

Foto O. Krejčí

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- Palynological research and paleological analysis of peat bogs and limnic sediments in correlation with radiocarbon dating contribute substantially to understanding climatic and vegetative developments in the period of the Cenozoic, which is important for comparative studies on the European scale. The results are employed for **reconstruction of geochronological development** of the given territory, glacial relicts, vegetation and biotopes

Šumava National Park and adjacent areas

Foto E. Břízová

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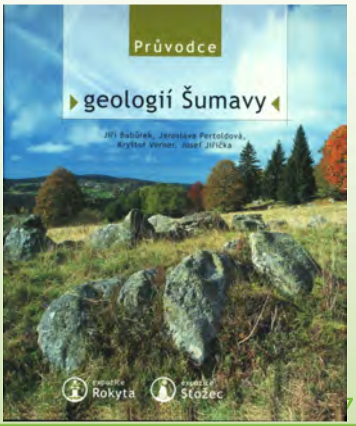
- An important aspect lies in **popularization of geoscientific fields**, e.g. through installation of the instructive outdoor geological exhibitions “Rokyta” and “Geopark Stožec” in Šumava and publishing of the monograph “Guide to the Geology of Šumava”, which was carried out in cooperation with the administrations of the National Park Šumava Mts.



- **Definition of important geological locations** assists the state and public administration in suggesting touristically interesting geological sites in the framework of care for the landscape of given territory.

These activities substantially promote and increase the development of tourism in the mapping areas.

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STRUCTURAL GEOLOGY: crucial geological research for HLWD

Structural geology is the three-dimenstional study of processes and products of deformation of sedimentary, magmatic and metamorphic rocks.

The main goal of **structural geology** is to use tectonic measurements of rock anisotropy to uncover information about the history of rock deformation and understanding the regional stress field.

Structural geology is also important for **engeneering geology**, which is concerned with the physical and mechanical properties of natural rocks.

Fabrics and structures of rocks (brittle, brittle-ductile and ductile) such as e. g. faults, joints, folds and foliations are internal weaknesses of rocks which may affect the stability of underground disposals.

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METHODS OF STRUCTURAL RESEARCH

Field structural mapping and microstructural analyses
Identification and desctiption of structures and textures including analyses of their temporal and space relationships

Application of analytical methods in structural geology
Anisotropy of magnetic suceptiblity (AMS)
Electron Back-Scatter Diffraction (EBSD)
Strain and paleostress analyses

Verification of structural indications with other analytical methods
Geophysical methods such as gravity modelling or seismics
Geochemisty and interpretation of petrophysical properties
Remote sensing and image analysis

Processing of synthetic structural map and three-dimensional model of tectonic anisotrophy of rocks

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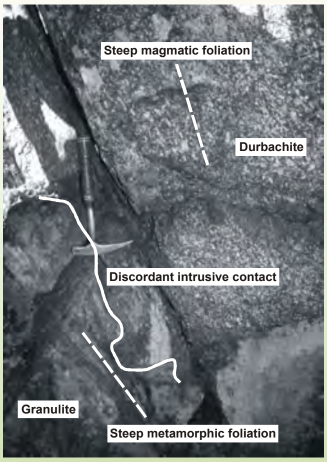
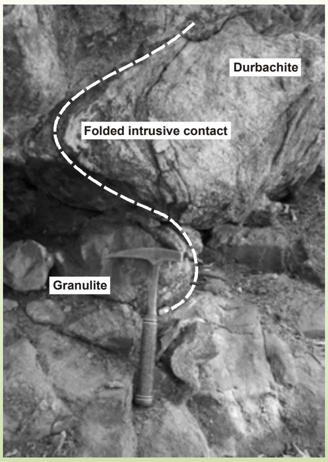
Ductile fabrics and structures in magmatic and metamorphic rocks

Pervasive structures as the result of regional geodynamic evolution of rocks reflecting emplacement processes, high-grade deformation or metamorphism

Folded intrusive contact of durbachites and magmatic fabric defined by space orientation of K-feldspars





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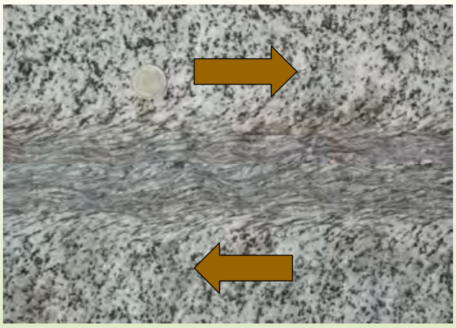
Brittle-ductile structures

Localized planar fabrics of later stages of deformation, often accompanied with retrograde metamorphism and partial recrystallization of rocks



Shear zone with evidence of right-lateral kinematics (tonalite)

Low-temperature shear structures Reflecting thrusting kinematics (migmatite)

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Extensional joints

Faults and joints

Results of deformation in brittle enviroment

Fault plane with kinematic indicators

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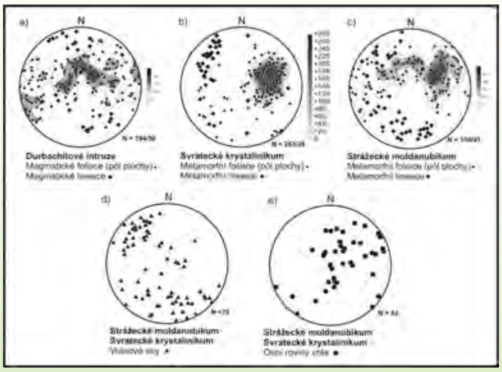
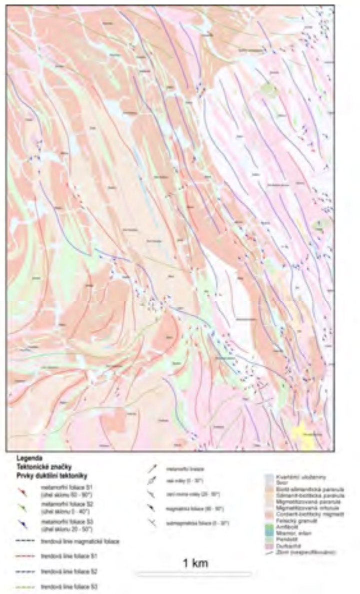
Processing of mesoscopic structural data



Orientation diagrams of structural elements



Structural map

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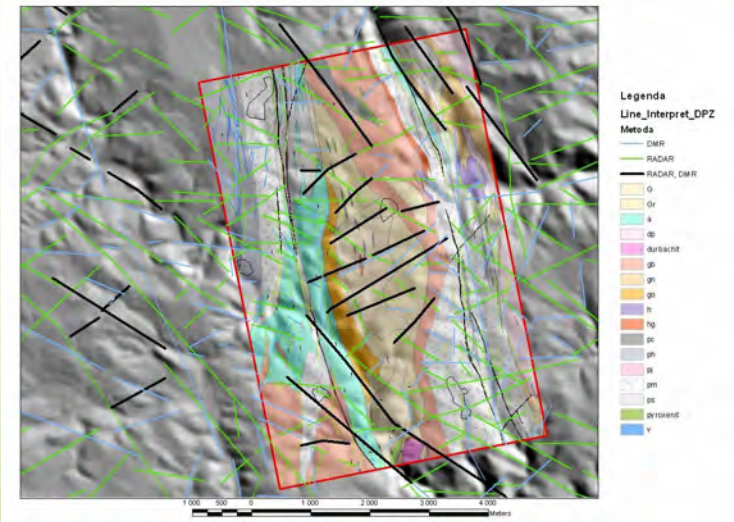
Tectonic indications based on Remote sensing analyses



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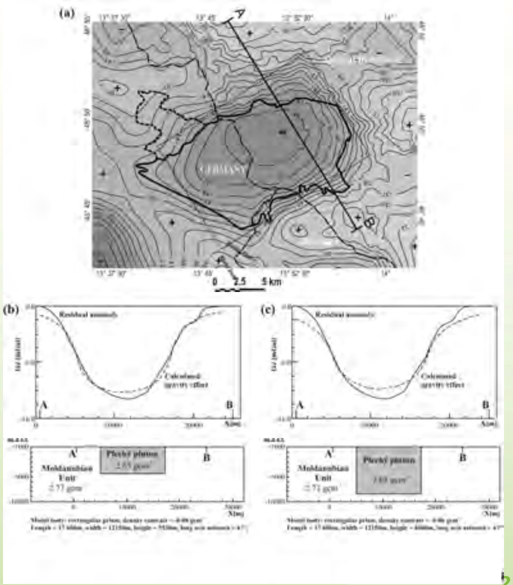
Results of gravity modelling indicating geometry and depth of granitoid plutons



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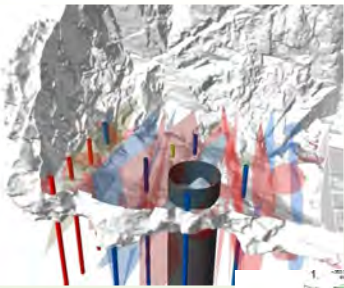
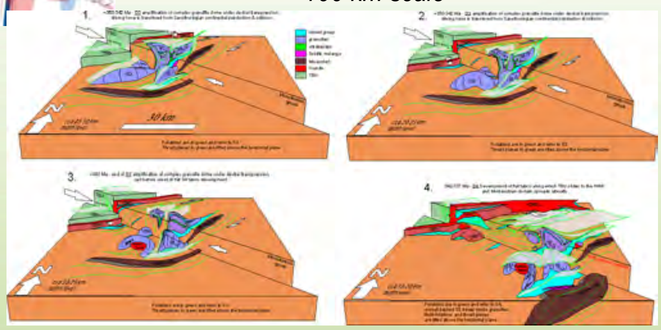
Interpretation of structural data



5 m scale

100 km scale



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C O N C L U S I O N

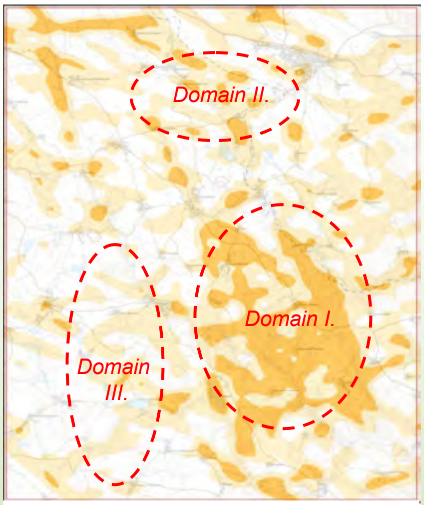
Map of tectonic anisotrophy of rocks

Synthesis of partial results of **structural, geophysical and remote sensing analyses** with broad implication for model of intensity of tectonic anisotrophy.

Domain I.
Strong intensity of RA

Domain II.
Moderate intensity of RA

Domain III.
Low intensity of RA



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Summary

- The geological map compiles and evaluates all the available and up-dated data on knowledge of the geological structure and current state of the geological environment, critical values for environmental proceedings, natural risks and land-use planning.

  New geological informations are required for sustainable development of modern society and thus geological mapping occupies an important place.

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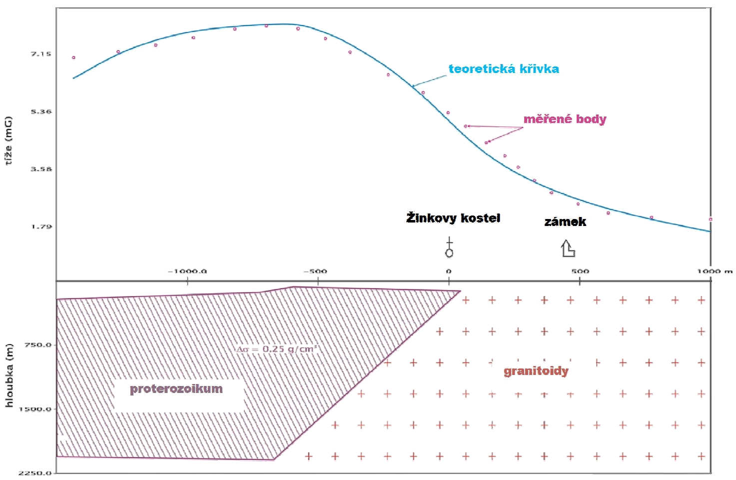
Application of Geophysical Methods for HLW Disposal in CR

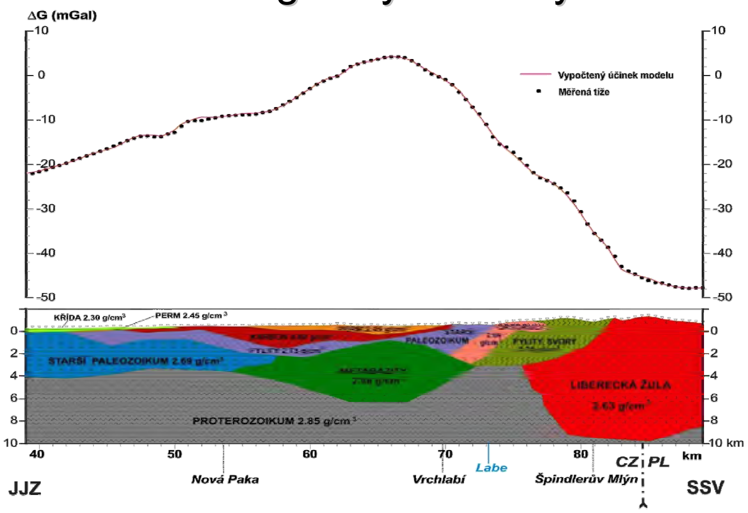
Miloš R. Karous
RNDr. PhD. DrSc., Professor of Geophysics
GEONIKA Ltd. Prague
Faculty of Science, Charles University

Interpreted gravity cross-section Žinkovy

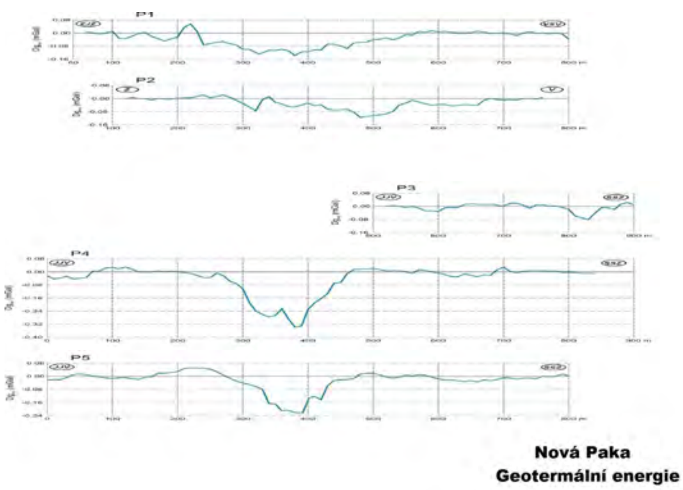


Gravimetrie 2

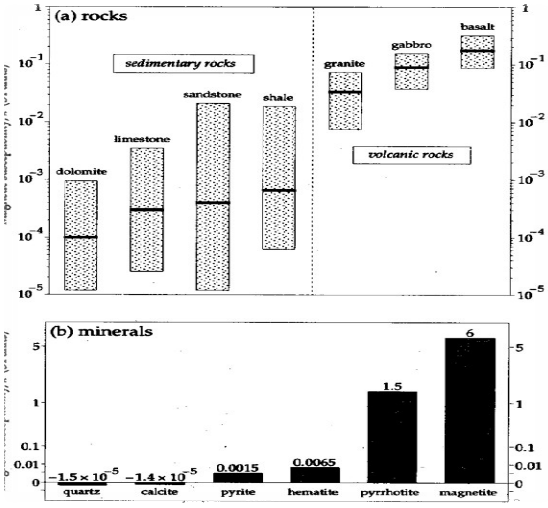
Interpreted cross-section from gravity anomaly



Gravity anomalies over faults



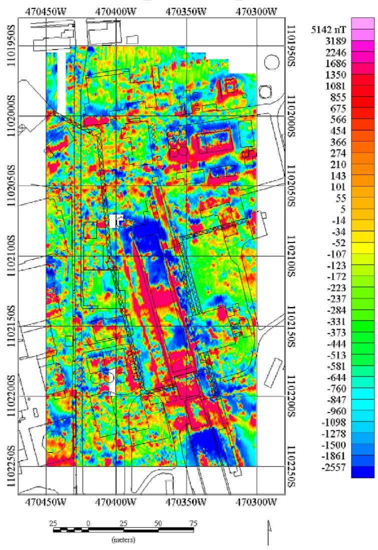
Susceptibilities of rocks and minerals



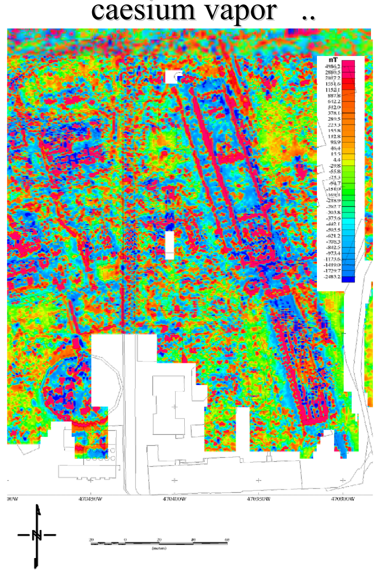
Magnetometrie 5

Results of different types of magnetometers

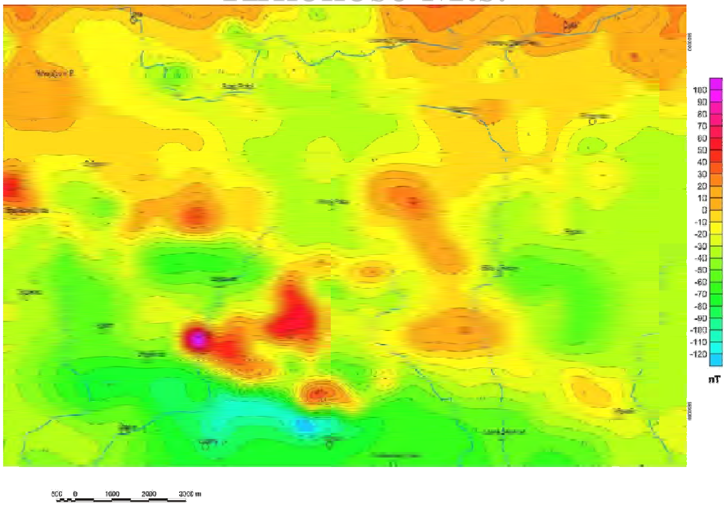
nuclear proton precession



caesium vapor ..



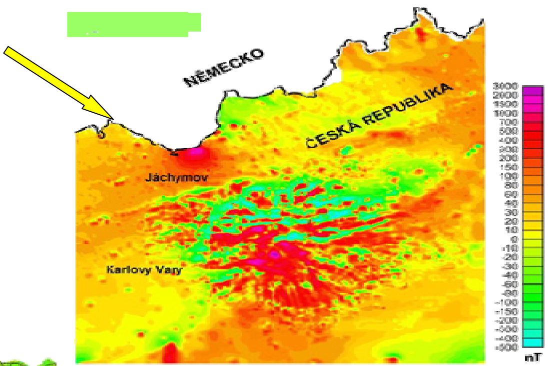
Aeromagnetic contour map Krkonoše Mts.

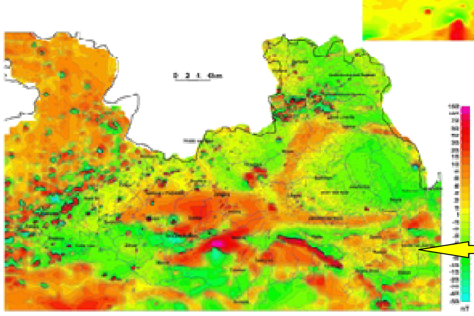


Úvod do užité geofyziky 7

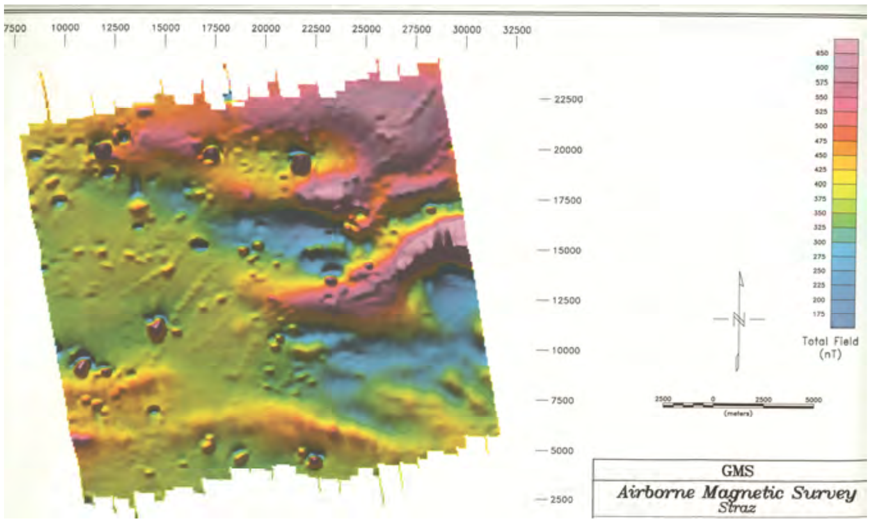
Airborne magnetic measurements

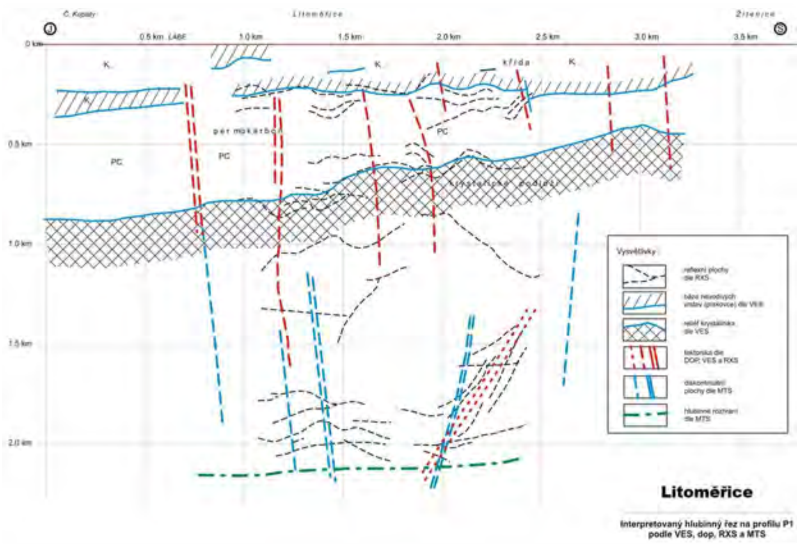
Volkano Doupov





Aeromagnetic map Northern Bohemia





Interpreted cross section from complex of geophysical methods

Overview of aeroelectromagnetic methods

a) - d) stable AEM profilling, e) - g) unstable

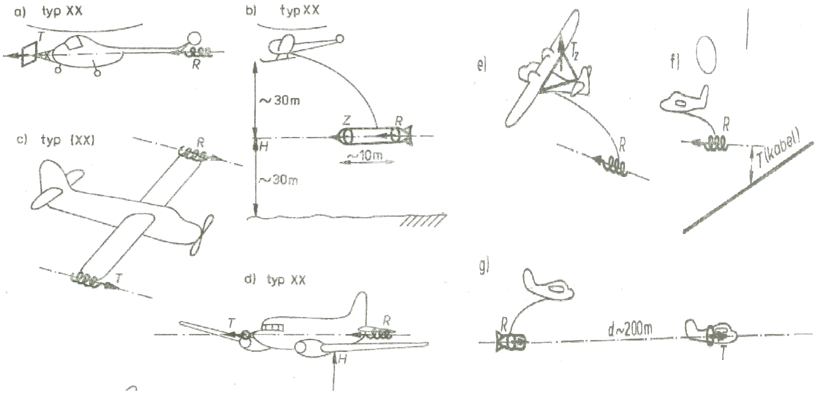


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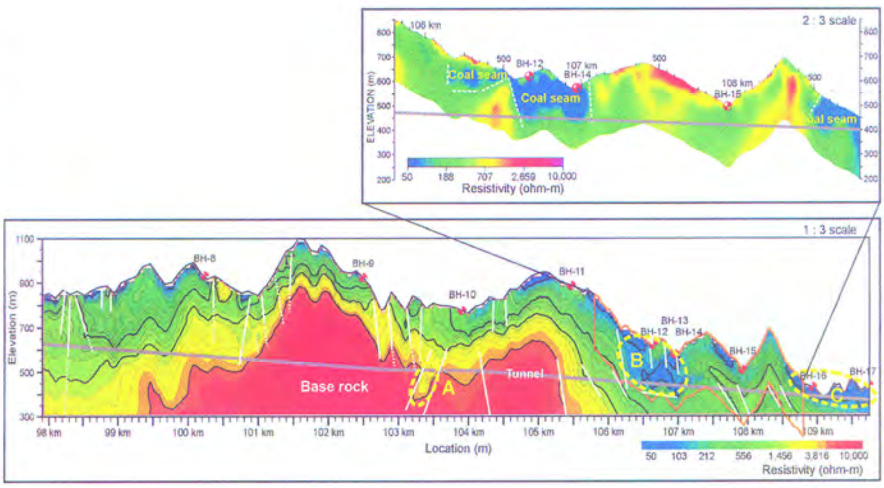
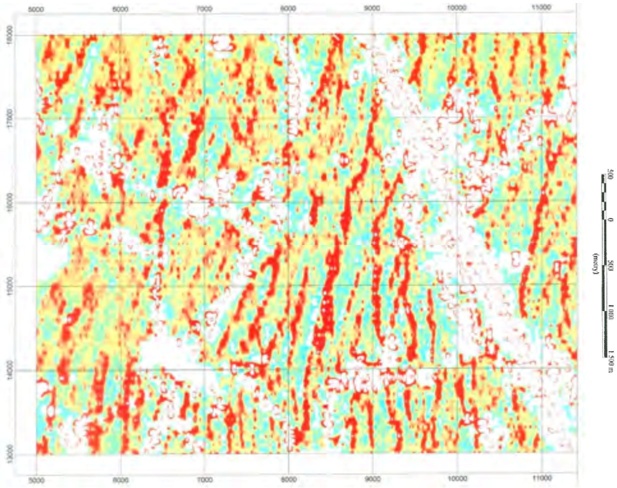
Table 16.1 Concentrations and ratios of U, Th, and K in some rocks and minerals

Rock or mineral	Concentration of element, ppm (parts per million)		
	Uranium	Thorium	Potassium
Sediments			
limestone	2	2	3,000
sandstone	2	11	27,000
shale	4	12	25,000
Igneous and metamorphic			
andesite	2	6	25,000
basalt	1	3	10,000
gabbro	0.05	0.15	800
granite	4	25	40,000
pegmatite	10–100		
schist	3	11	27,000
ultramafic	0.001	0.004	30

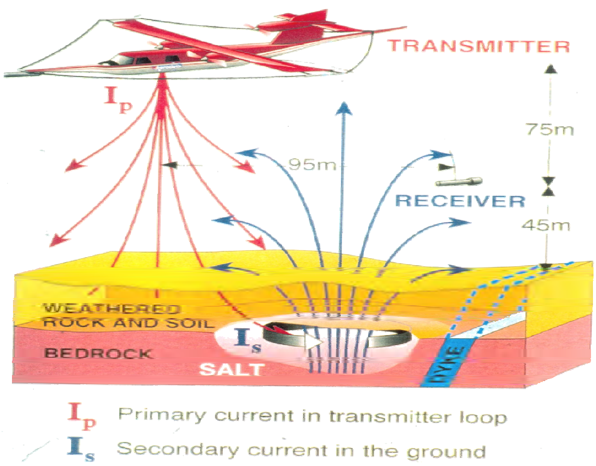
The data, which are derived from various sources, are intended only as a guide to values.



Conductive tectonic lines according to electromagnetic VLF method Melechov granite massive



Principle of aeroelektromagnetic method Questem System



Aeroelectromagnetic methods of exploration

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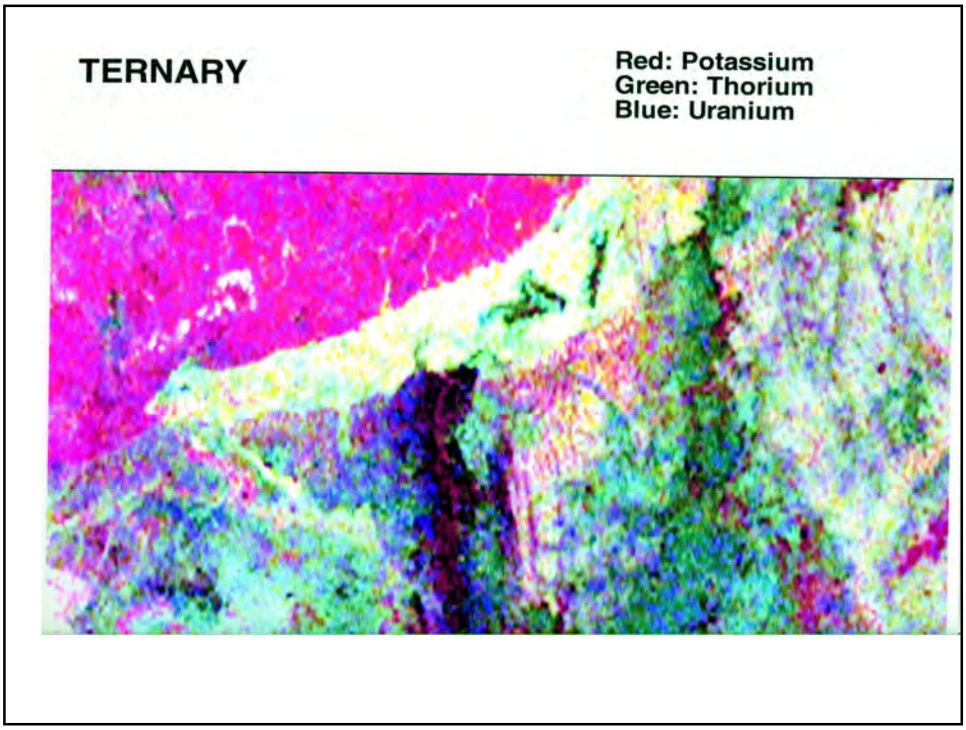
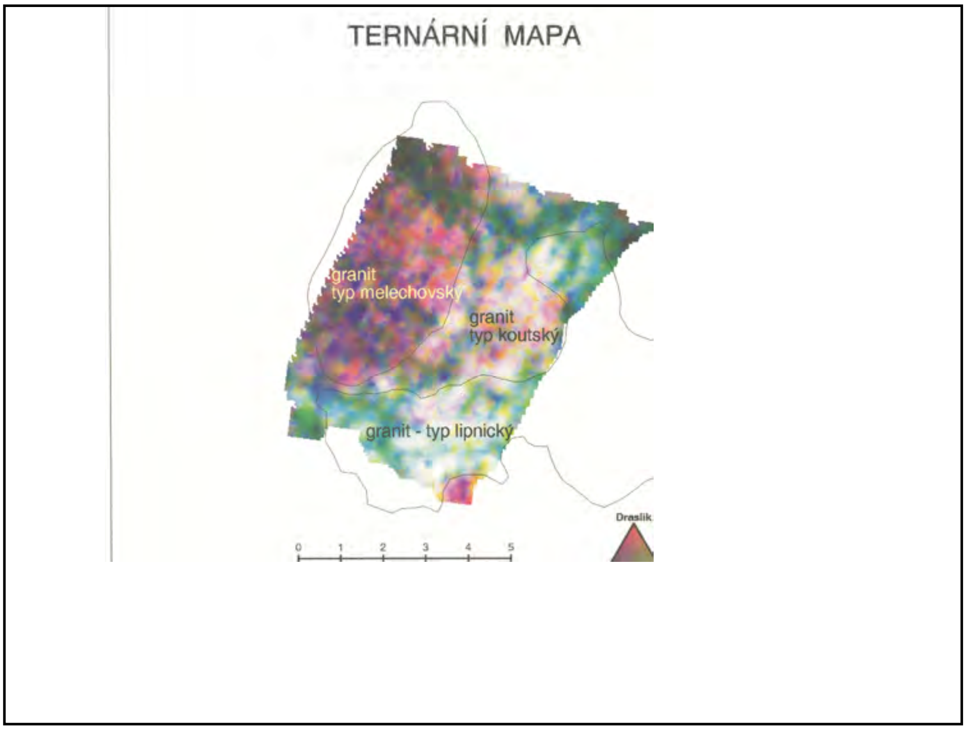
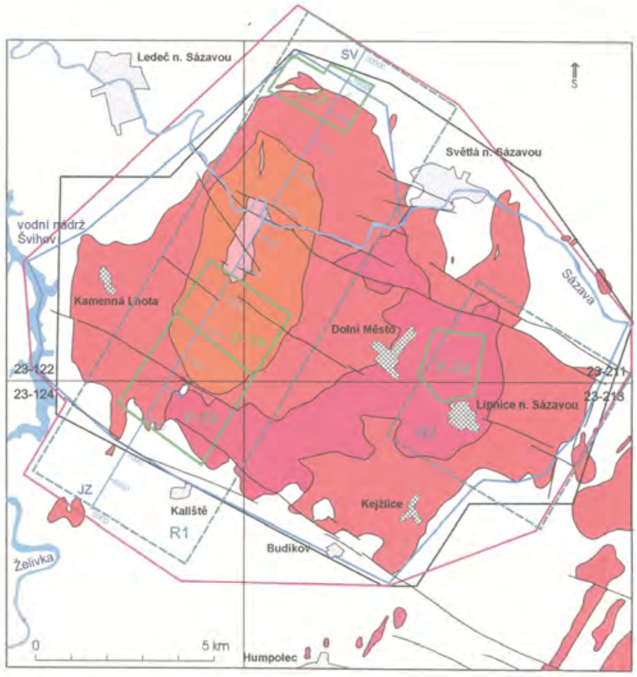
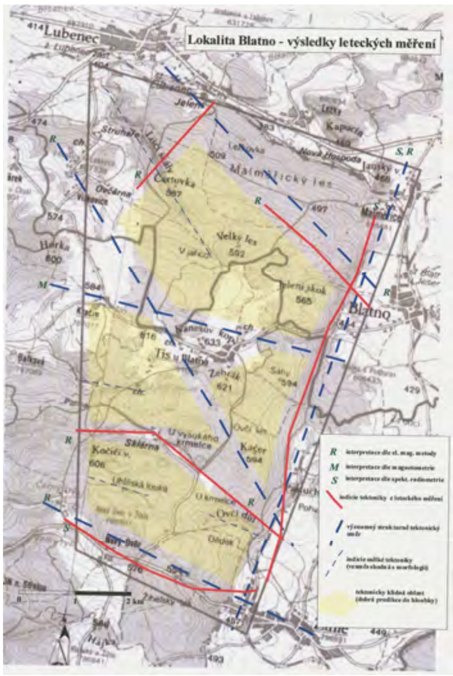

TERNARY
Red: Potassium
Green: Thorium
Blue: Uranium


TERNÁRNÍ MAPA
granit
typ melechovský
granit
typ koutský
granit - typ lipnický
0 1 2 3 4 5
Draslik

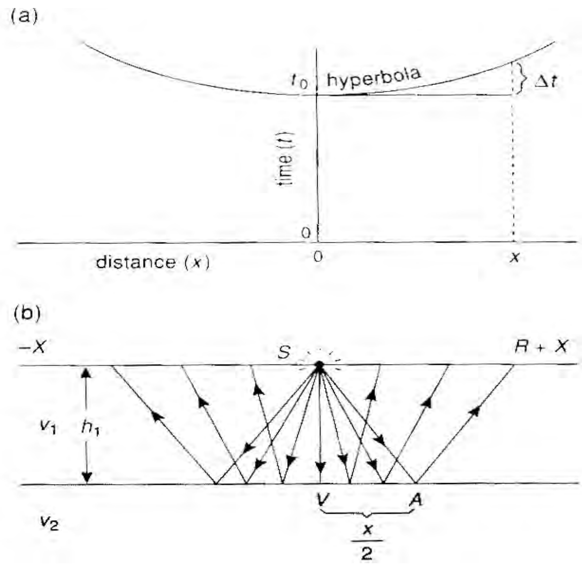


The cumulative results of airborne geophysical measurements

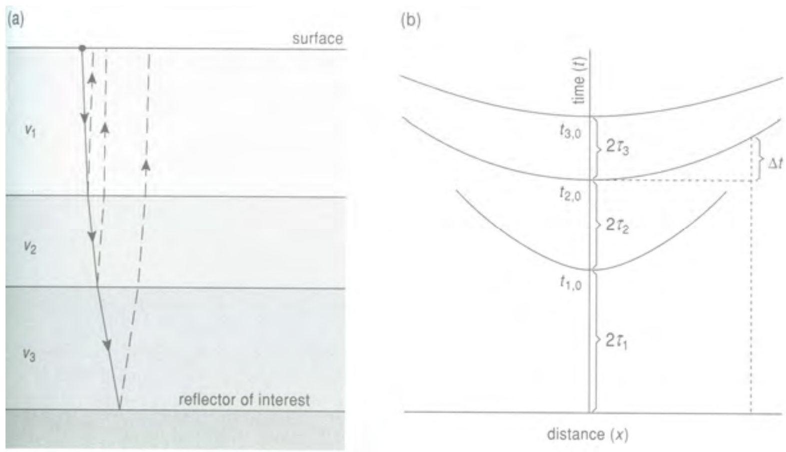
Blatno

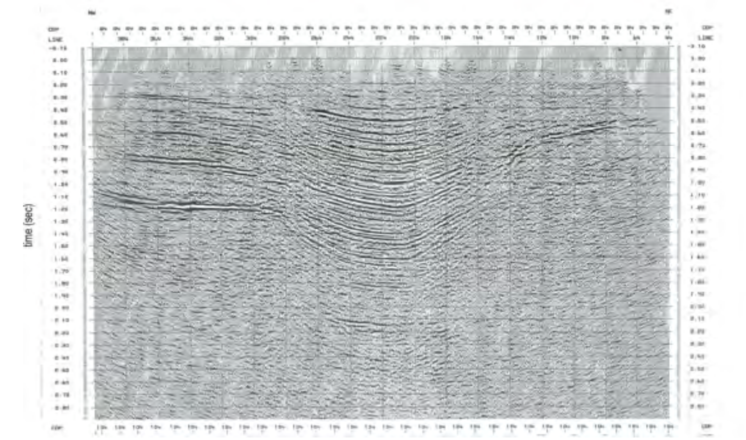


Reflected seismic waves from horizontal plane boundary



Reflected seismic waves from parallel horizontal boundaries

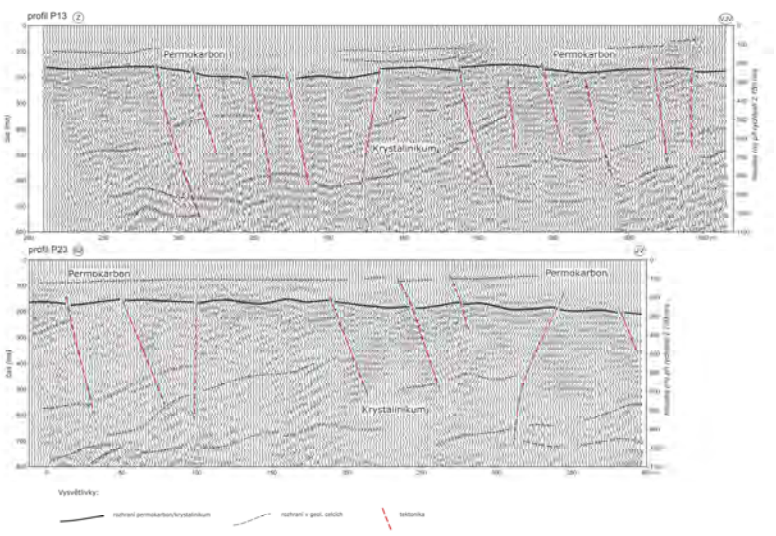




Interpretation of deep reflection seismics in the surrounding of Ebreichsdorf town in Austria.

Suppl. 1. Example of seismic time section

Seismic cross-section Semily

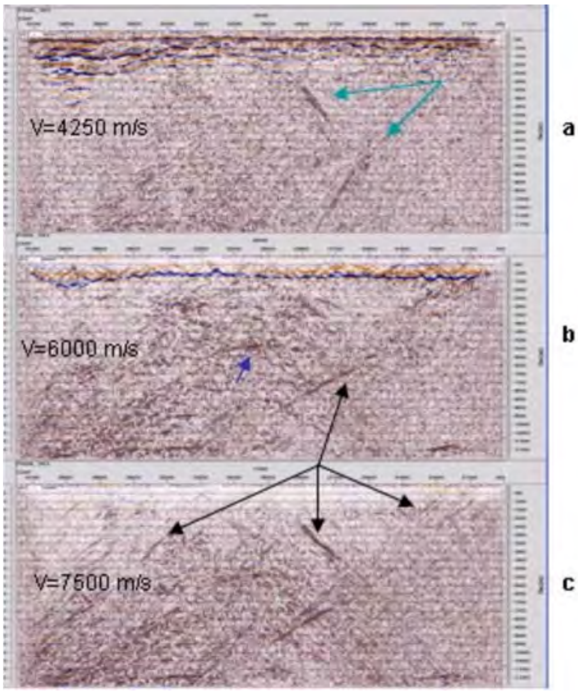


A vibroseis truck

Seismic
time
cross-
sections

from

3-D
seismics



Thank you for your attention

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The application of surface and airborne geophysical methods for recognition of geological conditions at candidate locations for radioactive waste repository in Czech Republic

Abstract / Annotation

The concept for the disposal of nuclear fuel waste in Czech Republic is very similar over all the entire world, i.e. the developing the repository in deeper part (about 500 m) of the geological environment to be safety for even many thousands years. In CR we give a preference to crystalline rock environment with multiple barrier system including geological one. The knowledge of the deep geology is therefore basic necessity. The effective survey may be realized using so called applied geophysical methods - geophysics studies the naturally and artificially generated physical fields to assist in determining geological conditions.

The presented contribution deals with the application of surface and airborne geophysical methods for understanding the geological conditions at greater depths. For the disposal of radioactive wastes there is required a large volume of solid compact crystalline rocks in order to prevent movement of contaminated fluids to the surrounding of the store via different broken and permeable zones. Hard rocks create the second, so called far field barrier of safety (first are waste cans).

Geophysical methods bellow to the wide group of applied methods of a geological survey. In comparison of the other ones they have some advantages:

- they are non-destructive (in contrary to wells, boreholes, ditch etc.),
- they can bring continuous picture of the geological environment in 2-D (maps, cross sections) and 3-D models,
- they are cost effective.

Applied geophysical methods are divided according to the character of the measure field: gravimetric, geomagnetic, geoelectrical and electromagnetic, radiometric and nuclear, and last but not least seismic methods. According to site of measurement, geophysical methods have several variants: surface, underground (boreholes, galleries, shafts), airborne and remote sensing.

In this presentation are given examples of application of the different surface and airborne geophysics to recognition of geological conditions at candidate locations in Czech Republic for the nuclear waste repository (proper locations have not been yet determined) and comparison of the possibilities and positives of different methods.

APPLICATION OF WELL LOGGING FOR STUDY OF GRANITOID MASSIF FOR STORAGE OF RADIOACTIVE WASTE

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RNDr.Jiří Lukeš, RNDr.Michal Pitrák
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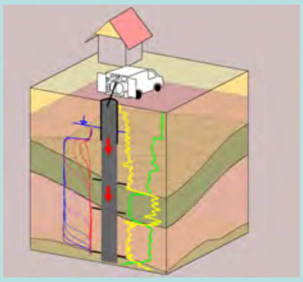
aquatest

Well logging = set of geophysical methods in boreholes

In situ measurements of:

- physical properties of rocks
- mechanical properties of rocks
- the stage of tectonical deformation of rocks, detection of all fractures and fissures,
- detection of open fractures
- fractures orientation (their dip and azimuth)
- groundwater movements (detection of yields, measurements of the intensity of water flow)
- technical parameters of borehole (well orientation-dip and azimuth, detection of cavities, quality of cementation etc.)
- optical information from inner space of borehole



Synthesis of results

Measurements are continuos, depth step of digitalization of acquized data is usually 5 cm.

aquatest

Well logging methods:

Fluid resistivity log

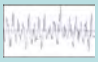
Photometry log

Gamma log

Resistivity logs

Magnetic suscept.

analog. Acoustic log



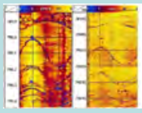
Caliper log

Wull wave acoustic log (sonic log)

Neutron-neutron log

Temperature log

Acoustic scanner

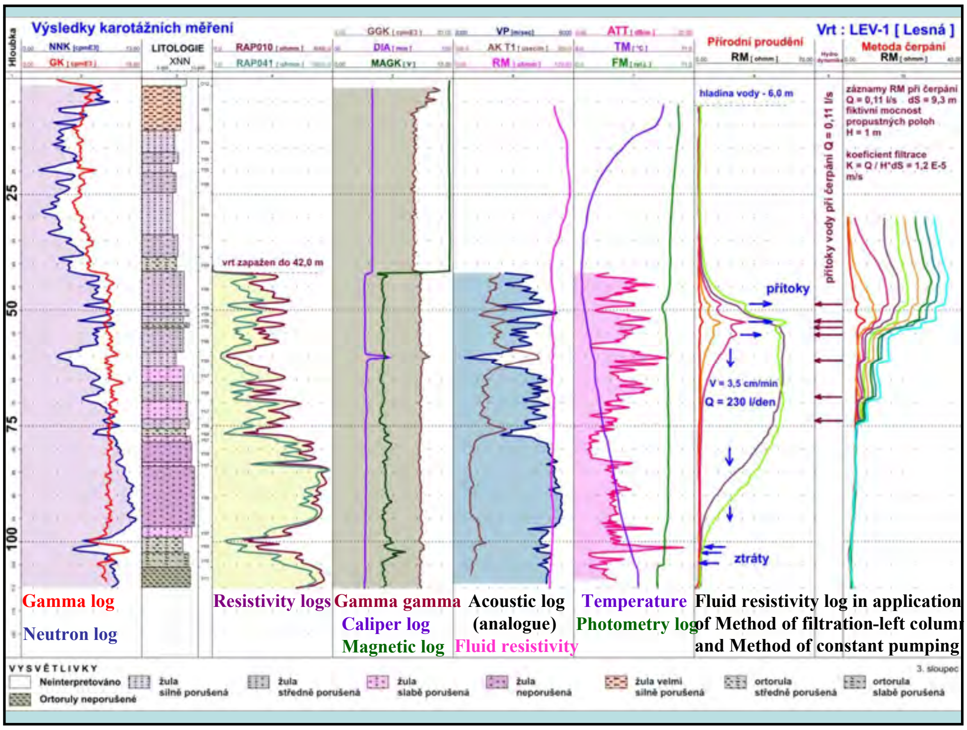


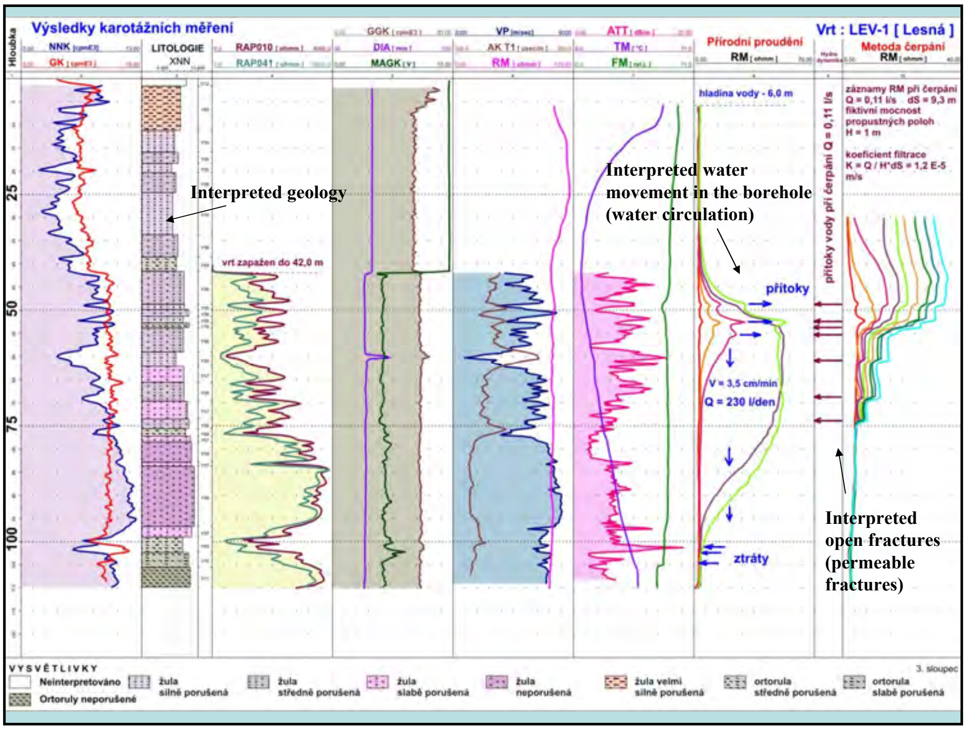
Gamma-gamma log

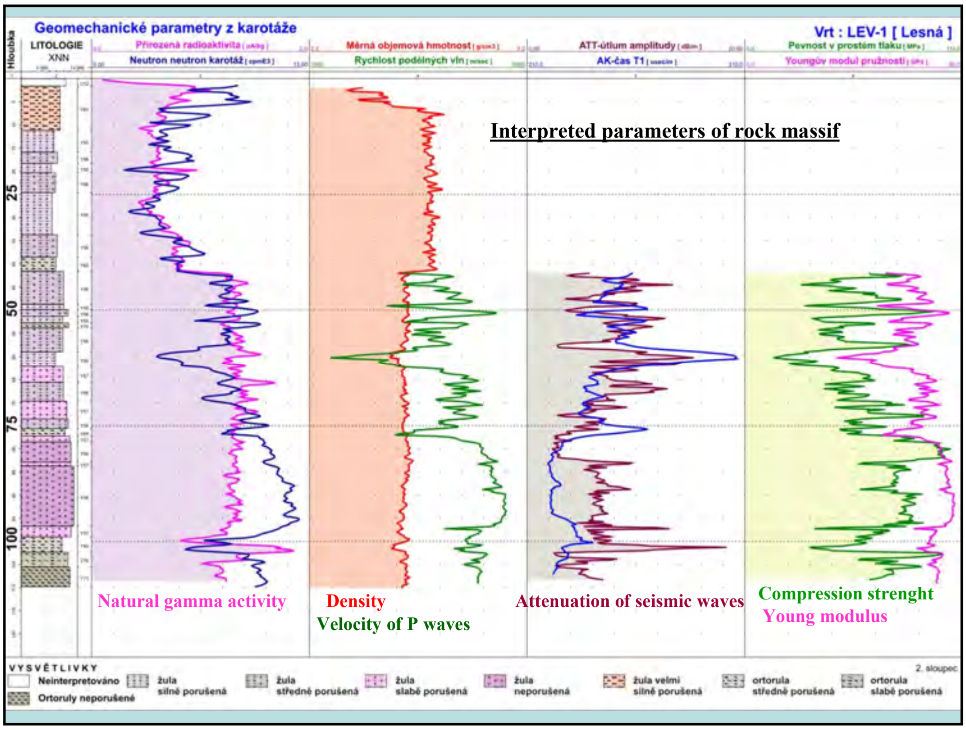
Borehole TV

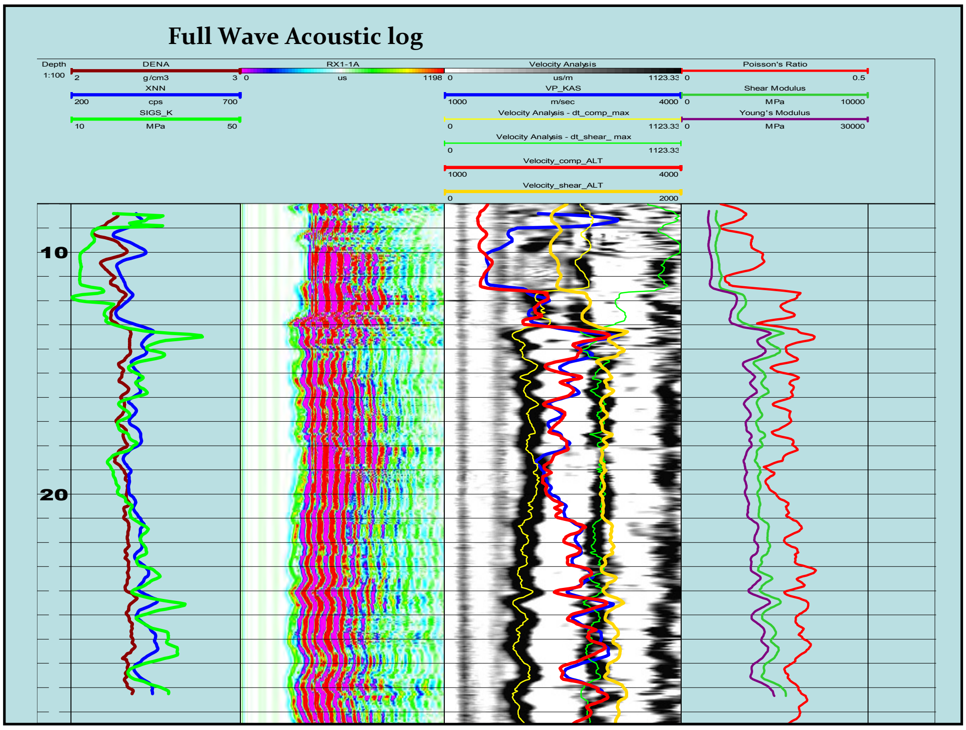
Krušné Mountains – borehole near Lesná village

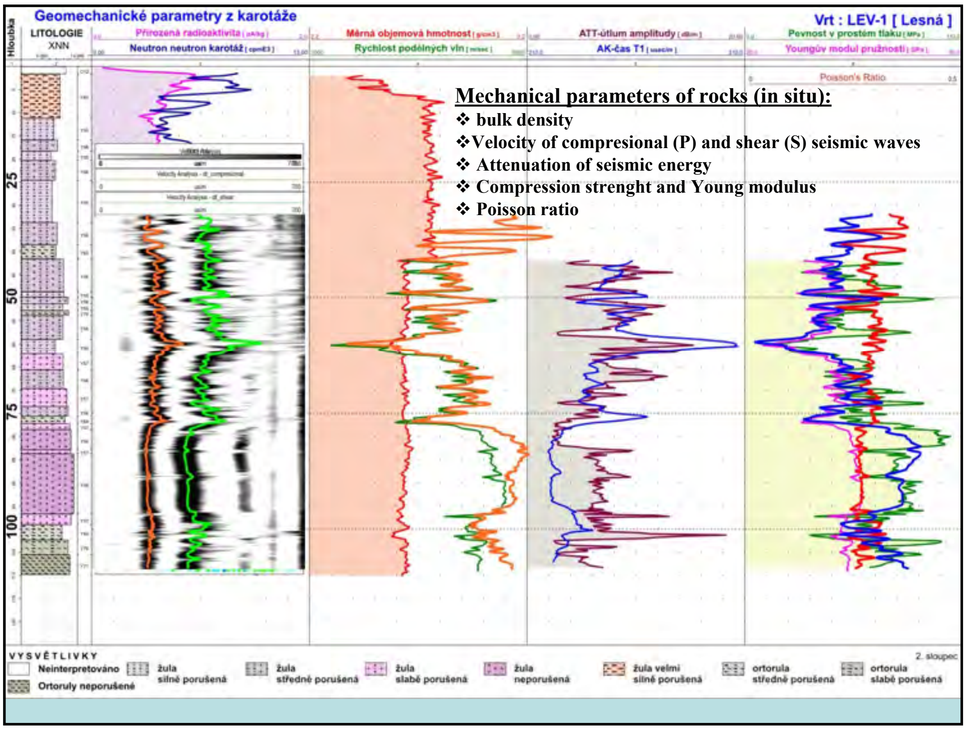
Diameter 76 mm, core drilling, depth 100 m, water level 6 m


Výsledky karotážních měření
Vrt : LEV-1 [Lesná]
LITOLOGIE
Přírodní proudění
Metoda čerpání
hladina vody - 6,0 m
vrt zapažen do 42,0 m
přítoky
V = 3,5 cm/min
Q = 230 l/den
ztráty
Gamma log
Neutron log
Resistivity logs
Gamma gamma
Caliper log
Magnetic log
Acoustic log
(analogue)
Fluid resistivity
Temperature
Photometry log
Fluid resistivity log in application
of Method of filtration-left column
and Method of constant pumping
VYSVĚTLIVKY

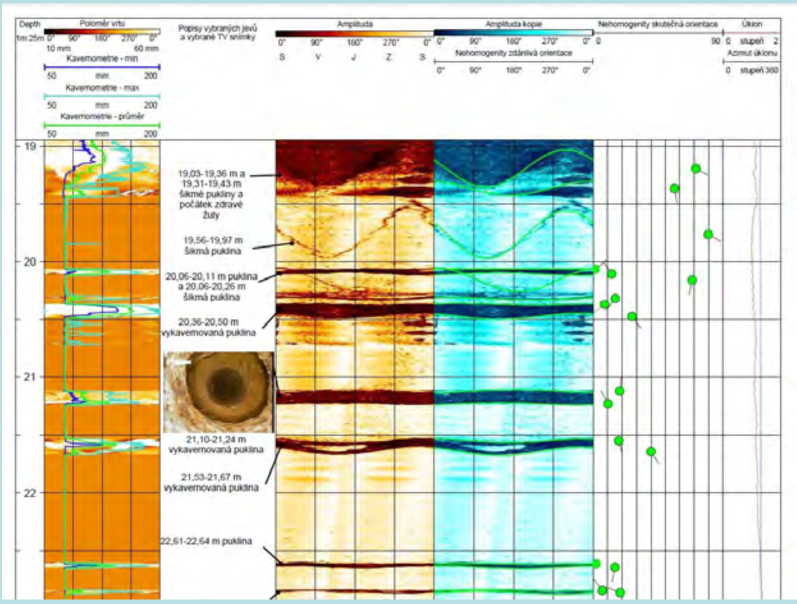

Výsledky karotážních měření
Vrt : LEV-1 [Lesná]
LITOLOGIE
Přírodní proudění
Metoda čerpání
hladina vody - 6,0 m
vrt zapažen do 42,0 m
Interpreted geology
Interpreted water
movement in the borehole
(water circulation)
přítoky
V = 3,5 cm/min
Q = 230 l/den
ztráty
Interpreted
open fractures
(permeable
fractures)
VYSVĚTLIVKY


Geomechanické parametry z karotáže
Vrt : LEV-1 [Lesná]
Hloubka
LITOLOGIE
XNN
Přirozená radioaktivita
Neutron neutron karotáž
Měrná objemová hmotnost
Rychlost podélných vln
ATT-útlum amplitudy
AK-čas T1
Pevnost v prostém tlaku
Youngův modul pružnosti
Interpreted parameters of rock massif
25
50
75
100
Natural gamma activity
Density
Velocity of P waves
Attenuation of seismic waves
Compression strenght
Young modulus
VYSVĚTLIVKY
2. sloupec
Neinterpretováno
Ortoruly neporušené
žula silně porušená
žula středně porušená
žula slabě porušená
žula neporušená
žula velmi silně porušená
ortorula středně porušená
ortorula slabě porušená

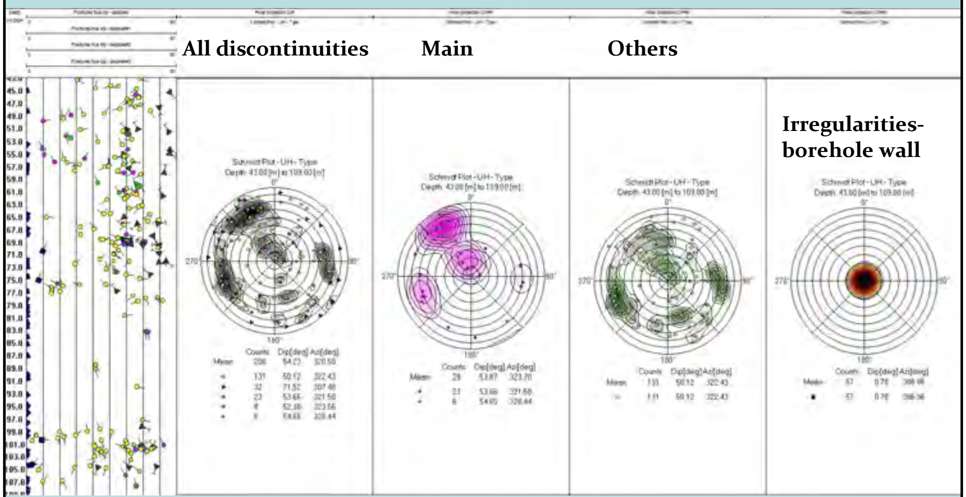

Full Wave Acoustic log
Depth
1:100
DENA
2 g/cm3 3
XNN
200 cps 700
SIGS_K
10 MPa 50
RX1-1A
0 us 1198
Velocity Analysis
0 us/m 1123.33
VP_KAS
1000 m/sec 4000
Velocity Analysis - dt_comp_max
0 1123.33
Velocity Analysis - dt_shear_ max
0 1123.33
Velocity_comp_ALT
1000 4000
Velocity_shear_ALT
0 2000
Poisson's Ratio
0 0.5
Shear Modulus
0 MPa 10000
Young's Modulus
0 MPa 30000
10
20



Acoustic scanner

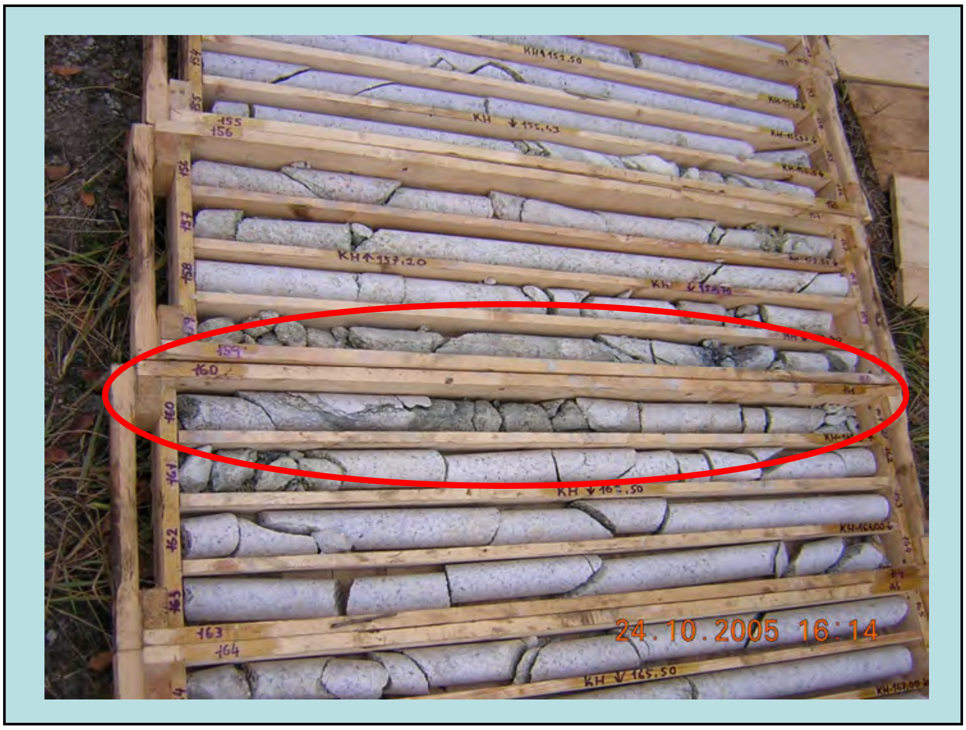


Results of acoustic scanner – discontinuities (fractures,fissures, veins…)



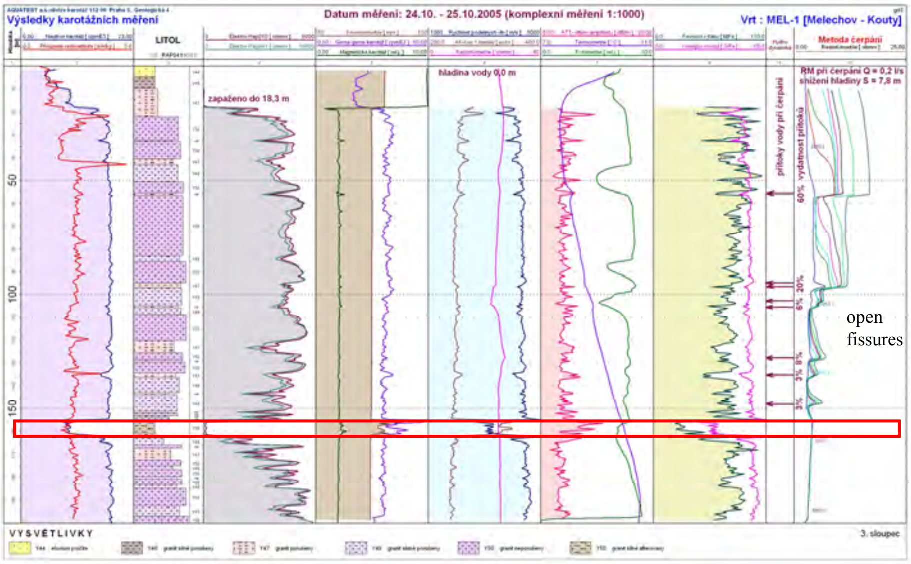
Results of acoustic scanner – virtual oriented core


Synthesis of well logging data


24.10.2005 16:14

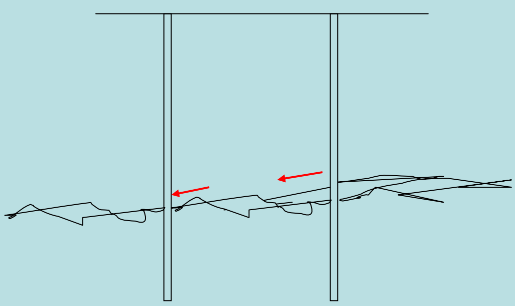
Absence of permeable fractures in the most tectonically deformated zone!

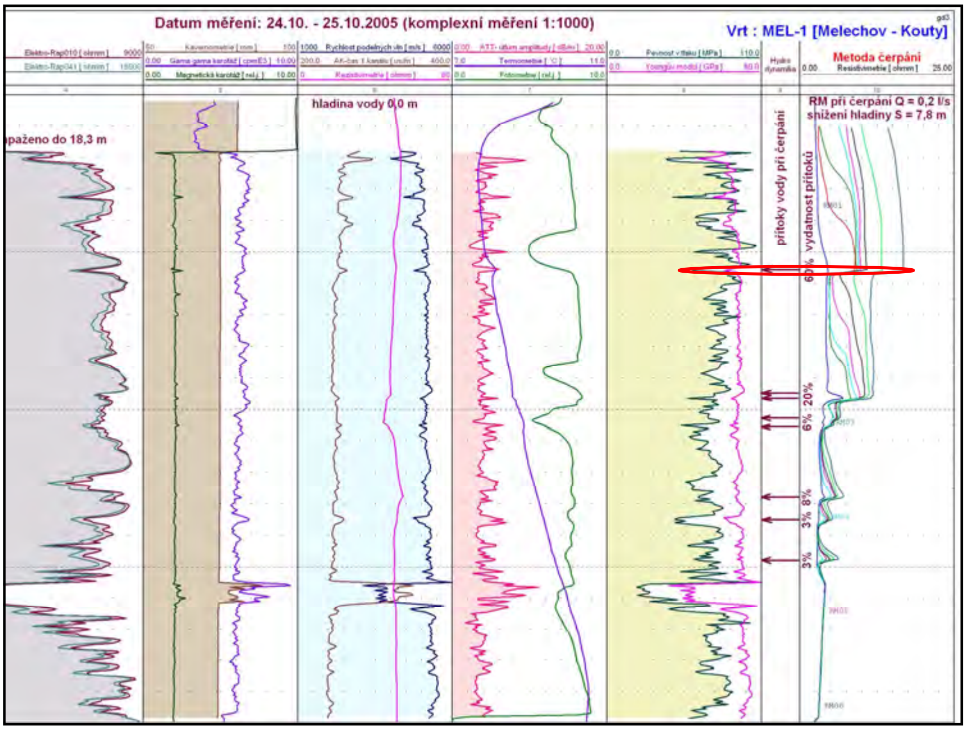
This case is relatively common (fractures in strongly alterated rocks are usually closed by clayey minerals)



Well logging for Tracer tests

Monitoring of connectivity fissures



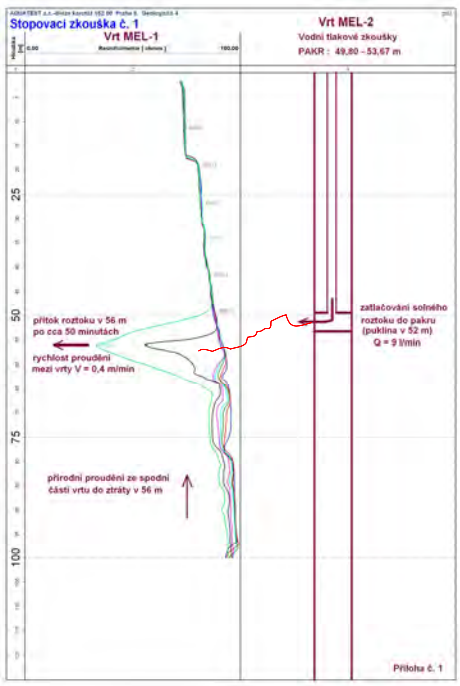


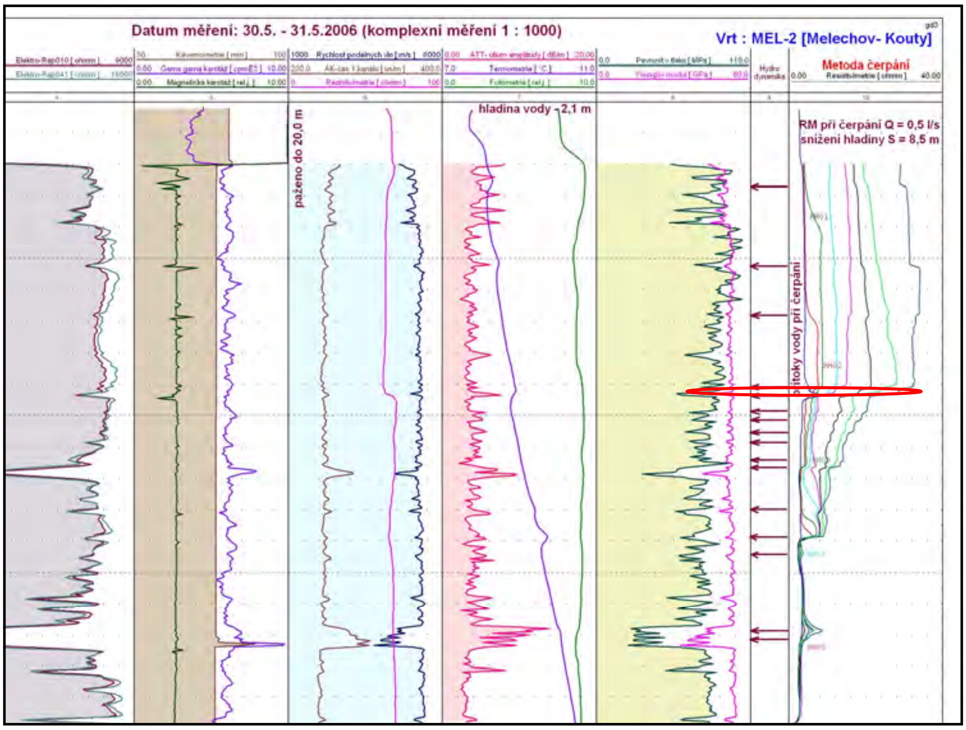
1. **<u>Tracer test</u>**
<u>Monitoring of connection of the fissure at depth 56 m between MEL-1 and MEL-2 (20 m distance)</u>

MEL-2:
Water pressure test (0,1 Mpa) by saline

MEL-1:
Saline appeared in 50 minutes at depth 56 m

Velocity of induced water flow was: v = 0,4 m/min.



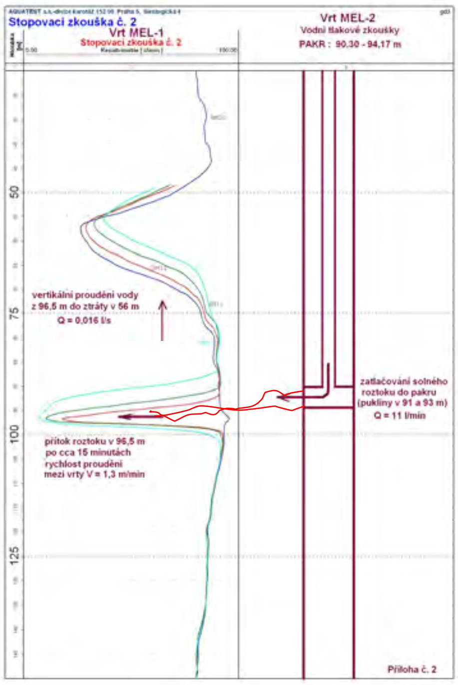


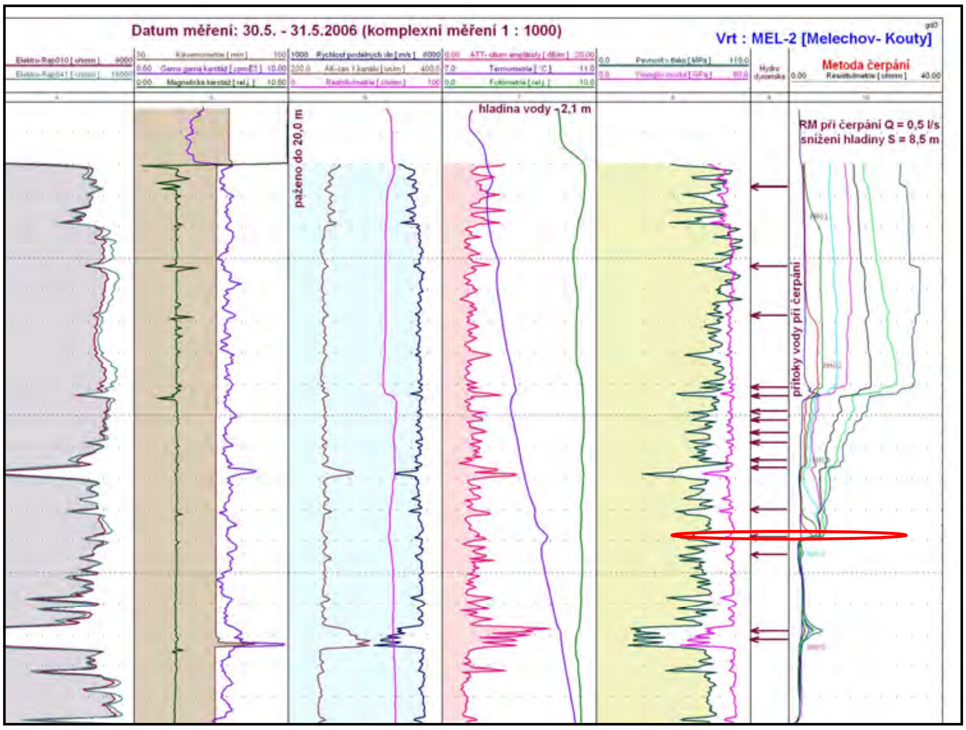
<u>2. Tracer test</u>
<u>Monitoring of connection of the fissures at depths 91 and 93 m between MEL-1 and MEL-2 (20 m distance)</u>

MEL-2:
Waler pressure test (0,1 Mpa) by saline

MEL-1:
Saline appeared in15 minutes At depth 96,5 m

Velocity of induced water flow was v = 1,3 m/min.



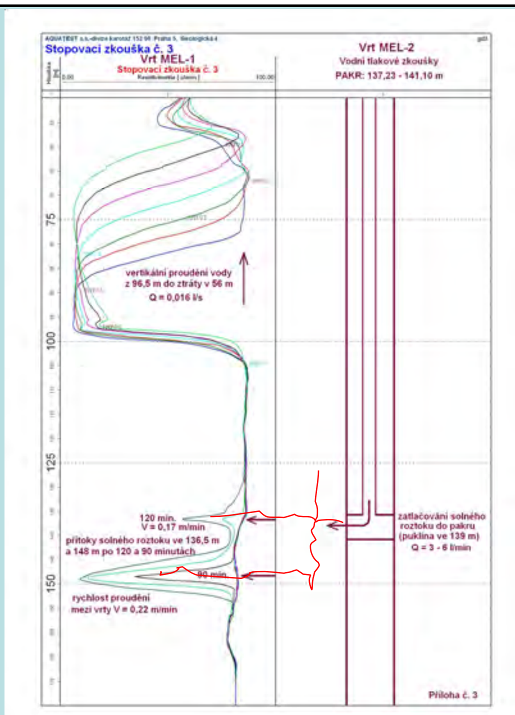


3. Tracer test
Monitoring of connection
of the fissures at depth 139 m
between MEL-1 and MEL-2
(20 m distance)

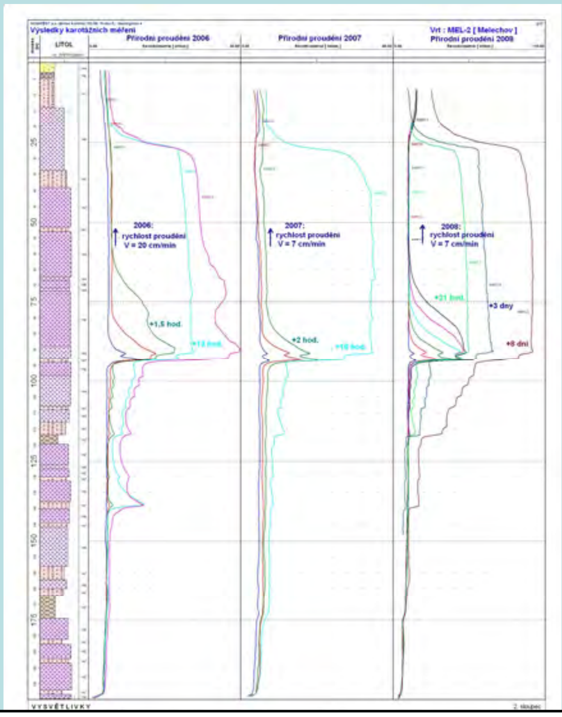
MEL-2:
Water pressure test (0,1 MPa)
by saline

MEL-1:
Saline appeared in 90 minutes
at depth 148 m and in
120 minutes at depth 137 m

Velocity of induced water flow
v = 0,22 m/min.,
v = 0,17 m/min.

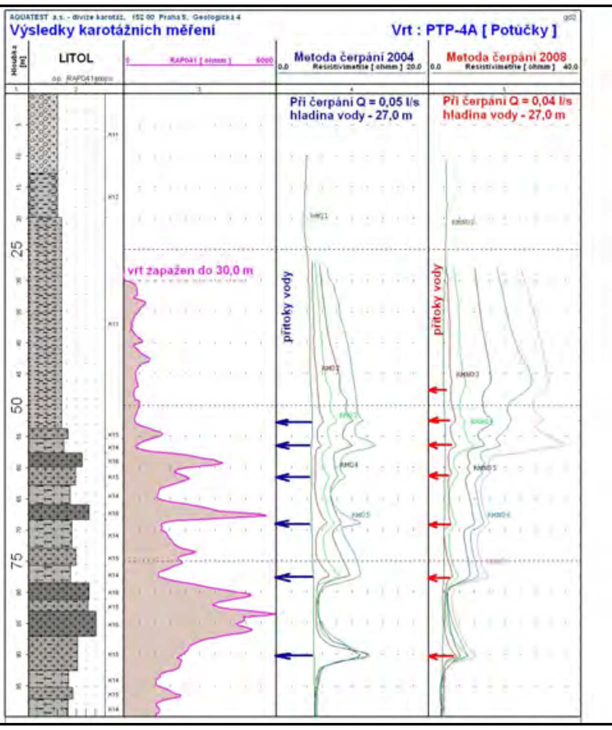


- **Hydrogeological communication between neighbouring boreholes is also demonstrable by combination of logging and simultaneous pumping in the second borehole.**



- **Measurements of water flow in the borehole in different times after borehole completion.**

- **Control of natural flow in boreholes longer time after borehole was completed is useful, velocity of flow becomes significantly lower.**



- Measurements of water inflows and their yields in different times after borehole completion.

- Water inflows and their yields are even after long period practically identical.

CONCLUSIONS :

- **Well logging is offering wide information on rock massif in situ:**

- **Detailed lithology and physical parameters of rocks**
- **Geomechanical parameters of rocks**
- **Information of the stage of tectonical deformation, detection of individual fractures and fissures, detection of open fractures**
- **Virtual oriented core with oriented fractures and fissures**
- **Water inflows and their yields**
- **Groundwater flow and its intensity in individual fractures**
- **Information on hydrogeological communication between neighbouring boreholes**
- **Long term monitoring of hydrodynamic conditions in the borehole**
- **Technical parameters of the borehole**

Well logging is non-destructive method. Compared to surface geophysics- well logging do not affect utilities

Thank You for Your attention

Uncertainties in hydrodynamics and hydrochemistry in granites considered as a host rock for spent nuclear fuel in the Czech Republic

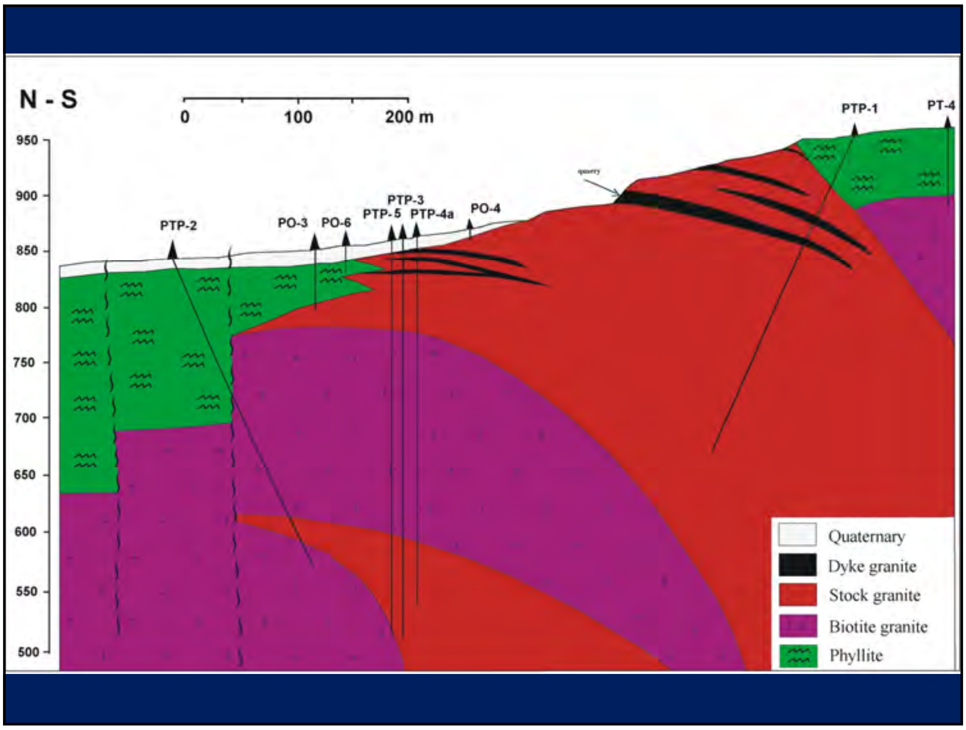
T. Paces and L. Rukavickova

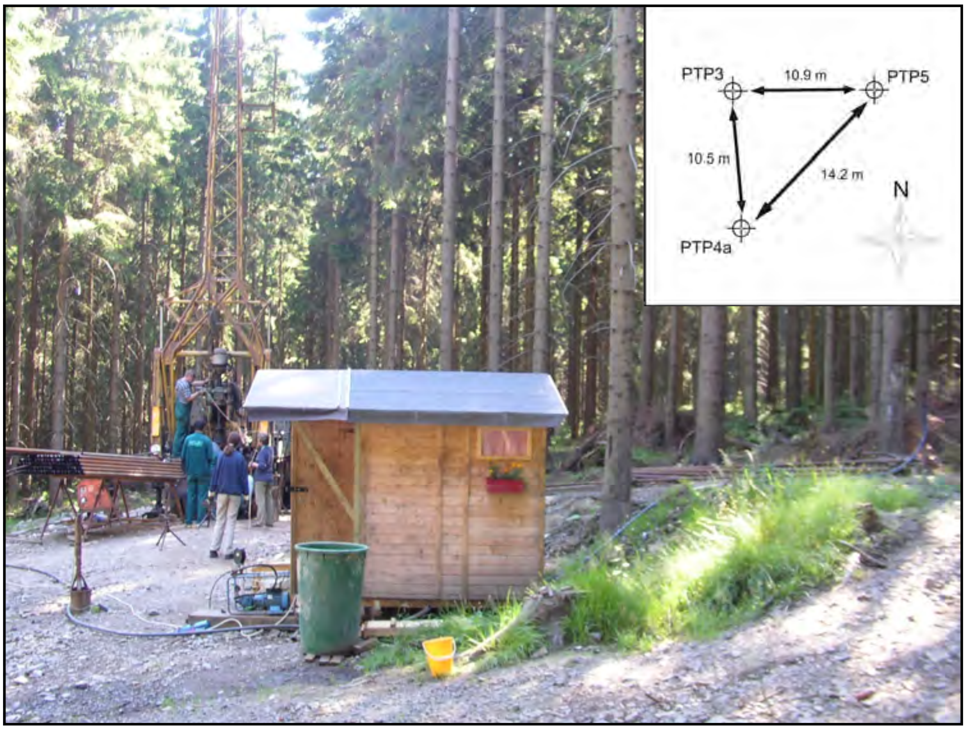
Czech Geological Survey, Czech Republic

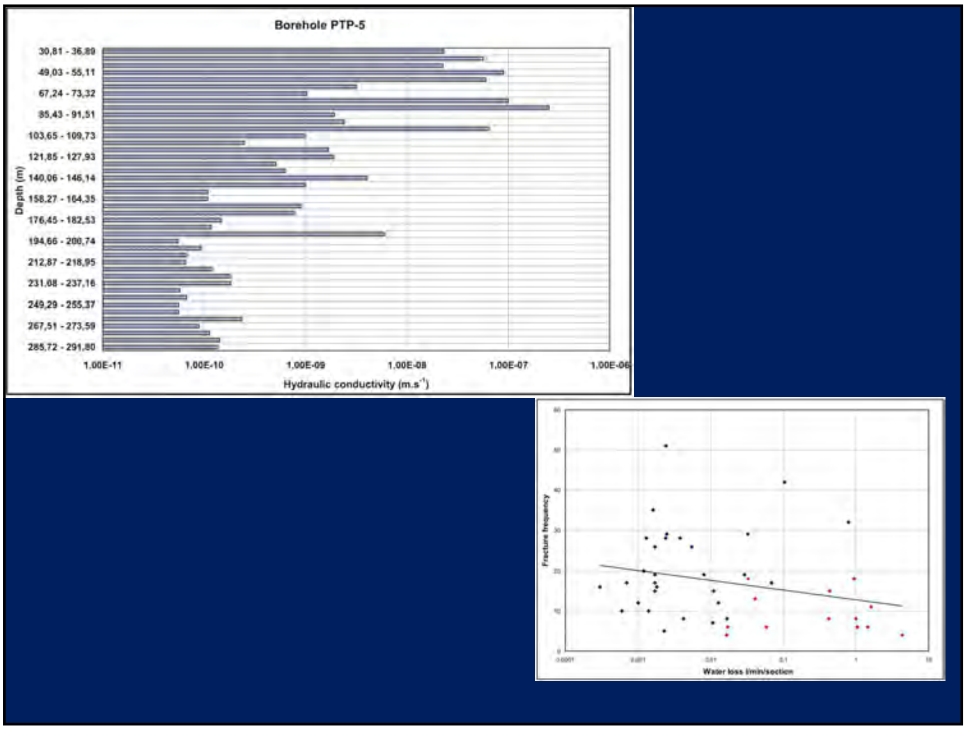
tomas.paces@geology.cz

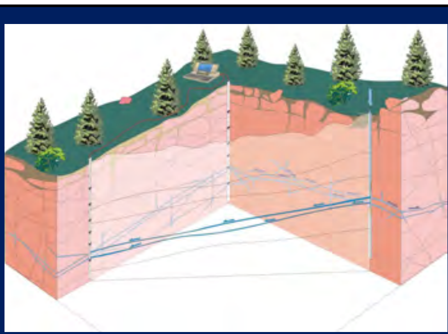
We studied flow and hydrochemical behaviour of ground water in mineralogically and chamically homogenous granite for 5 years

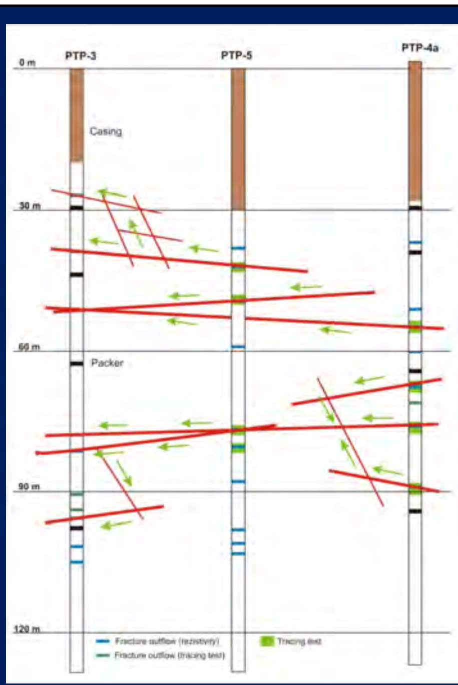
We needed this information to understand water-rock interaction in far-field of a deep repository of spent nuclear fuel in the Bohemian massif in Central Europe.


N - S
0
100
200 m
950
900
850
800
750
700
650
600
550
500
PTP-2
PO-3
PO-6
PTP-3
PTP-5
PTP-4a
PO-4
PTP-1
PT-4
Quaternary
Dyke granite
Stock granite
Biotite granite
Phyllite

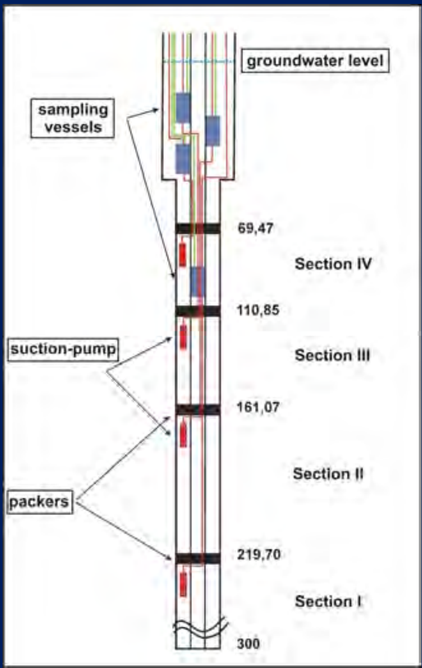

PTP3
10.9 m
PTP5
10.5 m
14.2 m
N
PTP4a


Borehole PTP-5
30,81 - 36,89
49,03 - 55,11
67,24 - 73,32
85,43 - 91,51
103,65 - 109,73
121,85 - 127,93
140,06 - 146,14
158,27 - 164,35
176,45 - 182,53
194,66 - 200,74
212,87 - 218,95
231,08 - 237,16
249,29 - 255,37
267,51 - 273,59
285,72 - 291,80
Depth (m)
1,00E-11
1,00E-10
1,00E-09
1,00E-08
1,00E-07
1,00E-06
Hydraulic conductivity (m.s-1)
Fracture frequency
Water loss l/min/section



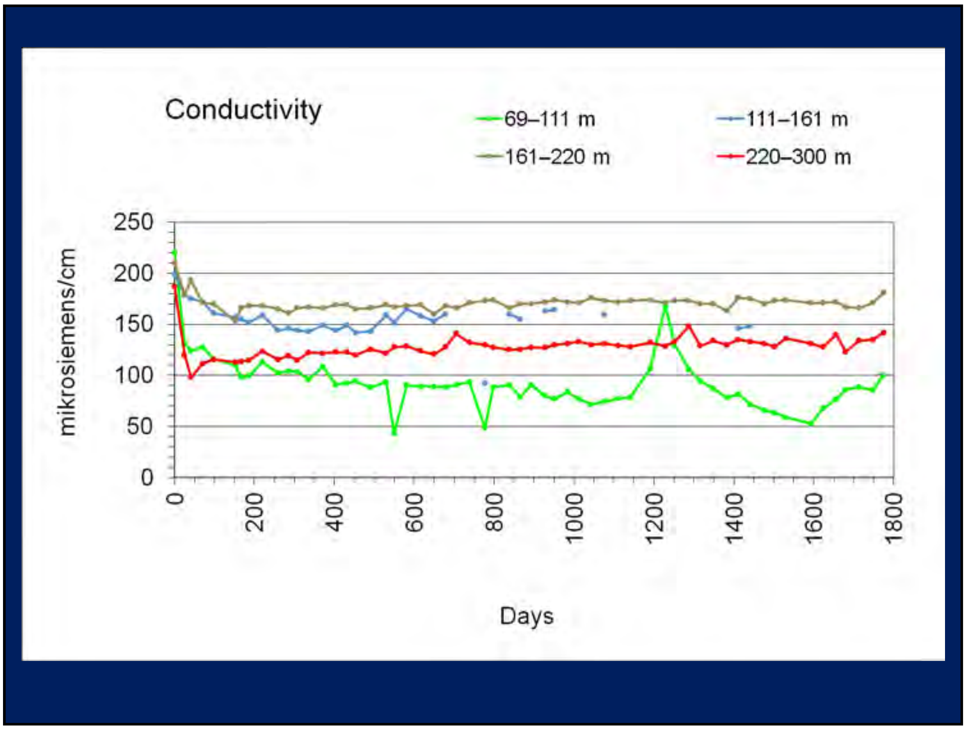


Hydraulic conductivity *K* *(m.s^{-1})*	Rock environment
10^{-13} - 10^{-10}	Compact granite without fractures or with closed fractures or fractures filled with secondary minerals
10^{-9} - 10^{-8}	Subsurface zone of granite with opened sub-horizontal fractures or fracture zones only partly filled with secondary minerals
10^{-7}	Opened water conducting fractures of smaller extend
10^{-6}	Regionally significant opened fractured zones
10^{-5}	Individual opened fractures in larger fractured zones

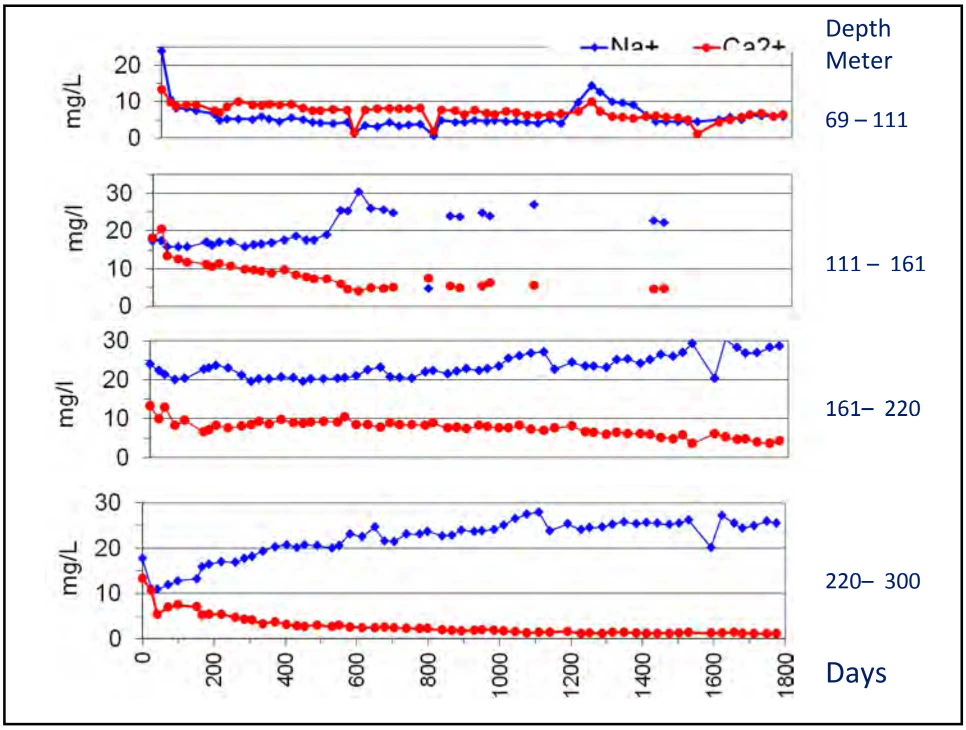


Arrangement of pumps for periodic sampling of groundwater from poorly permeable granite from several depths

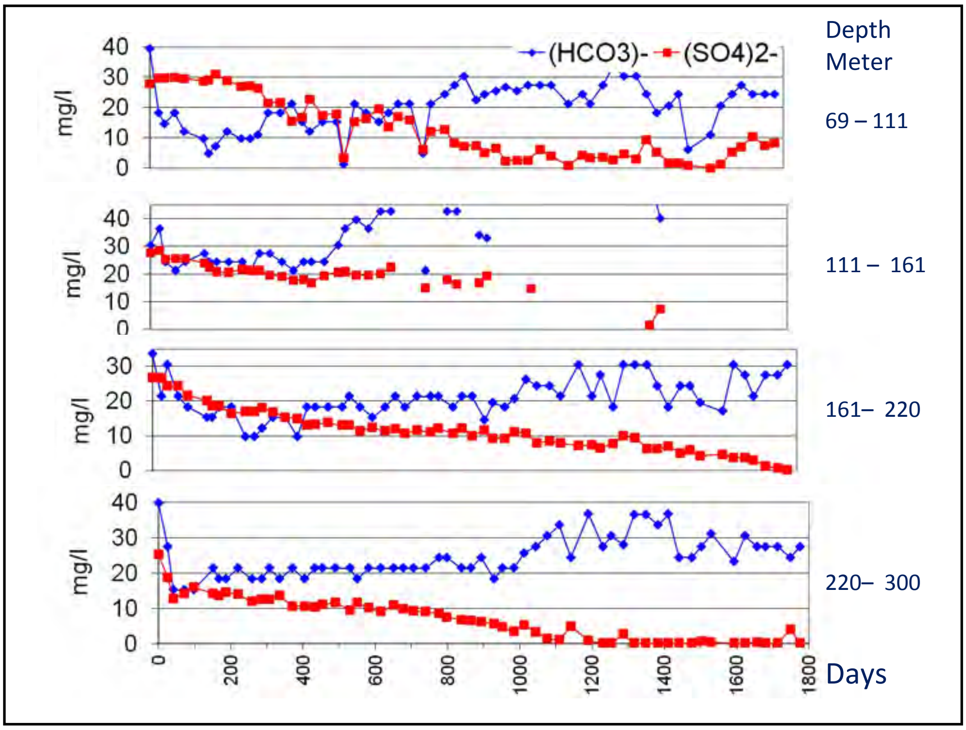
PTP-5	average	var coef %
C μS/cm	149	23
pH	7.3	13
	mg/l	
Na^{+}	16	37
K^{+}	2.0	32
Ca^{2+}	10	35
Mg^{2+}	1.1	64
Cl^{-}	15	51
HCO_3^{-}	22	41
SO_4^{2-}	23	25
SiO_2	5.0	62
TOC	35	111

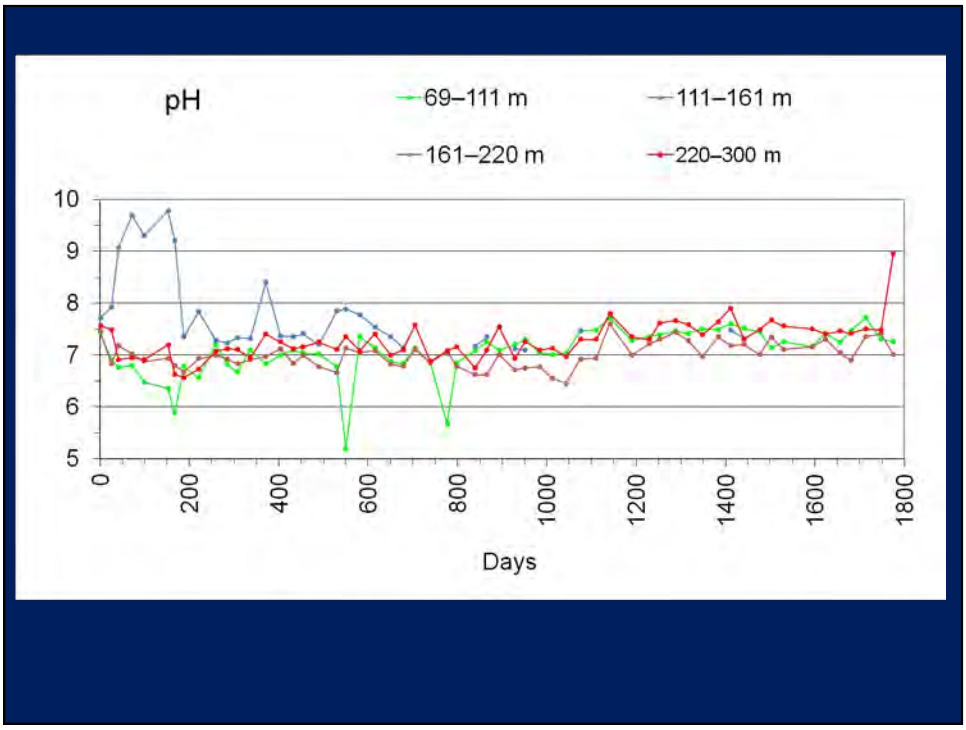


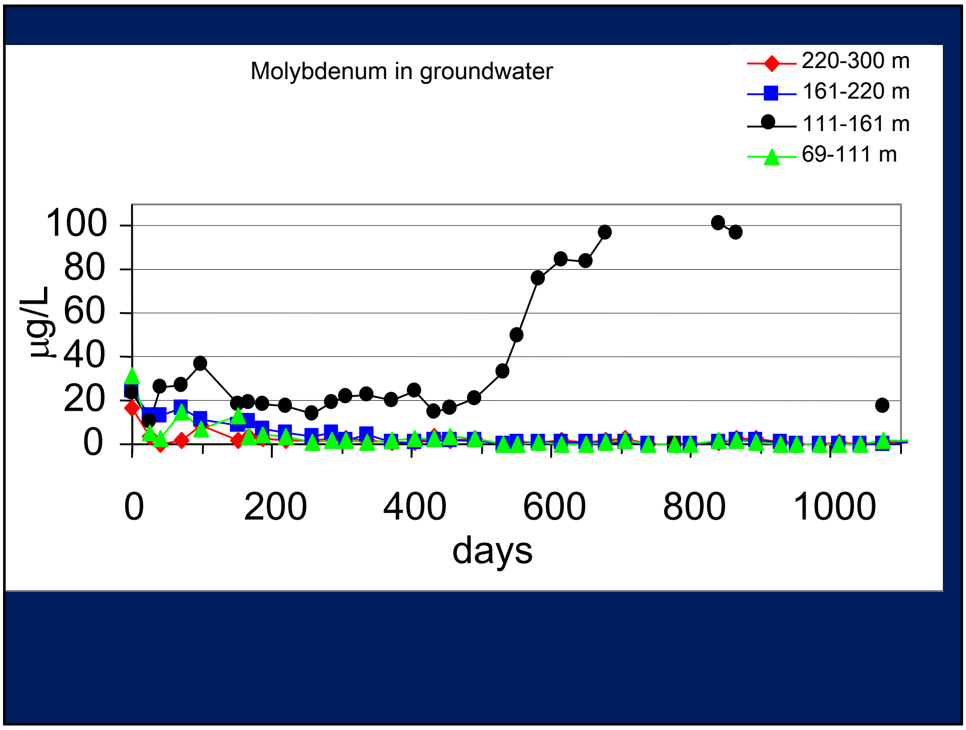
Conductivity
69–111 m
111–161 m
161–220 m
220–300 m
mikrosiemens/cm
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
1600
1800
Days

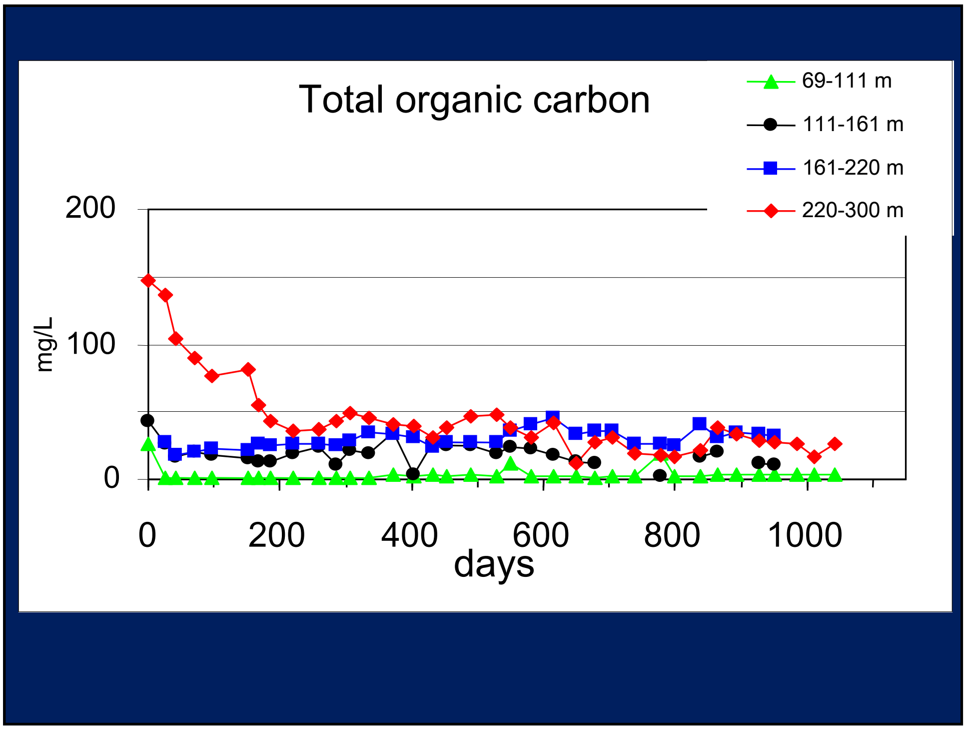


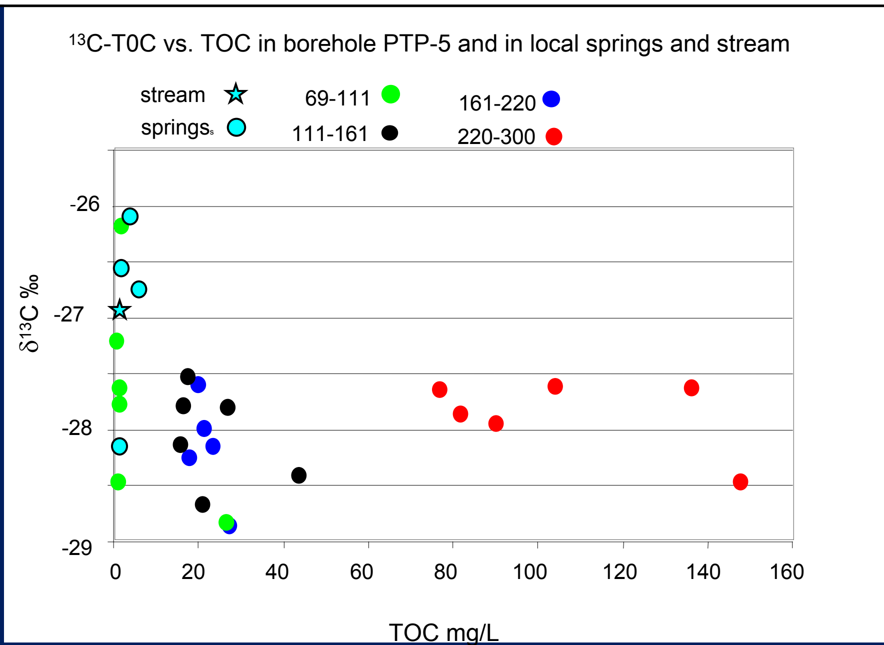
Na+
Ca2+
Depth
Meter
mg/L
69 – 111
mg/l
111 – 161
mg/l
161– 220
mg/L
220– 300
0
200
400
600
800
1000
1200
1400
1600
1800
Days


(HCO3)-
(SO4)2-
Depth
Meter
69 – 111
111 – 161
161– 220
220– 300
mg/l
Days


pH
69–111 m
111–161 m
161–220 m
220–300 m
Days


Molybdenum in groundwater
220-300 m
161-220 m
111-161 m
69-111 m
µg/L
100
80
60
40
20
0
0
200
400
600
800
1000
days


Total organic carbon
69-111 m
111-161 m
161-220 m
220-300 m
mg/L
200
100
0
0
200
400
600
800
1000
days



Conclusions

We identified three chemically different water bodies in mineralogical and chemically very uniform granite. Their compositions are influenced by mixing of deeper groundwater with subsurface shallow water and by differences in fracture permeability.

The chemical composition of groundwater in the compact granite with discrete fractures with low permeability was disturbed by installation of packers and by previous drilling and hydraulic testing.

The return to a steady state composition was a slow process involving mixing of water from different groundwater bodies and kinetics of dissolution of aluminosilicates (this conclusion is based on mathematical model of the processes).

Each chemical component reacts differently to the disturbance. This is manifested by different concentration trends observable long after the drilling and hydraulic testing has ended.

The periods after which a steady state or chemical equilibrium was established varied usually from 20 to 200 days, depending on the dissolved component involved. However, in some cases the steady state was not reached even after 1800 days.

The temporal trends are caused by water-rock interaction and by inflow velocity of water from individual fractures

We were not able to identify sources of the high concentration of dissolved organic carbon (steady state concentration about 30 mg/l TOC). The origin of the organics in not in the surface organic matter and it is not a pollution generated either by a surface pollution source or from drilling technology. (This conclusion is based on $\delta^{13}C$ differences)

We were not successful to determine the composition of the organics in the deep groundwater in the granite.

The results shows to our managers, that obtaining hydrogeological and hydrochemical data for a risk analysis of the geological repository will require long time before we will be sure that our results will represent a stady state conditions needed as an input for computer modelling and the risk analysis.

Thank you

PTP-5	average	var coef %
	μ g/l	
Al	55	83
As	3.7	109
Be	2.8	164
Cd	0.26	89
Cr	2.0	54
Co	5.6	107
Cu	10	226
F	1500.0	26
Fe	1102.0	131
Hg	< 0.08	
Li	37	30
Mn	382	111
Mo	14	69
Ni	3.0	81
NH_4^+	170	68
NO_3^-	950	41
Pb	5.1	148
Zn	168	148
V	<10	

Radioactive Waste Disposal Data Management

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Jitka Mikšová

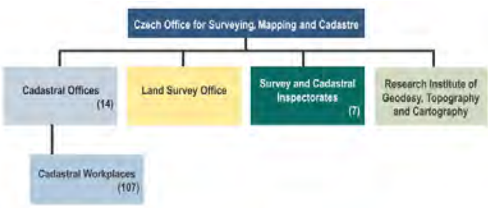
Technical Development Project Manager

Geological Repository Development Department

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Geographical Data Management

Czech Office for Surveying, Mapping and Cadastre

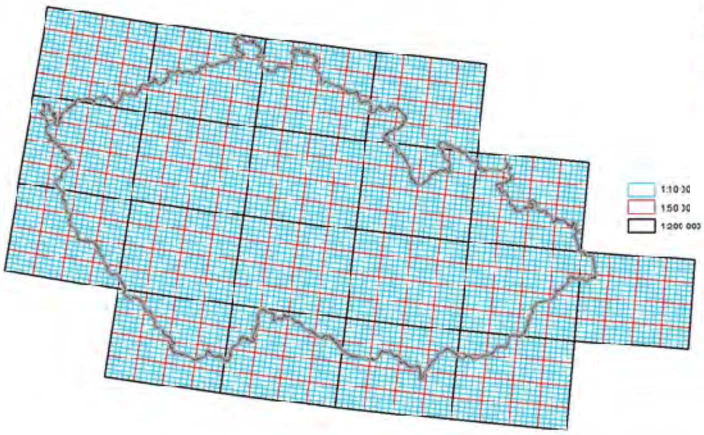


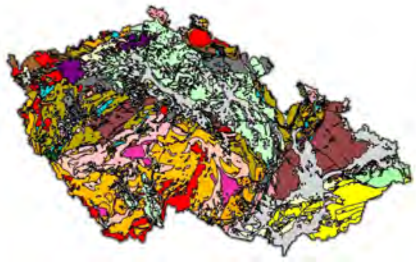
Role and position:

•Complete administration of the Cadastre
•Maintenance and modernisation of horizontal, vertical and gravity control in the Czech Republic,
•Large-scale mapping (cadastral maps, scale 1:5 000)
•Medium-scale mapping (Base map of the Czech Republic 1:10 000, 1:25 000, 1:50 000, 1:100 000, 1:200 000),
•Small-scale mapping of the Czech Republic (1:500 000, 1:1 000 000),
•Creation of the Fundamental Database of Geographical Data (ZABAGED),
•Geodetic surveys and documentation of state boundaries,
•Development and maintenance of the Information System
•Standardisation of geographical names.

2 SCIENTIFIC VISIT ON CRYSTALINE ROCK REPOSITORY DEVELOPMENT
Prague, 24th – 27th September, 2012

Map Sheets





Geological Data Management

Czech Geological Survey

Legal framework:

•Act No. 62/1988 Coll., on geological work, as amended

•Act and Decree of the Ministry of the Environment No. 368/2004 Coll., on geological documentation.

•Act No.365/2000 Coll., on public administration information systems

•The task of the state geological survey is **to gather and supply data**

on the geological structure of the Czech Republic

on the protection and utilization of its natural mineral and groundwater resources as well as on geological hazards

It is **obligatory for all individuals and legal entities** conducting geological work in agreement with geological legislation to submit the data acquired to the CGS (state institution).

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Czech Geological Survey

Data and information management - key activities:

- collection and storage of the results of geological work
- information systems and map server development
- provide access to
  - geological work results
  - related geological documentation
  - material evidence

•Main scientific and research domains in which the CGS is involved:

- regional geology and geological mapping
- applied geology
- environmental geochemistry and biogeochemistry
- global change

5 SCIENTIFIC VISIT ON CRYSTALINE ROCK REPOSITORY DEVELOPMENT
Prague, 24th – 27th September, 2012

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Geological Data Register – Rules

•all plans for geological work **must be registered before** work commences

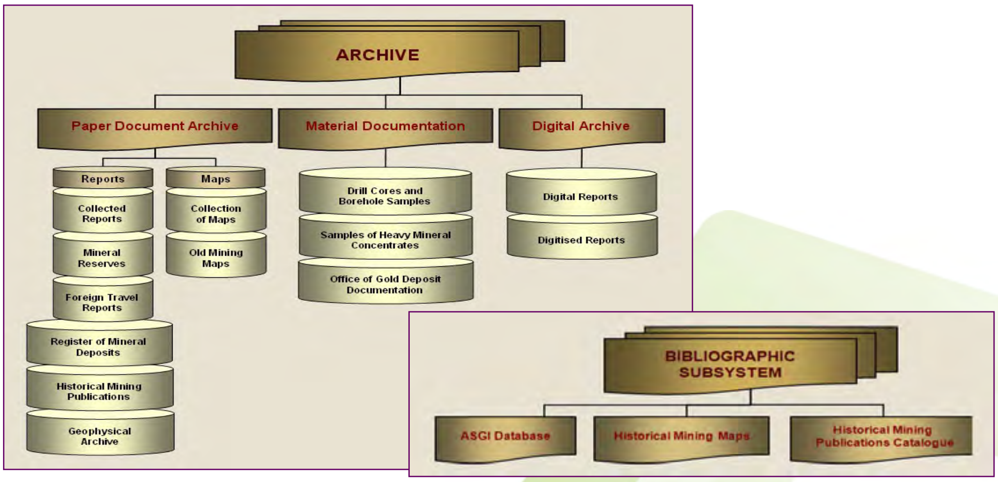
•the data for registration must be completed by the organization responsible for undertaking the geological work

•the organization is obliged to forward such data to the Czech Geological Survey at the earliest 30 days in advance and, at the latest, one day in advance of work commencement

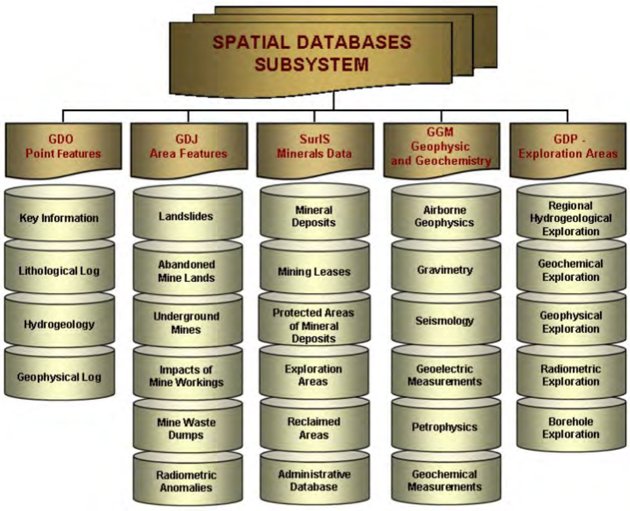
•The CGS issues a certificate to the relevant organization confirming receipt of the completed registration form

6 SCIENTIFIC VISIT ON CRYSTALINE ROCK REPOSITORY DEVELOPMENT
Prague, 24th – 27th September, 2012

Data and Information Structure

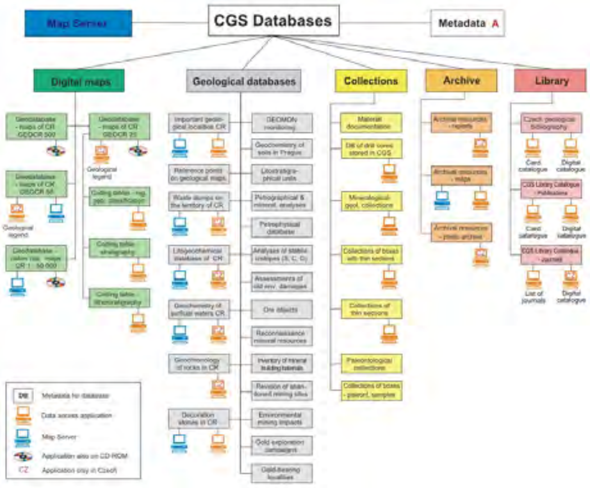


Spatial Data Structure



The Spatial subsystem has been under construction since the mid-1970s.

CGS Databases Overview



SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Metadata

MUST BE MANDATORY

•Metadata is information that describes the **content, quality, condition, origin,** and **other** characteristics of data

•Metadata may describe and document its subject matter;
how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to agreed standards

•Metadata can **support the necessary overview** of applied data and information

•Metadata allows a knowledge of the **quality of the data** and its characteristics during the whole period of expected utilisation in relation to long term radioactive waste management

•To fulfil metadata requirements, items can be obligatory depending on the level of the national IT standard used - INSPIRE

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Metadata

Metadata standards

Status of the data
Dokončeno
Data update frequency: 1 ročně

Time period for which the data is relevant
Date and time: 2006

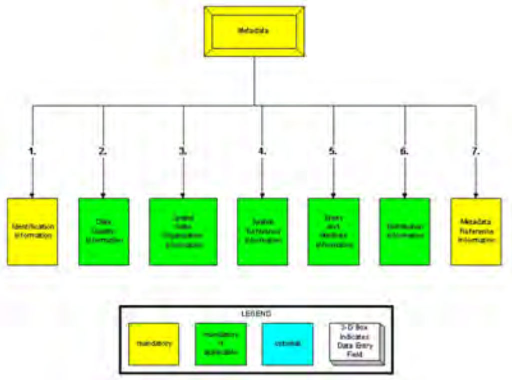
Publication Information
Who created the data: P. Novotný, B. Mlčoch, B. Schulmannová, K. Breiter
Date and time: Nepublikovaný materiál

Data storage and access information
File name: GE_ME_PP_GMP
Type of data: vector digital data
Location of the data:
- \\KOPACKOVAN\G\melechov\10_2006\databaze\Melechov_10_06.mdb

Data processing environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.1.0.722

Constraints on accessing and using the data
Access constraints: Pouze pro účely řešení a spolupráce v rámci projektu ČGS 4110 - Geologický výzkum testovací lokality Melechov, zadavatel SÚRAO
Use constraints:
Zákaz používání mimo rámec projektu ČGS 4110

Details about this document



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Data Sources

Natural environment characterisation

Remote data – remote sensing and radar data of the Earth's surface
screening phase of siting, monitoring of possible impacts on the environment, results of remediation within the repository lifecycle, regional scale, large areas.

- Potential data providers - mainly international companies

Data from airborne methods – airborne topographic images, airborne geophysics;
screening, site selection phase, monitoring

- Topographic data – national or local providers.
- Airborne geophysics – might be in the databases of local companies but probably foreign exploration company involvement (in terms of the relatively expensive equipment required for such measurement)

SÚRAO | SPRÁVA ÚLOŽIŠŤ RADIOAKTIVNÍCH ODPADŮ

Data Sources

Natural environment characterisation

Data from the surface – surface investigation, site characterisation stage and monitoring within the repository lifecycle.

- archive data – might be in national/state-owned databases as well as in the internal databases or archives of research organisations and investigation companies; also in local municipality archives.
- new data acquisition will be carried out by research and investigation companies.

Data from the geological environment – data from borehole or other underground investigation, site characterisation phase, repository construction phase, monitoring.

- Data sources might be the same as those for surface data.

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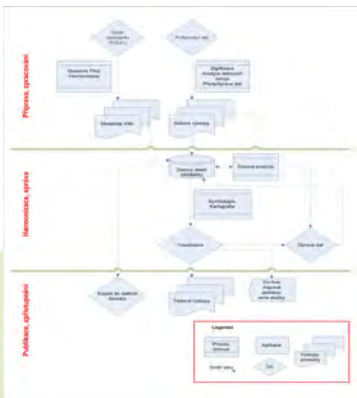
Data Properties and Data Workflow

- origin
- age
- quality
- type
- character
- time dependence
- acquisition frequency
- thematic framework
- range
- sources
- availability
- accessibility
- level of confidentiality etc.
- ,,,,

Data acquisition and data processing

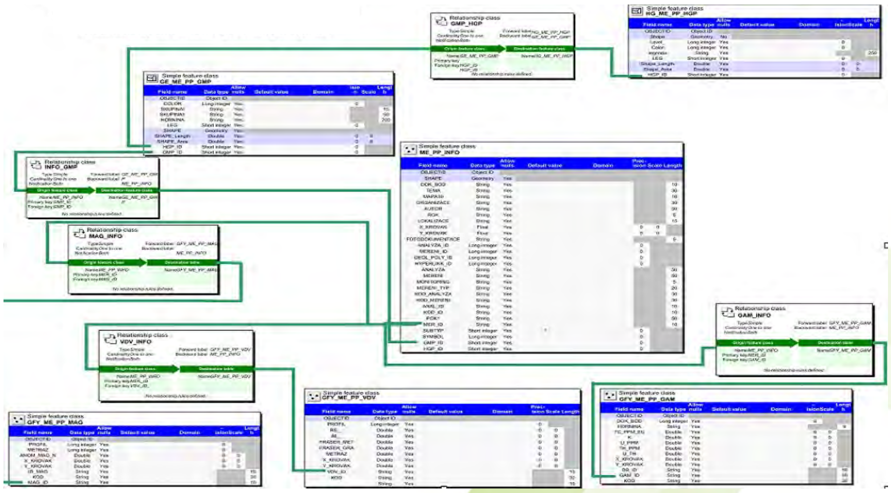
Data harmonisation

Data and results publication



SÚRAO

Database Structure



15 SCIENTIFIC VISIT ON CRYSTALINE ROCK REPOSITORY DEVELOPMENT
Prague, 24th – 27th September, 2012

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Spatial Data

GIS - necessary steps

- GIS scope definition
- GIS system design
  - System architecture
  - Meta-information catalogue
  - System and data security
  - System and data archiving
  - SW tools
  - HW equipment
  - Unified obligatory procedures for all GIS users and producers
  - Defined rules for users and administrators
  - Maintenance (GIS system, SW, HW)

Conceptual model

Logical model

Physical model

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Spatial Data

GIS - necessary steps

- Resources identification and provision – finance, staff, HW/SW
- GIS establishment, functionality testing
- Creation of data model(s)
- Data collection/input/transfer
- Data processing/analysis (spatial analysis, 3D, DTM…)
- Data interpretation
- Data availability and retrievability
- Results publication for different groups of users
- Inclusion in existing information system
- **Data and results storage and archiving (LONG TERM PRESERVATION)**

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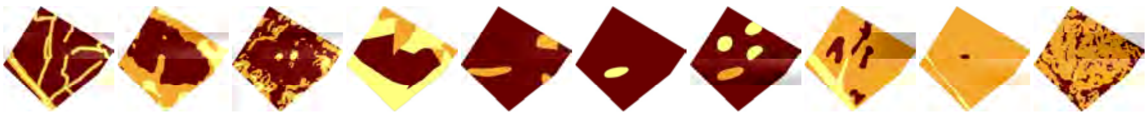
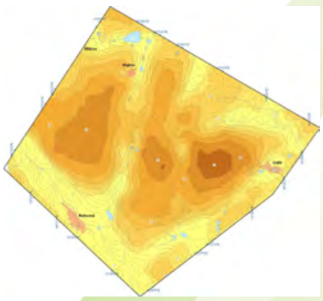
Why GIS? – Spatial Analysis

Geological data



- Tectonics (distance from tectonic fractures) (30)
- Resistivity (from airborne geophysics) (10)
- Horizontal gradient of total vector of magnetic field (10)
- Lithological homogeneity (xenolites) (5)
- Dike rocks (5)
- Occurrence of hydrothermal veins in rocks (5)
- Mineral deposits and accumulation (5)
- Stability of rock massif (5)
- Hydrogeological properties (20)
- Flat relief (slope) (5)



unsuitable (yellow)
suitable (orange)
very suitable (dark brown)

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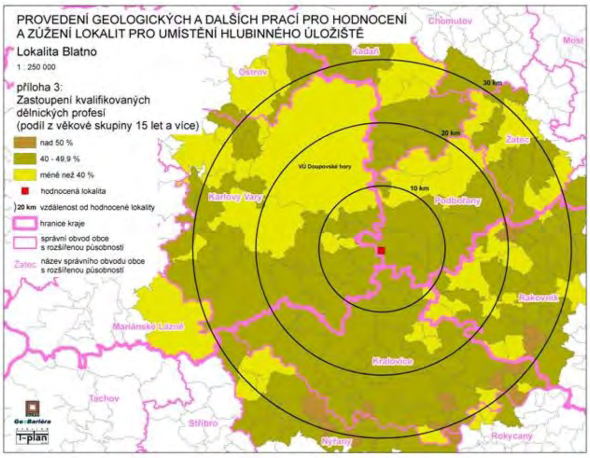
Why GIS? – Spatial Analysis

Socio-demographic analysis



distribution of villages at defined distance from place of interest

Why GIS in the Site Selection Process?

GIS can be a convenient tool for data integration and processing
in
all stages of the repository life cycle

over 20 raster layers of the whole of the Czech Republic
over 40 raster layers
over 180 vector layers
at each of the six potential sites

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Data Storage

•Data archiving strategy - storage frequency, timescale, what data has to be stored and how long - depending on its importance for the appropriate disposal stage and depending on its necessity for other uses with respect to current legislation – safety, institutional control, IT, RWM etc.

•It is highly important to consider the long term storage of chosen data and information incorporating all the RW disposal phases and the facility's lifecycle. It could be in excess of hundreds of years.

•To bear in mind that storage media could become damaged over time as could the associated media quality and settings.

The preservation of Records, Knowledge and Memory (RK&M) is seen as an integral part of radioactive waste management.

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Why Data Management?

→ **It helps us in the decision-making process**

DATA MANAGEMENT

ESSENTIAL element of KNOWLEDGE MANAGEMENT

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Thank you

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Prague, 24th – 27th September, 2012

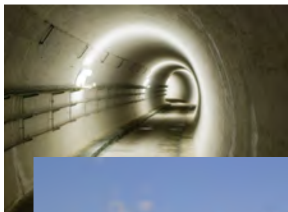
Linking communication theories into Czech reality

Lucie Steinerová
Communications Manager

Prague, September 2012

Siting of nuclear repositories

History of participation in repository site selection



3 LILW repositories in operation:
- Richard from 1964
- Bratrství from 1974
- Dukovany building phase from 1987, operation from 1995 (at NPP site)

All of them were built during communism
The decision was made as a government directive
NO PARTICIPATION
NO INVOLVEMENT

2

Atomic Act 1997 – establishment of SÚRAO

The State is responsible for the safe disposal of all radioactive waste in the Czech Republic

SÚRAO is a specialized state organisation responsible for safe repository operation

- 2000 Repositories transferred into State ownership
  - Bratrství and Richard owned by ARAO Ltd.
  - Dukovany by ČEZ Ltd.

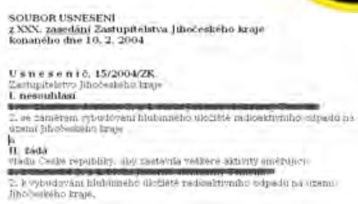
- 2002 The Concept of radioactive waste and spent fuel management
  - Deep geological repository for HLW and SF situated in a suitable host rock is considered the only feasible option for the final management of spent fuel
  - Other options – disposal in an international repository and disposal of high level waste generated in reprocessing and the further utilisation of its products in advanced nuclear reactors including reactors designed for waste transmutation are also considered – currently seen as unrealistic

3

Geological research – public protests

during geological research – especially the airborne geophysical survey stage – huge public disagreement

- Dozens of referenda against the repository project and research itself
- Local public demanded right of VETO
- Activation of local and national NGOs
- Resolutions of protest from local government


SOUBOR USNESENÍ
z XXX. zasedání Zastupitelstva Jihočeského kraje
konaného dne 10. 2. 2004

Usnesení č. 15/2004/ZK
Zastupitelstvo Jihočeského kraje
I. nesouhlasí
[redacted]
2. se záměrem vybudování hlubinného úložiště radioaktivního odpadu na území Jihočeského kraje
II. žádá
vládu České republiky, aby zastavila veškeré aktivity směřující
[redacted]
2. k vybudování hlubinného úložiště radioaktivního odpadu na území Jihočeského kraje.

- MORATORIUM ON GEOLOGICAL WORK 2004 – 2009 at the earliest

4

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ARGONA project 2006 -2009

Arenas for Risk Governance — argona — **www.argonaproject.eu**

- The overall objective was to support the transparency of decision-making processes in the radioactive waste programmes of participating countries.
- Risk communication forms a fundamental part of the dynamic process of risk governance. It is essential not to communicate risk *to* stakeholders but *with* stakeholders.

WORK PACKAGES:

- Policy-Making Structures
- Theoretical Perspectives on Participation and Democracy
- Mediators of Issues and Mediators of Processes
- Risk Communication
- Evaluation, Testing and Application of Participatory Approaches
- Guidelines for Participation and Transparency

5

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Evaluation, Testing and Application of Participatory Approaches in the Czech Rep.

To discover a safe space for decision-making and discussion aimed at increasing understanding

The approach is based on Swedish experience with the "RISCOM MODEL"

- Establishment of a Reference Group (all stakeholder representatives signed a formal agreement on cooperation and set up an agenda following RISCOM principles)
- Establishment of a Working Group (consisting of experts)

The Reference Group sets the agenda and provides the Working Group with guidelines for those activities that the Working Group plans and executes. The Working Group also provides the Reference Group with analysis and proposals.

THE WORKING GROUP CONTINUES ITS ACTIVITIES UP TO THE PRESENT

6

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Working group for dialogue

Established with the support of the Ministry of Industry and Trade to enforce the transparency of the DGR siting process in the Czech Republic in November 2010

Members of the WG:

Local representatives circa 14, MIT, ME, local NGOs, national NGOs,
Regulator, Implementer, Member of Parliament, Expert in Social Science, Expert chosen by municipalities, Legal Expert…

- ✓ Advisory body
- ✓ Executive – provides recommendations and suggestions
  - 9/2011 – updating of Atomic act. - Direct annual payments for municipalities only for sites where RAWRA receives a licence for geological survey work. Annual maximum of 4M CZK (160 thousand €) per municipality. Fixed 600 thousand CZK + 0.30 CZK per m^2 of exploratory area
- ✓ Informative body for the public and involved parties

7

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IPPA Project 2011 - 2013

Implementing Public Participation Approaches **www.ippaproject.eu**

In short, the project involves:
- Enhancing the quality of decision-making processes in nuclear waste management through improving clarity, awareness, fairness and trust
- How to implement participation and transparency processes and how stakeholders should be involved in a "safe space"
- Practical organization of safe spaces in national programmes and the exploration of how this can also be done in the multi-national context
- In the Czech case it is one of the ways forward in terms of deepening public participation
  - To receive objective WG feedback from "the time of ARGONA"
  - Cross-border issues (EIA, Aarhus Convention, added value issues…)

8

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What can we learn?

Every country is unique from the point of view of history, politics, legislation and national character

- We can learn from
  - Theory
    - RISCOM – transparency arenas, its rules and tools
    - COWAM approaches – consensus
    - PARTNERSHIP MODEL in Belgium
    - Haberman's theory
  - Experience
    - Sharing knowledge
    - Studying processes applied in other countries to avoid making the same mistakes
    - Selecting practices or tools which can then be applied in the domestic context with the support of foreign experts

9

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THE SHOW MUST GO ON!

Although my presentation may be coming to an end, the decision-making process is like a long distance train which is forced to make regular stops!

We have to be careful to:
- Follow the right direction
- Enjoy and learn on the way
- Maintain forward momentum
- Be tolerant with the passengers!

10

KURT Activities and prospects

Sep. 26, 2012

Yongkwon KOH

Korea Atomic Energy Research Institute

Contents

- **Overview of KURT**
- **Plan of KURT extension**
- **Activities in KURT**

1

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KURT_KAERI Underground Research Tunnel

2

- Off-site generic underground research laboratory
  - Only for R&D
  - Not potential site for waste disposal

- Goals of KURT
  - To establish techniques for site investigation, data analysis and integrated assessment of the geological environment
  - To develop and demonstrate the disposal concept and technologies for rad-waste repository
  - Information provider to public and stakeholders for safety of geological repository

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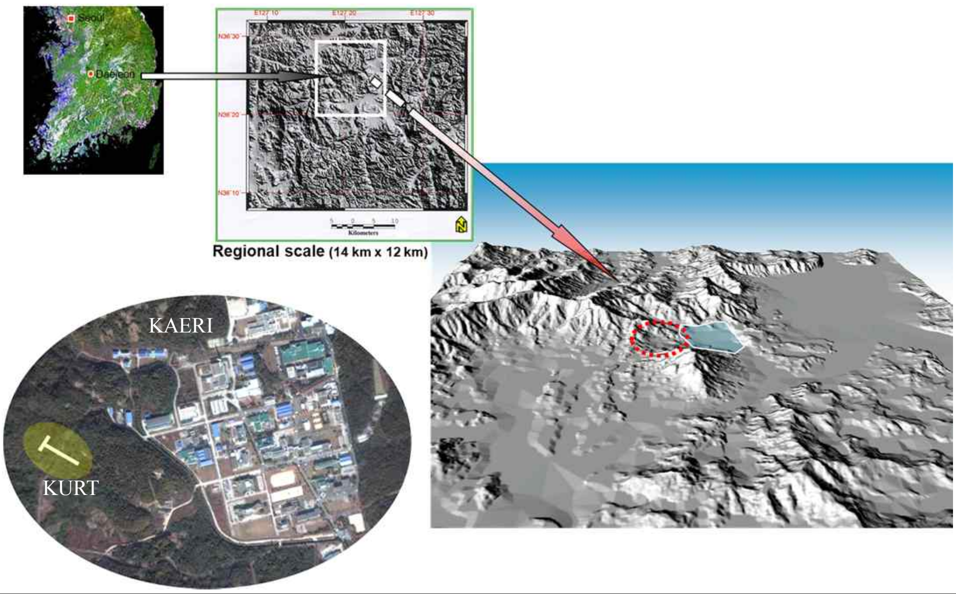
Location and Topography

3



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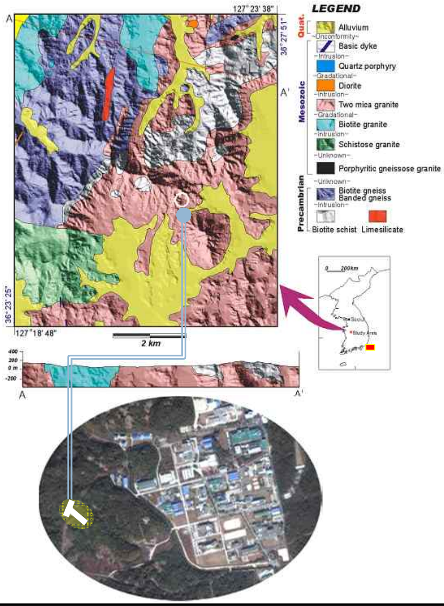
Geology

Geology around KAERI site

- Precambrian metamorphic rocks
  - biotite gneiss and banded gneiss
  - limesilicate, biotite schist
- Mesozoic plutonic rocks
  - schistose granite, biotite granite, two mica granite
- dykes

KURT

- located in western part of KAERI site
- medium to coarse-grained two-mica granite
  - biotite>>muscovite



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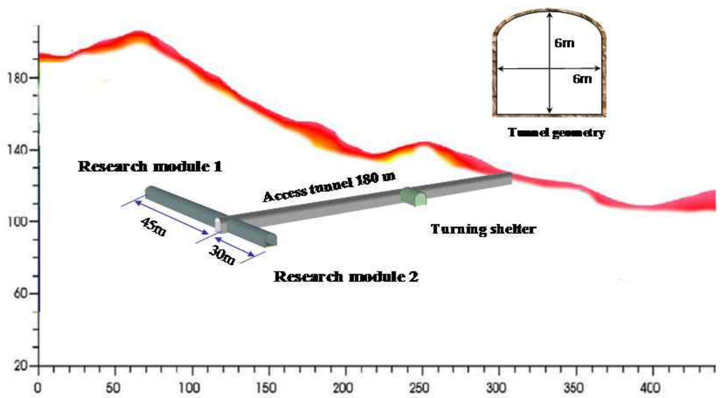
Layout



Tunnel dimension	•Tunnel section : 6 m x 6 m •Access tunnel : −10 %, 180 m •Research modules : L 30 m / R 45 m
Overburden	•Maximum 90 m from the ground surface

History

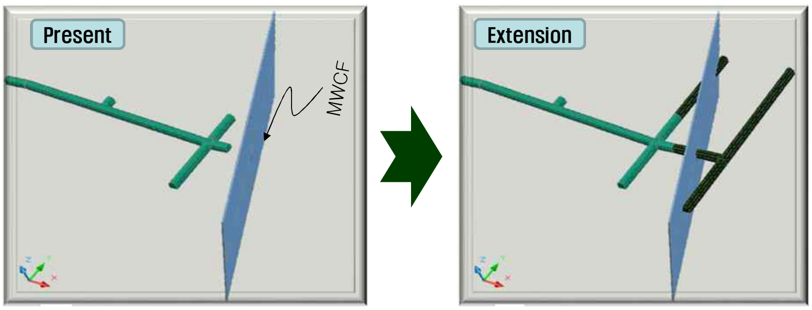
6

- Project launch and site characterization in 2003
- Design and licensing for construction in 2004
- Construction started in March, 2005
- First stage construction was completed in Nov., 2006

KURT extension

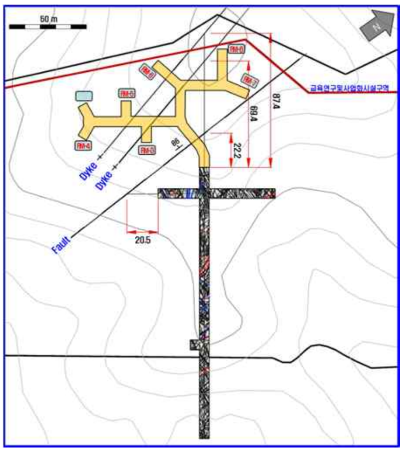
7

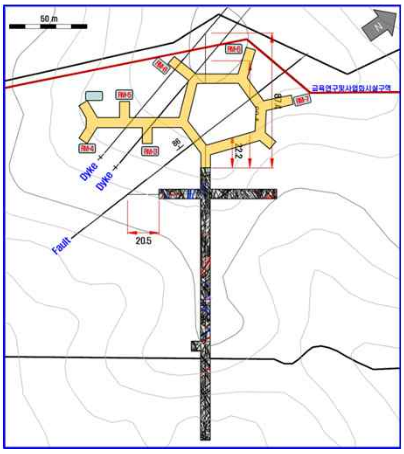
- **KURT extension will be planned during 2013 and 2014**
  - To characterize the MWCF
    - Geo-structure, Hydrogeology, Geo-chemistry, Transport property
  - To demonstrate the in-situ long-term of EBS



Extension plan

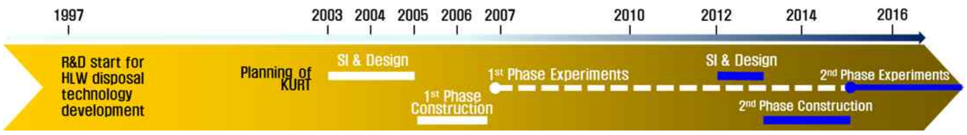
- **Tunnel layout: will be designed based on requirements for in-situ tests**
- **Tunnel excavation method: Drilling and Blasting (w/ diamond cutting)**





Extension plan

- **Schedule & Activities**



Year	2012	2013	2014
	• **SI & Design**	• **Construction**	
Activity	-Site investigation -Tunnel layout -Excavation method -Basic and detail design -License for construction -Long-term planning of KURT research program	-Tunnel excavation (~100m) -Tunnel face mapping -Monitoring of tunnel excavation effects on groundwater system -Database of geology, hydrology, groundwater chemistry, and rock mechanics	-Completion of tunnel excavation -Installation of utilities -Preparation of DEBS-KURT facility -Establishment of 3-D geological and rock mechanical model

<u>Site investigation activities</u>: geological mapping, borehole investigation, geophysical logging, hydraulic testing, installation of monitoring well

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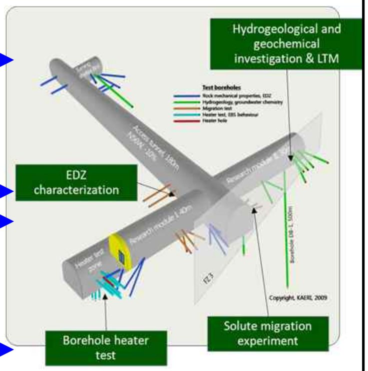
Tests in KURT

10

Experiment	1st Phase	2nd Phase				
	07~11	12	13	14	15	16
• Borehole heater test						
• DEBS-KURT						
• EDZ characterization						
• Migration experiment						
• Deep borehole investigation						
• Groundwater monitoring						
• Very long-term corrosion experiment						
• Hydro-structural modeling						
• Cubic-law testing						
• Spontaneous potential testing						
• MWCF characterization						
Fracture zone properties						
Redox front						
Tracer test						
Pseudo-radionuclide migration experiment						



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1st Phase (Borehole Heater Test)

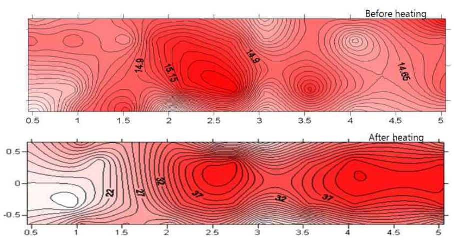
11

- **Small-scaled single heater(5 kW) test to study on the following area :**

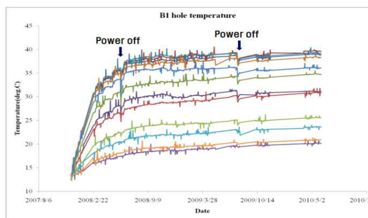
① Validation of thermal properties of damaged rock zone
② Validation of ventilation effect on TM behavior of rock mass
③ In situ test of thermo-mechanical behavior of rock under overheating condition

KURT Borehole heater test

Temperature distribution



Temperature change in rock



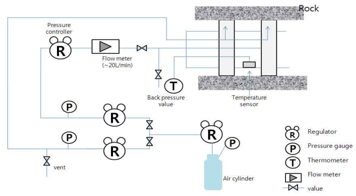
1st Phase (EDZ characterization)

12

- **Rock mechanical and hydrogeological property around EDZ was studied as following purposes;**

① Development of techniques focused on the rock mechanical characterization
② In situ tests for evaluating the hydraulic and dynamic properties of EDZ
③ Investigation of the acoustic wave propagation property in discontinuous rock mass

Concept of the hydraulic test in EDZ



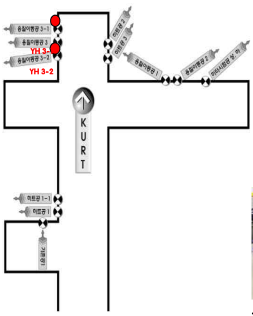
Measurement of Acoustic Emission

Instrument for hydraulic test

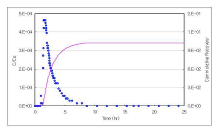
1st Phase (Migration test)

13

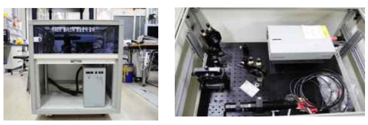
- **To improve the understanding the transport and retention of solute/colloid in KURT crystalline rock**
  - non-sorbing tracers (Uranine, Eosine), sorbing tracer(Rb, Ni, Sm, Zr)
- **To develop and validate solute/colloid transport models**
  - development of solute migration model



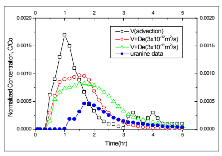
<In–situ migration experimental system>



<Breakthrough / recovery curves of eosin B>



<Mobile LIBD for groundwater colloid characterization>



<Comparison between exp. and model data>

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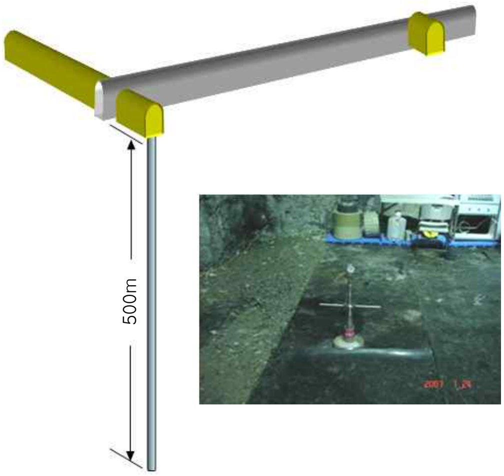
1st Phase (Deep BH drilling-DB-1)

14

- **To investigate the deep geology around study area**
- **To establish the QA based-test method in deep borehole for**
  - GW Sampling
  - Hydraulic test and Borehole logging
- **To perform the long-term monitoring of groundwater in hydrogeology and geochemistry**



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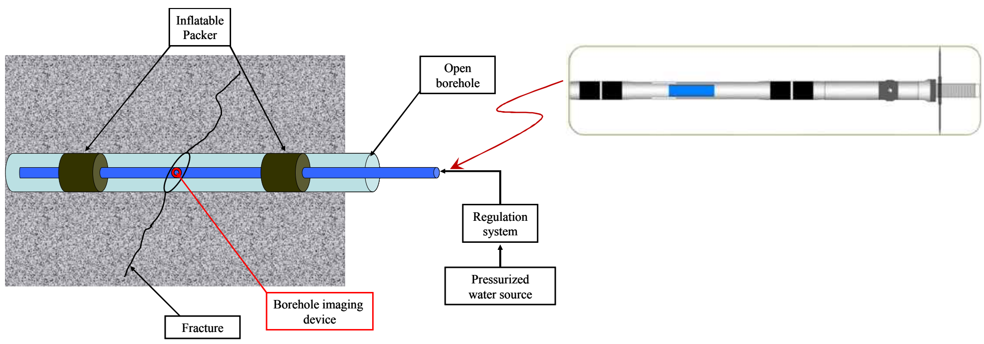
1st Phase (Fracture aperture by P change)

15

- KAERI and SNL launched a collaborative project in Feb. 2010, to investigate the influence of groundwater pressure on a fracture aperture size that controls the fracture transmmissivity in KURT.
- In-situ experiments had been carried out in 2011, which was focused on single fracture in borehole with specific equipment.



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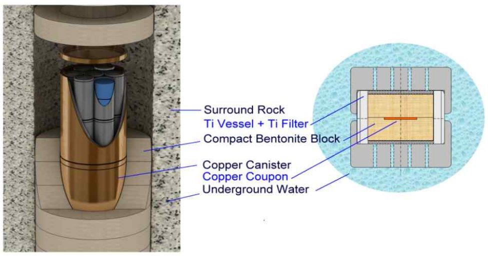
On-going (VLT Corrosion test)

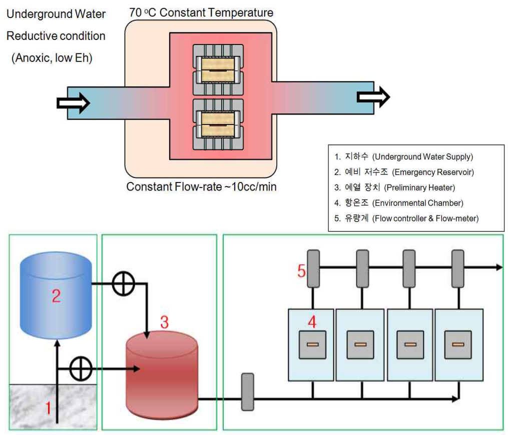
16

Research topics

① Empirical estimation of long-term corrosion rate of disposal canister materials
② Establishment of deep-geological corrosion condition
③ Investigation of the effect of DO, Eh, and pH on the corrosion behavior



Flow-diagram of Corrosion System



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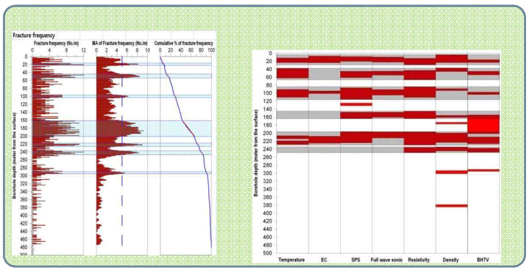
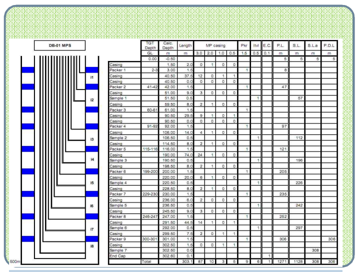
On-going (LT Monitoring)

17

- **To build a confidence on the hydrogeological and hydrochemical investigation technology**
  - Installation of multi-packer system (Solexpert) in DB-1 borehole
  - Long-term monitoring of hydrogeological and groundwater chemical properties in pack-off intervals
- **To produce the qualified hydrogeological data for its numerical modeling and safety assessment**



DB-1 data



Design of multi-packer system

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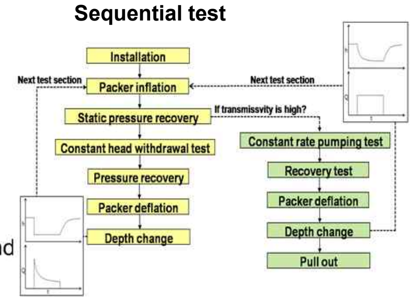
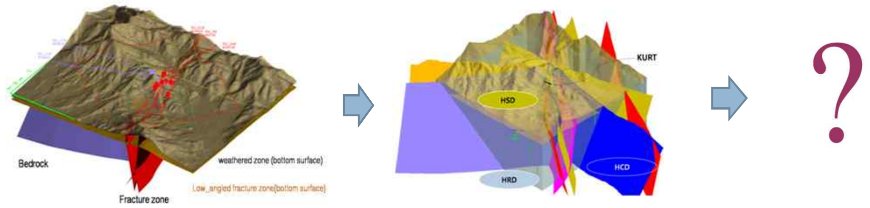
On-going (Hydrogeological modeling)

18

- **To revise the geological model and groundwater flow simulation**
- **Single hole dilution test and LT monitoring**
  - To verify the FZs in previous geological model
- **Sequential hydraulic testing in a deep borehole (up to 1,000m)**
  - To obtain the in-situ estimates of hydrogeological and geochemical properties

Sequential test





Ver. 1 GM **Ver. 2 GM** **Ver. 3**

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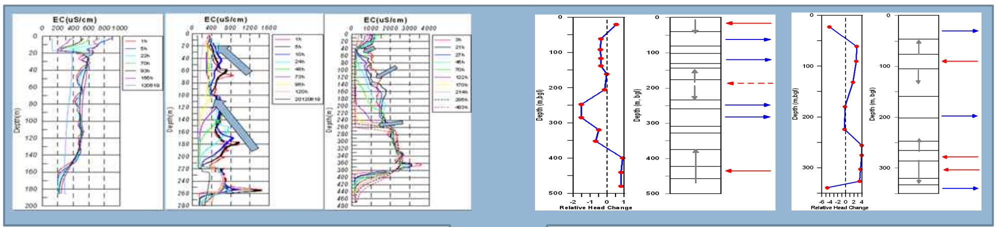
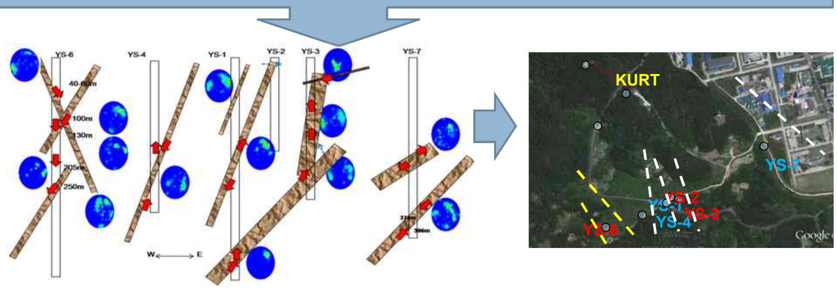
On-going (Hydrogeological modeling)

19

- **Single hole dilution test vs Long term monitoring in BH**





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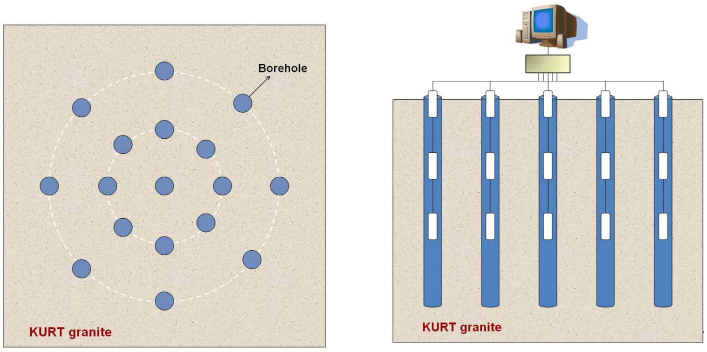
On-going (SP test in crystalline rock)

20

- KAERI and SNL launched new collaborative project in March 2011, to determine hydraulic properties and behavior of a 3D subsurface volume of saturated fractured rock using hydraulic head and streaming potential data
- Production Pumping test with simultaneous monitoring will be carried out of hydraulic head and streaming potentials at the installed well in the KURT



Layout of the well field for the in-situ experiment

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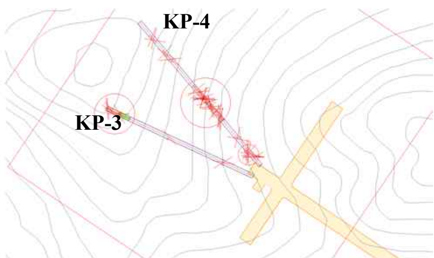
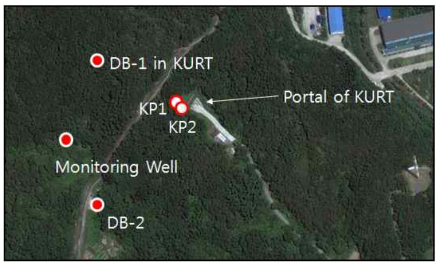
On-going (MWCF characterization)

21

- **Fracture zone properties**
  - Geological, geometrical, hydrogeological, geochemical, and rock mechanical properties
  - Long-term monitoring of tunnel excavation effects on groundwater system
- **Redox front**
  - Transition process mechanism on oxidation and reduction condition of groundwater during tunnel excavation
- **Tracer test**
  - Solute transport properties of MWCF





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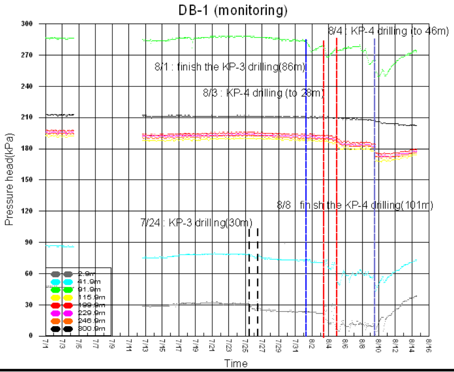
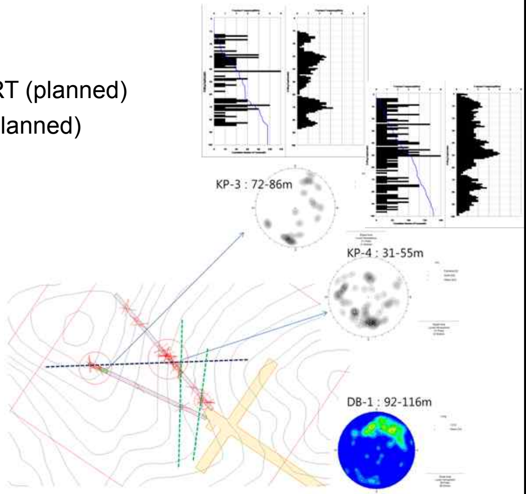
On-going (MWCF characterization)

- **Fracture zone properties**
  - 2 BH drilling for KURT extension(done)
  - LT Monitoring in DB-1 during drilling
  - 2 BH for hydraulic test at MWCF in KURT (planned)
  - 1 BH for LT monitoring outside KURT (planned)





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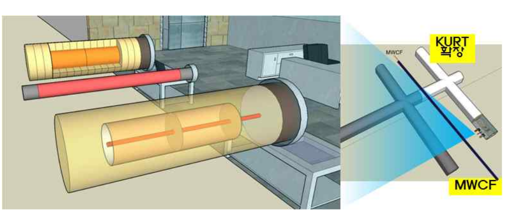
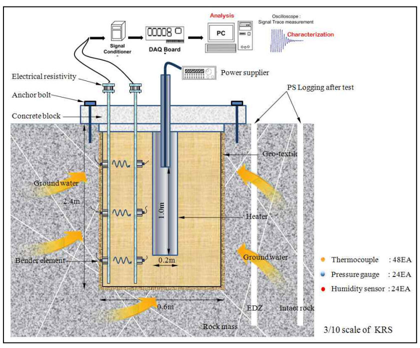
2nd Phase (DEPS-KURT)

23

- Establishment of a scale-up technology for the manufacture of medium scale(1/3) canisters
- Development of analysis tools for Thermal-Hydro-Mechanical behavior of EBS and in-situ demonstration facility for the EBS performance in KURT



< Scheme of DEPS-KURT >



< Excavation layout for DEPS-KURT >


Thank you for your attention!

Grimsel Test Site - Nagra's competence center for studies in fractured rock Formations

Crystalline Rock Repository Development
24-27 September 2012, Prague

Ingo Blechschmidt,
SWITZERLAND

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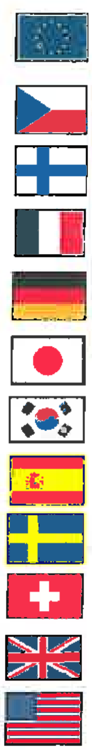
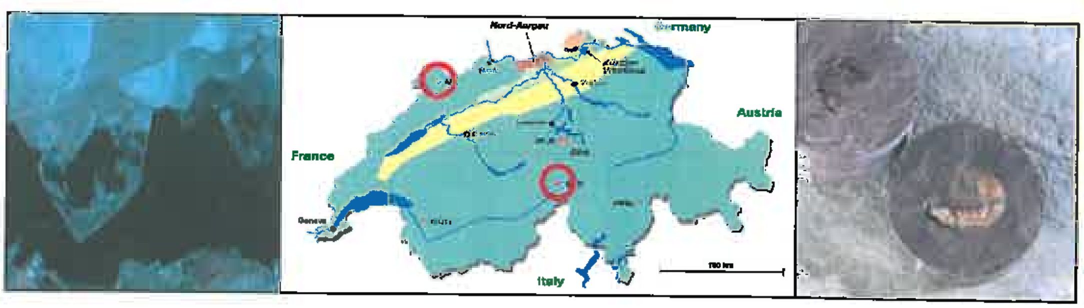
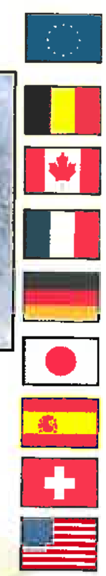
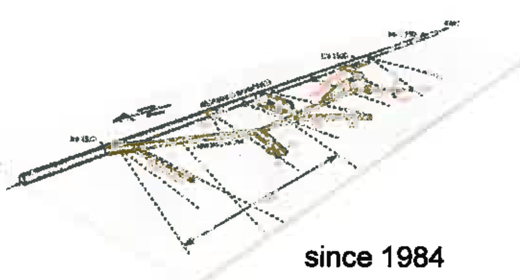
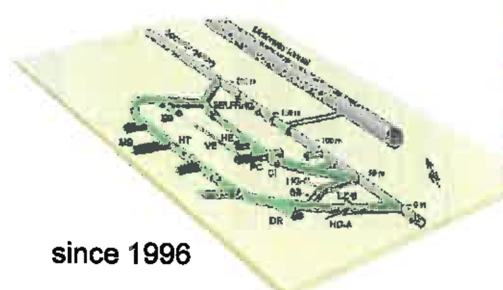
Switzerland - two URLs with a broad spectrum of experiments











since 1984

since 1996

Grimsel Test Site
(in crystalline bedrock)

Mont Terri Project
(in Opalinus Clay)

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Nagra's drivers for establishing the URLs

- For both the crystalline and the sedimentary rock programmes, it was recognized that many issues related to migration, construction and EBS behaviour must be studied in situ
  - GTS (1984) – the development of Project Gewähr (1985) for crystalline rock in Northern Switzerland made it clear that URL studies would be important for future development
  - MT (1996) – the positive results from sedimentary studies in the 1990s pointed to Opalinus Clay as a suitable potential formation; the MT location was an opportunity for a URL in a preferred rock, although not in a potential siting region
- Both URLs have easy acess (limited infrastructure needed) and represent opportunities to develop understanding in situ without having to wait for a disposal site URL

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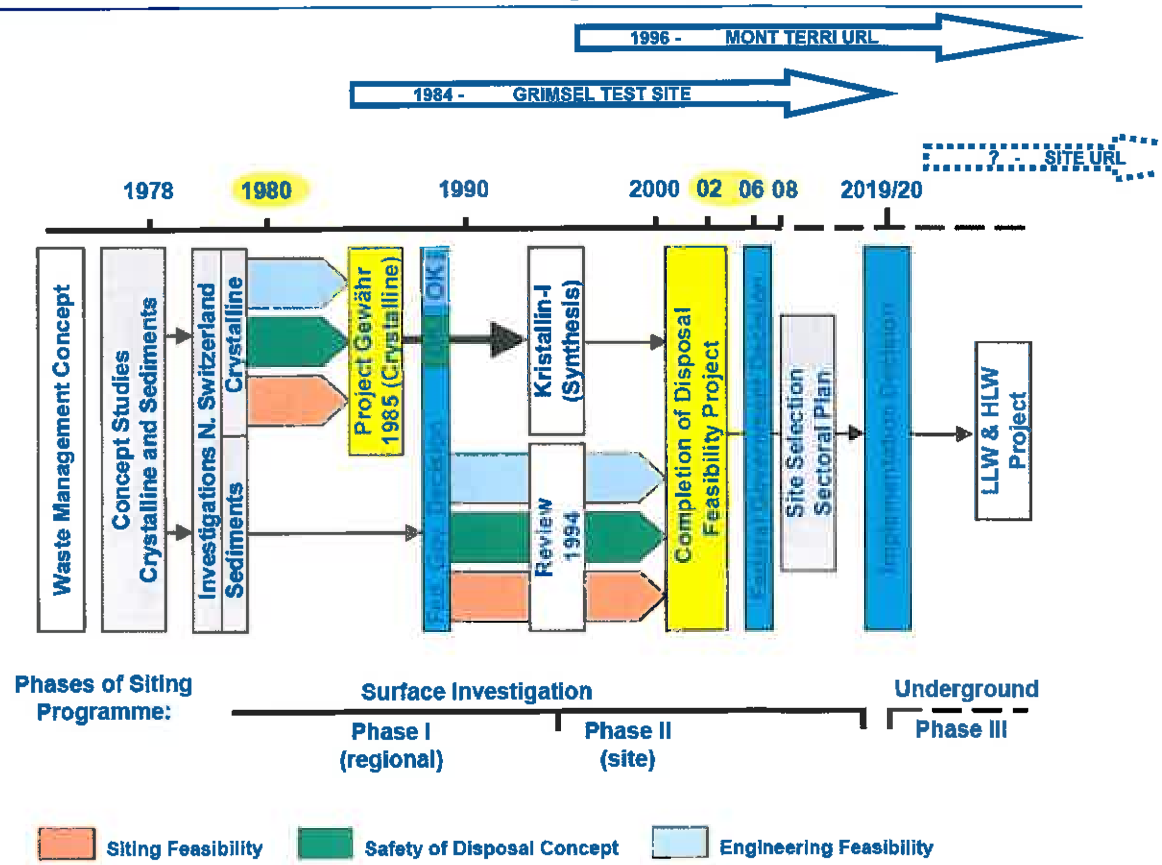
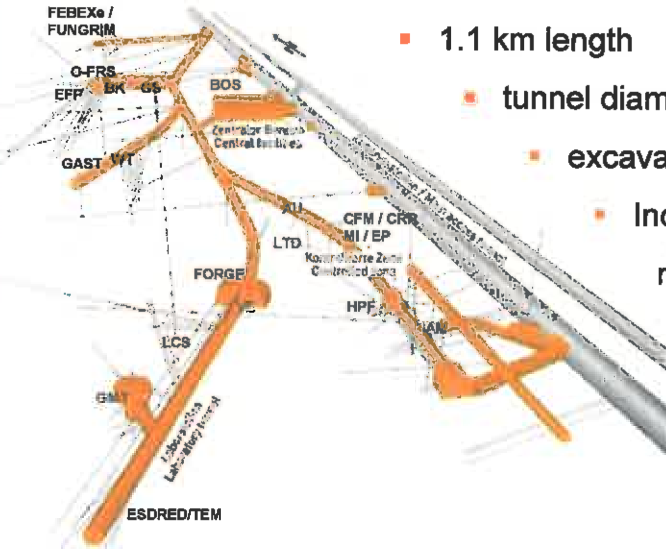
URLs in the context of the Nagra repository programme



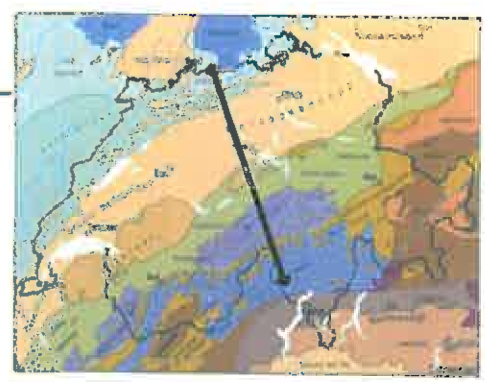
GTS - Overview

- Generic URL in granite
- owned by Nagra
- in operation since 1984
- 450 m overburden
- 1.1 km length
- tunnel diameter 3.5 m
- excavated with TBM / blasted
- Includes an IAEA level B/C radiation controlled zone



Geological overview - Location Grimsel Test Site (GTS)

- Foliated crystalline rock with saturated anoxic groundwater conditions – Central Aare Granite in the north of the URL and Grimsel Granodiorite in the south



Modified from Tektonische Karte der Schweiz, 1:500'000. swisstopo – Bundesamt für Landestopographie, Wabern, Switzerland.

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From *matrix* to *water-conducting features* (WCF)

Ductile		Brittle

Matrix:

Granodiorite

(massive – weakly foliated)

Mylonit

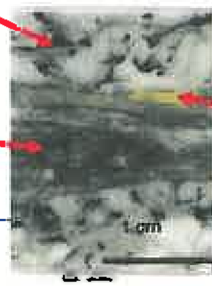
(fine grained, recrystallised)

Shear zone:

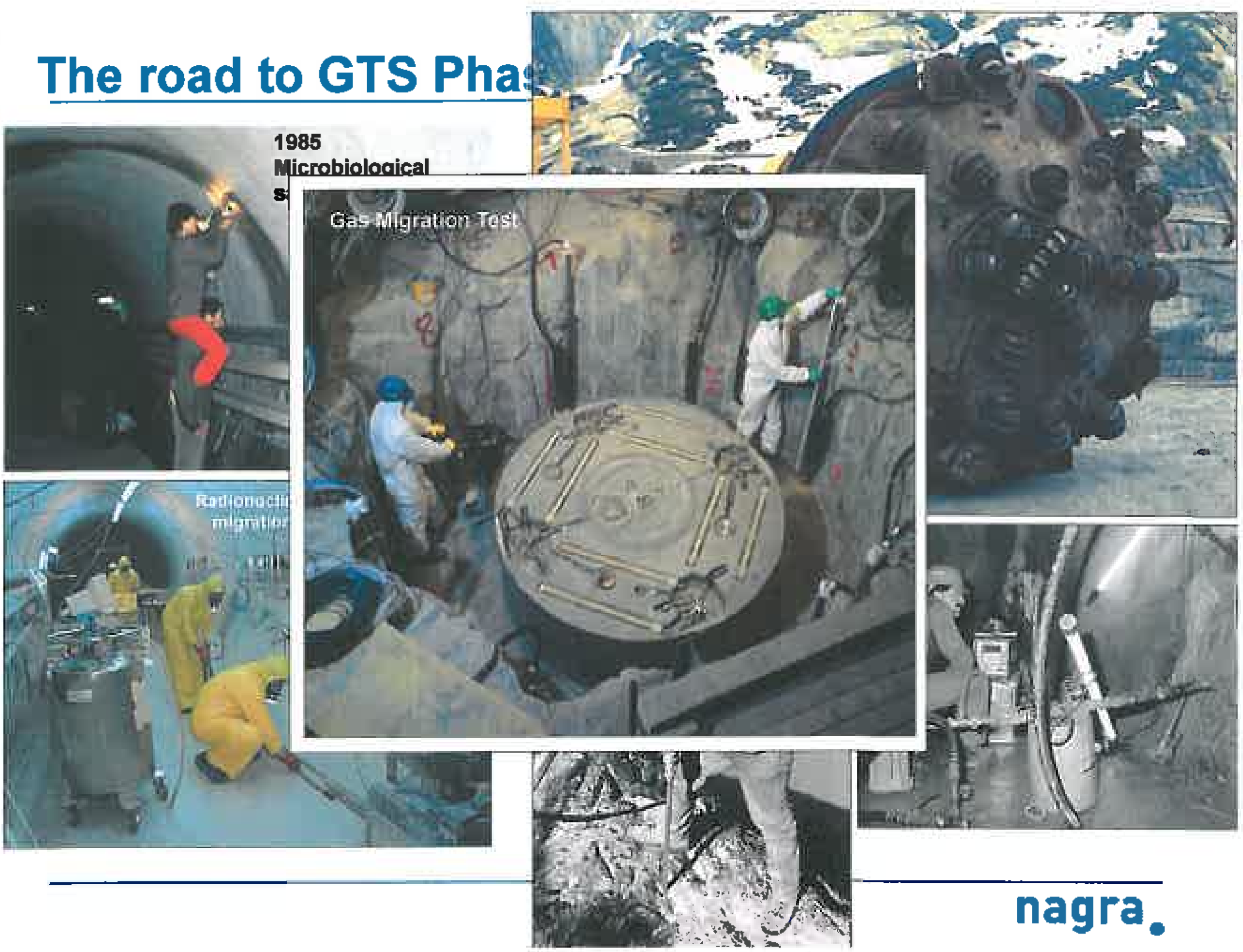
Concentration in ductile deformation

Water conducting features:

Brittly reactivated shear zones (breccia, fault gouge)



The road to GTS Phas



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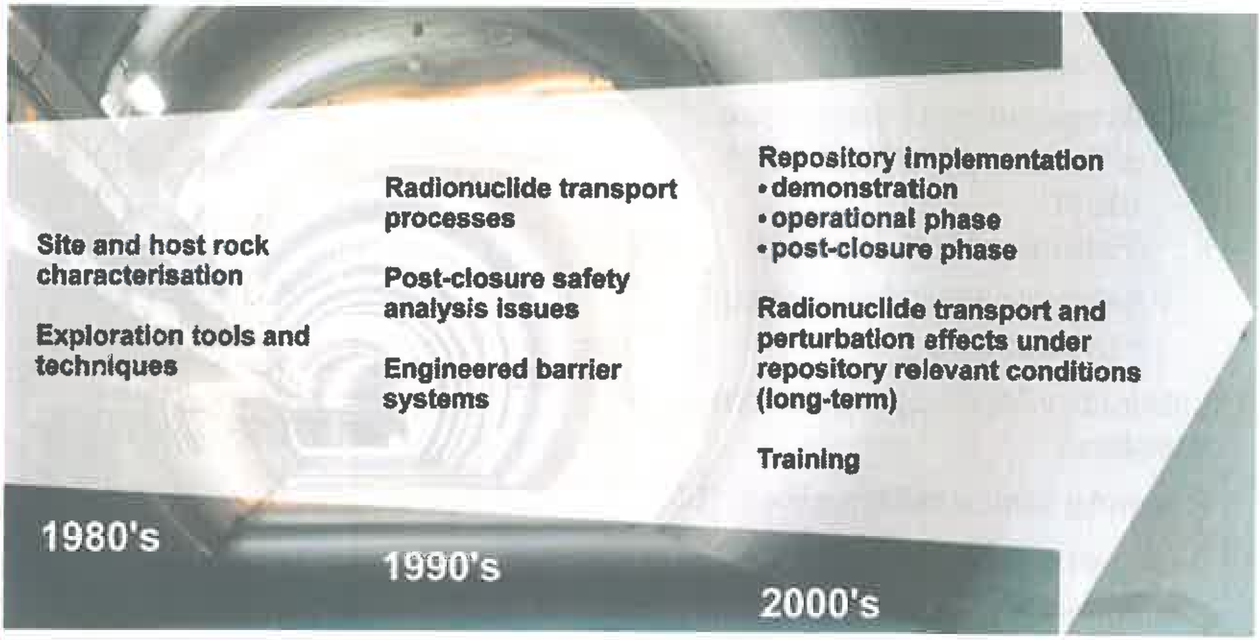
Evolution of experimental focus and activities



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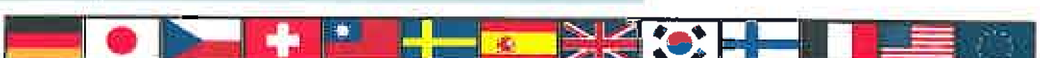
→ *Status Sept. 2012*

Grimsel Test Site – on-going experiments

Project	*Status June 2012*
LCS	Long-term Cement Studies
LTD*	Long Term Diffusion
CFM*	Colloid Formation and Migration
LSP	Low-pH Shotcrete Plug experiment
TEM	Test and Evaluation of Monitoring Techniques (part of MoDeRn EC project)
C-FRS	CRIEPI's Fractured Rock Studies
FEBEXe	Full-scale HLW EBS Experiment
JGP	JAEA Grouting Project at Grimsel Test Site
GAST	Gas Permeable Seal Test
FORGE	Mock-up
3D-SHM	Large-scale structural and hydraulic SDM

Projects in implementation phase	
BiMoG	Biochemical monitoring of granitic groundwater
LASMO	Large scale Monitoring
MaCoTe	Material Corrosion Test



***use of RN in in-situ experiments under realistic boundary conditions**

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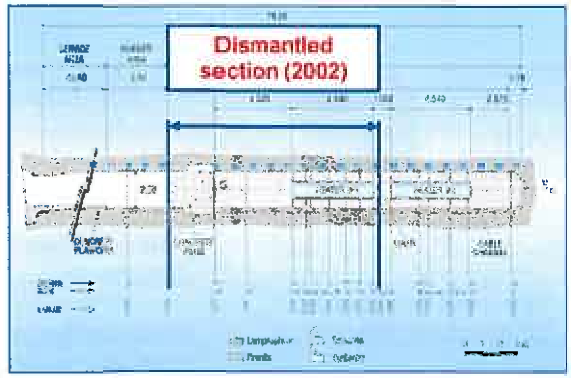
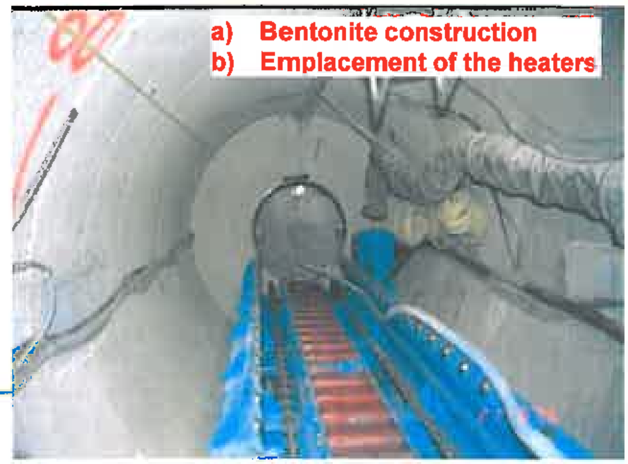
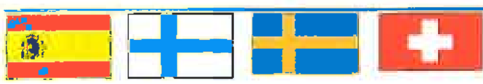
Full-scale High Level Waste Engineered Barriers Experiment (FEBEX)

- Horizontal emplacement (HLW) of full scaled EBS system under natural conditions
  - Temperature at the surface of the canisters(heaters) → 100 °C (February 1997 onwards)
  - Bentonite blocks and about >700 sensors
- Laboratory Mock-up test for cross validation
- **Running successfully since 1997**
- First part excavated in 2002
- Continuation until 2015

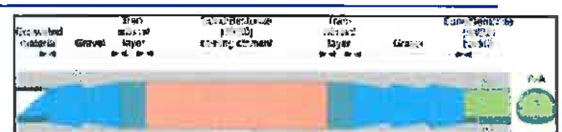


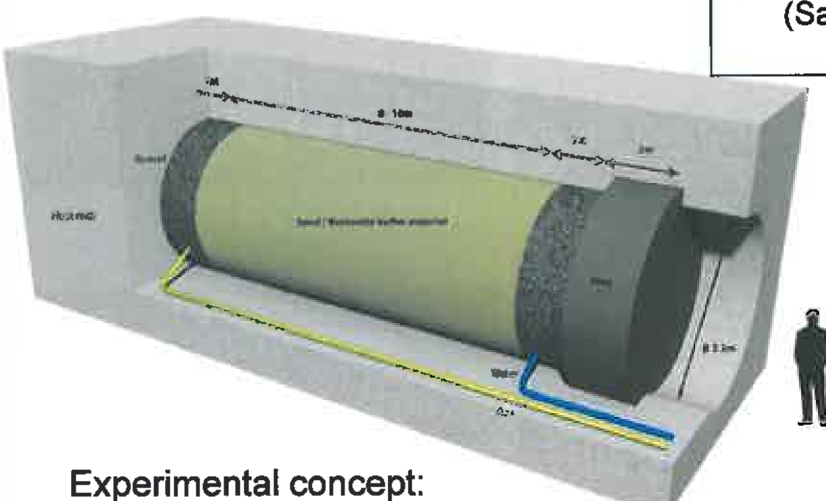




Gas Permeable Seal Test (GAST)

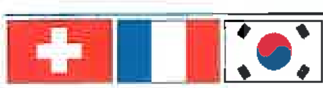
Background: Migration of repository-generated gas





Experimental concept:

- Test the emplacement techniques and behaviour seals/plugs at 1:1 scale
- Sand/bentonite seal -> Saturation up to 5 Mpa -> gas injection



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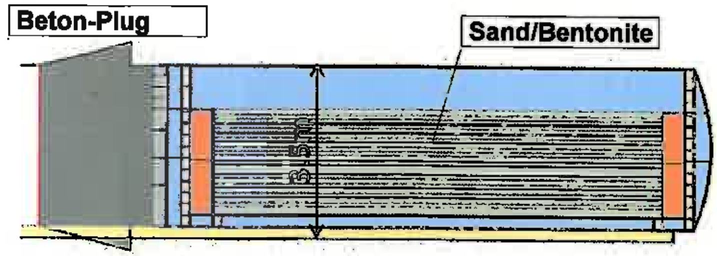
GAST – emplacement (Okt. 2011 – April 2012)



Ducts for sensor lines

SB emplacement and compaction

SB > 50% emplaced, concrete wall for reinforcment during

Long-term cement studies (LCS)

Field activities:

- 2 grout injection experiments
- Overcoring and lab studies
- Cement emplacement experiment on-going

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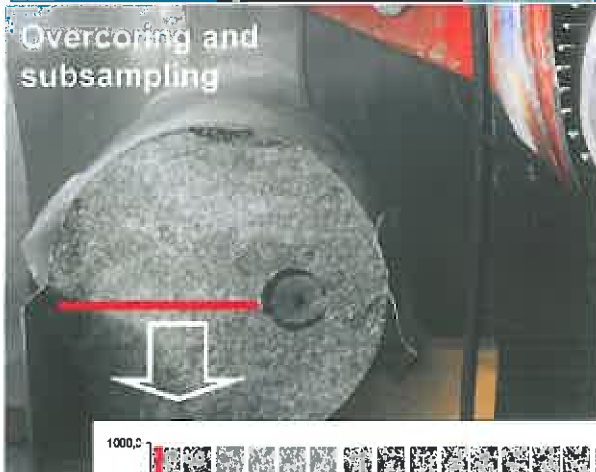
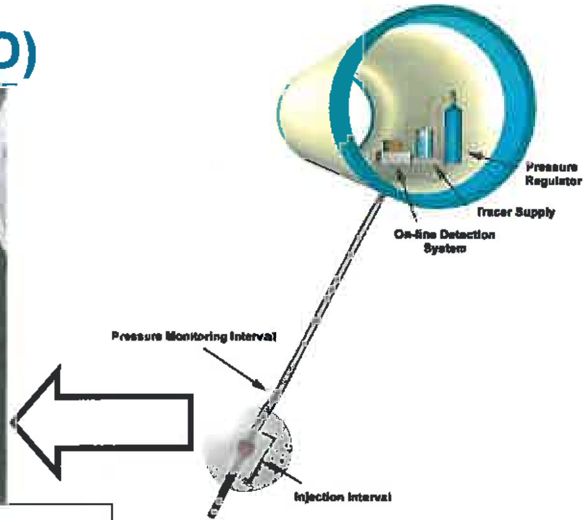
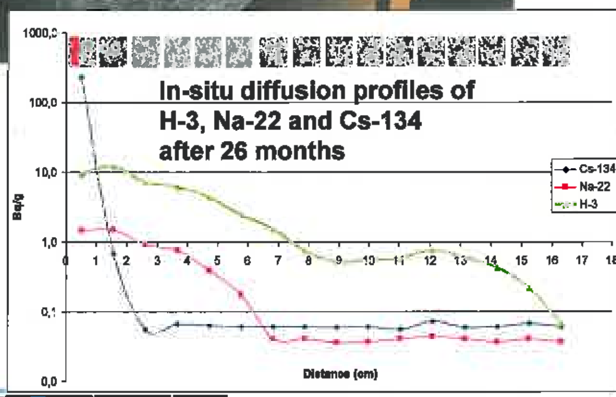
Long-term diffusion (LTD)







- Detailed post-mortem modeling of monopole I is ongoing
- Start of Monopole II longer-term in-situ test (2012 onwards)
- Study of matrix diffusion of radionuclides from water conducting features

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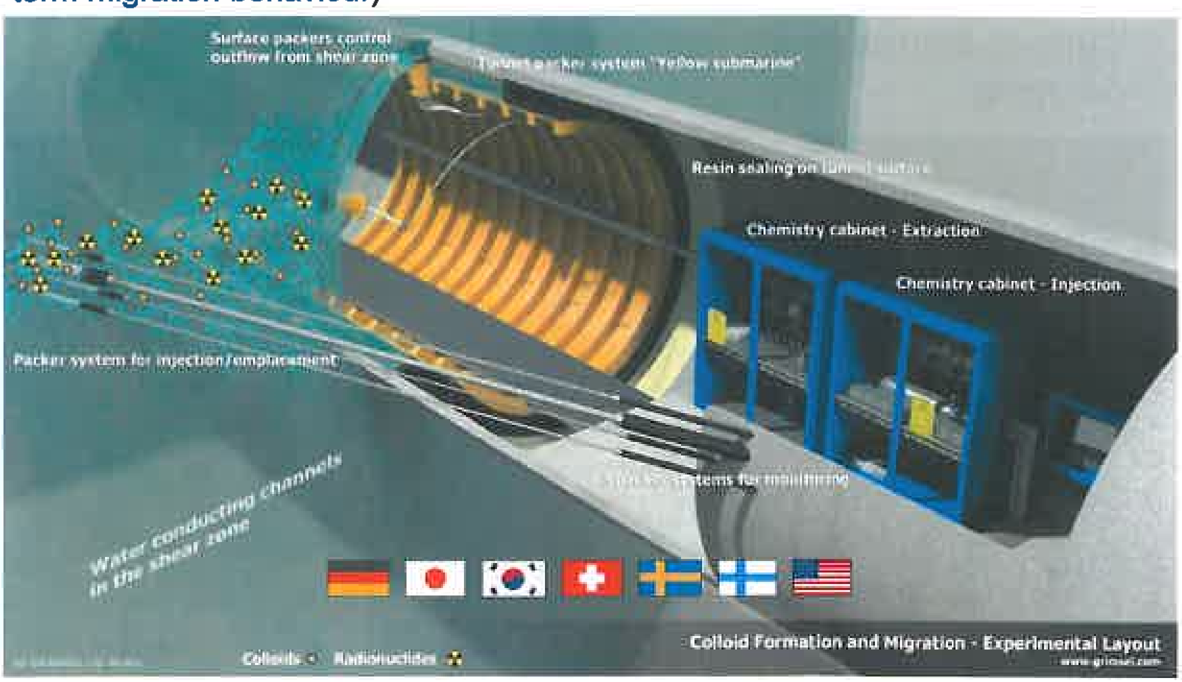
Colloid formation and migration (CFM)

Study the generation of colloids from a bentonite-based EBS and investigate the influence of such colloids on radionuclide migration in a fractured host rock under advective flow conditions which are closer to repository-relevant conditions than in preceding experiments (generation rates & mechanisms/long-term migration behaviour)



Colloid formation and migration – The Site

- Licence for RN use in the frame of the project approved by authorities in Jan. 2012
- First "hot" test started in Feb 2012
- Current planning horizon of the project until 2015/18

Nuclide
Na-22
Sr-85
I-131
Ba-133
Cs-137
Np-237
Am-243
Pu-242
Th-232

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Concluding remarks

- The focus of Nagra's activities at GTS (Crystalline rocks) has evolved over the last 28 years in accordance to the priorities of the RD&D plan:
  - current emphasis is on EBS components at the engineering scale -- these are to a large degree host rock independent
  - their performance at GTS is advantageous due to the favourable boundary conditions (practically non-existent excavation disturbed zone, rocks with high-compressive strength etc.)
- GTS offers a platform for:
  - cooperation with international partners
  - training and technical PR
  - interaction with interested stakeholders

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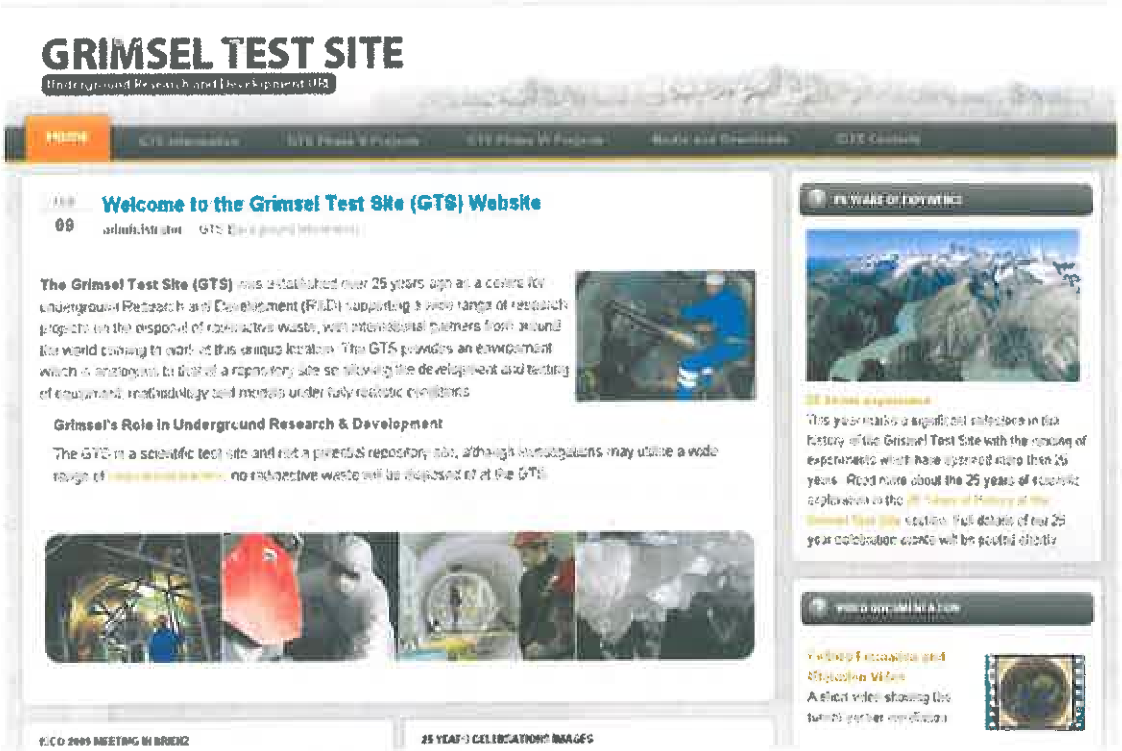
Come and visit www.grimsel.com



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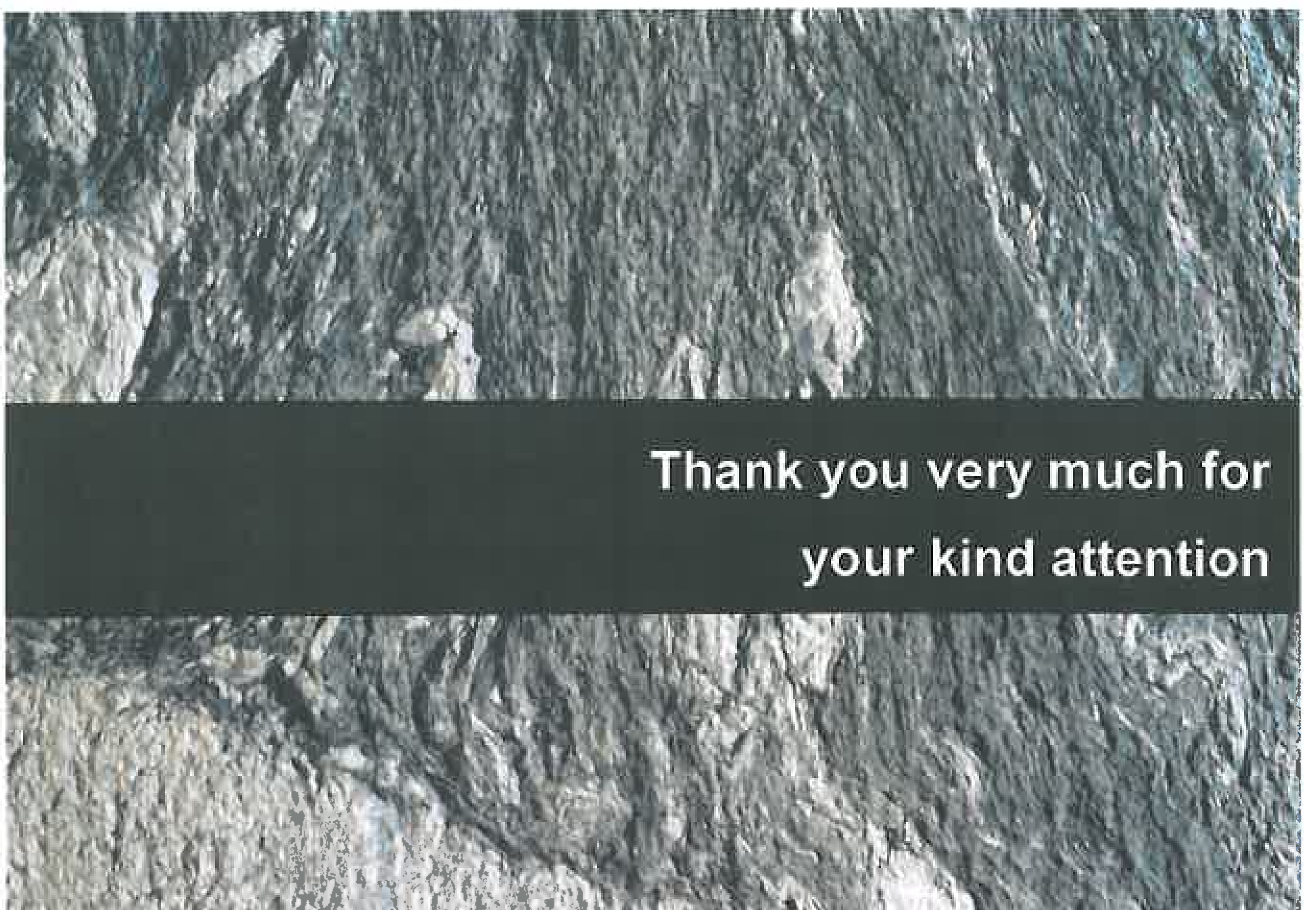

Ingo Blechschmidt *(ingo.blechschmidt@nagra.ch)*

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- Goals

- to introduce the various crystalline rock programs to each other, with emphasis on "emerging" programmes
  - status reports and peer to peer introductions
- to explore and identify common issues between the emerging crystalline rock repository programmes
  - DAY 1 status reports revealed most programmes have interest in
    - public acceptance and,
    - defining the regulatory or government frameworks, decision making process
  - DAY 2 discussions of repository programme development, the creation of safety cases and safety assessments, etc. identified several programmes having interest in
    - methods and approaches to technical site selection,
    - Disposal concepts (horizontal vs vertical cask emplacment, open vs closed reposiotry/storage,linking sotrage and disposal through cask size, IS concepts, cask & container design, conveyance & handling, shaft vs ramp)
    - data sources (raw data,.natural analogs, material prop, etc.) for creating safety cases/safety assessments, and
    - the planning of R&D programmes
    - Lesson learned
  - DAY 3 discussions on siting, site characterization, data, and URLs, identified issues specific to crystalline rock disposal concepts
    - flow & transport
    - EBS design and performance
    - fracture network characterization
    - assembling / synthesizing data (geo mapping, -> in-situ/borehole characterization, -> in-situ testing)
    - Knowledge management
- To explore the notion of creating a "crystalline rock repository club"
  - WHY?
    - to enhance programme to programme cooperation, collaboration, information sharing among the emerging programmes and to advance information flow from the advanced programmes to the emerging programmes

- Questions
- Did the workshop achieve its 1st goal of making introductions?
  - feedback?
  - what interactions were most useful?
- Did the workshop achieve its 2nd goal of identifying common issues?
  - feedback?
  - Are there other issues?
- Did the workshop achieve its 3rd goal of moving toward a xtal rock club?'
  - Was this workshop useful?
  - Should we consider a second meeting in one year?
    - What would be the primary topics to discuss?
    - What format should it take? Technical conference, workshop, etc?
  - Can we identify a few ideas to pursue programme to programme or pper to peer collaboration?
    - Lessons learned to public acceptance approaches
    - Disposal design concepts comparisons and reviews
    - Initial safety case or safety assessment development, FEP database and screening arguments
      - to influence the disposal concept
      - to outline the needed R&D programme
    - Modeling and simulation test cases for flow and transport
    - Optimization and influence on funding / economic considerations
    - Linking storage & disposal concepts and prgrammatic issues

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