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Evaluation of how the LUCOEX results can be utilized by less-advanced programs

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Evaluation of how the LUCOEX results can be utilized by less-advanced programs

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Abstract

The objective with this report is to investigate how results from the LUCOEX[1] (Large Underground Concept Experiments) project can be utilized by less-advanced radioactive waste management programs, with respect to high-level waste and spent fuel, in member states of the European Union. This includes an evaluation of how far the European Union member states have come in their radioactive waste programs.

High-level long-lived waste and spent fuel requires the most comprehensive disposal of all types of radioactive waste. One of the most safe and feasible way to take care of this waste with today's technologies is by a geological disposal system. Geological disposal is the preferred solution for most countries with high-level waste and spent fuel.

The purpose of the LUCOEX project is to demonstrate the technical feasibility in situ for geological repositories for long-lived high-level nuclear waste. This includes a safe and reliable construction, manufacturing, disposal and sealing of the repositories. Two proof-of-concepts are made in clay and two in crystalline rock.

The countries that consider clay as an option for suitable host rock for deep geological disposal are Belgium, Bulgaria, France, Germany, Hungary, Lithuania, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and United Kingdom.

The countries that consider crystalline rock as an option for suitable host rock for deep geological disposal are Bulgaria, Czech Republic, Finland, Germany, Lithuania, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and United Kingdom.

Spain, Slovakia, Hungary, United Kingdom, Germany, Czech Republic and Belgium are countries that have made significant progress in their radioactive waste management programs, and therefore are in a position where results from the LUCOEX project can be utilized in a perspicuous future. This also concerns the participant countries of LUCOEX; Switzerland, France, Sweden and Finland.

In addition Bulgaria, Lithuania, Poland, Romania, the Netherlands, Slovenia and Croatia can utilize the results from the LUCOEX project to get information of one concept to aim for in the future.

[1] The LUCOEX-project has received funding from the European Union's EUROATOM-research program (FP7) under grant agreement 269905 – The LUCOEX-project.

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1 Introduction

1.1 Method and Objective

The objective with this report is to investigate if and in which way results from the LUCOEX[2] project can be utilized by countries in EU with less-advanced radioactive waste management programs, with respect to high-level waste and spent fuel. This includes an evaluation of how far the EU member states have come in their radioactive waste programs.

The method used in this study has been information processing and interviews. International contacts have been made through e-mail to gather information about radioactive waste management in European countries. Also participation in the LUCOEX workshop at Äspö, Sweden, and the IGDTP-Geodisposal conference in Manchester, United Kingdom, has also been utilized for connecting with relevant representatives for WMO's.

1.2 Background

1.2.1 Radioactive waste and spent fuel

Radioactive waste is material which contains radionuclides with a certain level of activity. The waste is a result from operation of nuclear power plants, all activities related to the nuclear fuel cycle and also other tasks where radioactive material is used. It is important that all radioactive waste is handled in a safe manner and that humans and their environment is well protected from the waste [1].

1.2.2 Different types of radioactive wastes

Very low-level waste

This is radioactive waste with concentrations of activity levels around or just above a limit which require radiation safety and protection. Most of it consists of materials involved in operation and decommissioning from nuclear industrial sites. Also other industries, for example food processing and chemical, can produce very low-level waste since the natural radioactivity occurs in some of the used minerals in the processes. It have very limited hazard though. For protection the waste can be disposed in engineered landfill surface facility types [2, 3].

Low-level waste

Low-level waste is mainly produced in hospitals and industries. Also steps in the nuclear fuel cycle can generate this waste. This waste is suitable for near surface disposal. The low-level waste with little activity doesn't need shielding during transport and handling but the waste with a bit higher does and can require isolation for several hundred years [2, 3].

[2] The LUCOEX-project has received funding from the European Union's EUROATOM-research program (FP7) under grant agreement 269905 – The LUCOEX-project.

Intermediate-level waste

This waste comes primarily from chemical sludge and used reactor core components. Intermediate waste contains long-lived radionuclides and need more isolation than is provided by near surface disposal. The disposal needs to be between tens and hundreds meters underground. This makes it possible to use both natural and engineered barriers in the isolation [2, 3].

High-level waste

This is waste with high levels of activity. It is produced when uranium fuel is burned in a nuclear reactor. High-level waste can also be generated when spent fuel is reprocessed. Because of the process of radionuclides decay, significant amount of heat can be generated. It can also contain large quantities of long-lived radionuclides. This waste requires even more isolation than intermediate waste and this is possible with disposal in a deep geological repository [2, 3].

Spent fuel is viewed as its entirety. Figure 1 shows how much spent fuel the member states have generated and how much they are expected to produce in the near future [4].

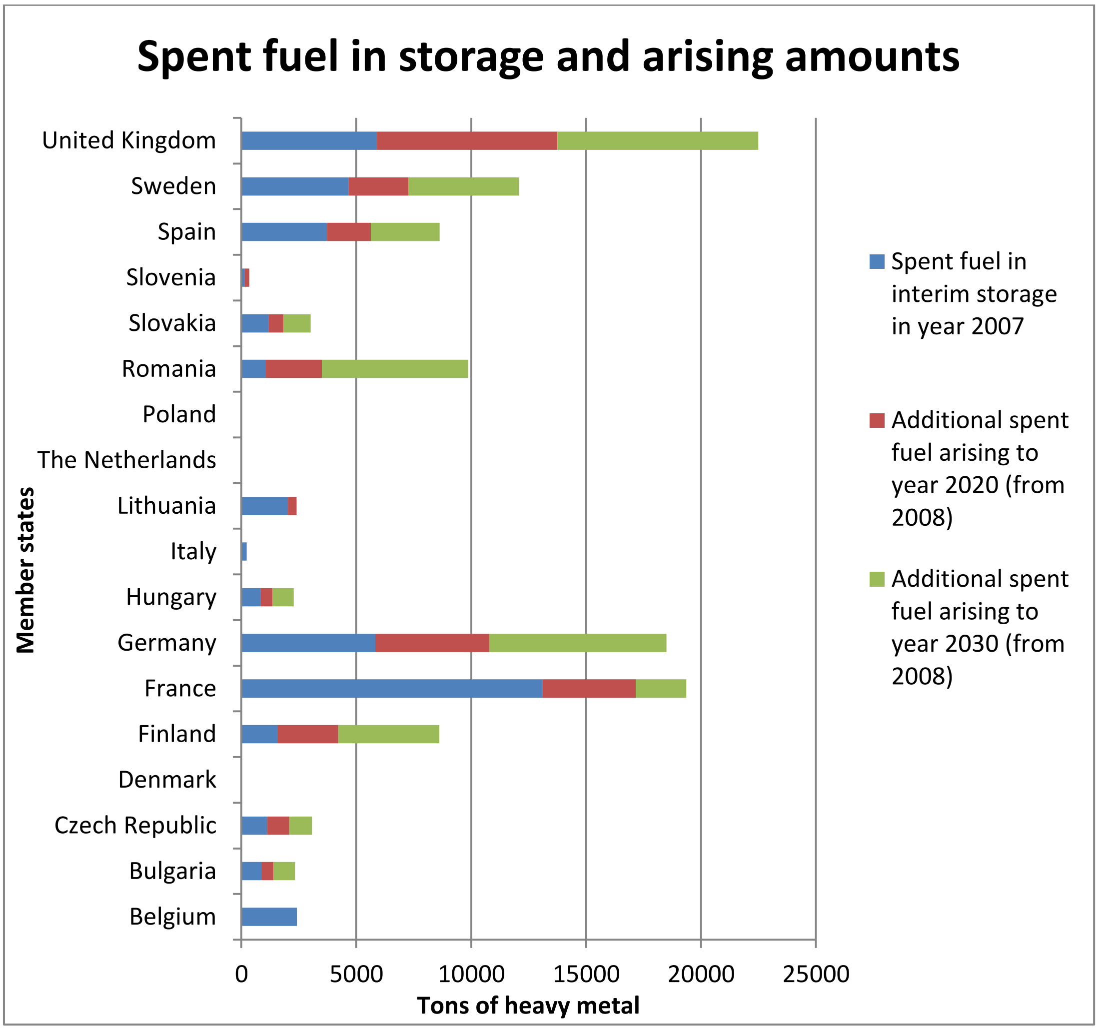

Figure 1 [4]

1.2.3 Geological Disposal

It is the high-level long-lived waste and spent fuel that requires the most comprehensive disposal of all the types of waste [4]. It has to be isolated from humans and the environment for several thousand years. With today's knowledge, the most safe and feasible way to take care of this waste is by a geological disposal system. This is a system that involves both the geology's ability and the engineered materials to establish several barriers with different functions to keep the safety functions at a high level. The disposal takes place hundreds of meters underground so the distance also contributes to the isolation [5].

Many countries have adopted deep geological disposal as the solution for their high-level waste and spent fuel in a long-term perspective. Several countries are making advancement towards implementation of geological disposal. Some countries face challenges that can make them take a step back, but still the geological disposal keeps being the reference option [5].

1.2.4 Reprocessing

In the current situation, there are three major options to manage the spent fuel. One is direct disposal, which includes geological disposal. Another one is the storage and postponed decision which is a ”wait and see” option. Finally there are also the reprocessing and recycling options [6].

Reprocessing means that the spent fuel is recycled and also that the amount of high-level waste can be reduced [7]. It can also improve the use of fissile materials [6]. With today's policy's, four member states will continue with reprocessing for their spent fuel and these are Bulgaria, France, Italy and the Netherlands [4].

Historically, reprocessing was made to produce plutonium for nuclear weapons. Later on, in the 1960's countries with nuclear programs which had plans for reprocessing had it with the aim to supply start up fuel for breeder reactors. These reactors turned out to be less economic than expected. Today, reprocessing is not an option in most countries with nuclear power [8].

1.2.5 LUCOEX project

The purpose of the LUCOEX project, co-financed by EURATOM research program under Frame Program 7, is to demonstrate the technical feasibility in situ for geological repositories for long-lived high-level nuclear waste. This includes a safe and reliable construction, manufacturing, disposal and sealing of the repositories. The project involves four nations in Europe; Sweden, Finland, France and Switzerland. For each of the proof-of-concept installations, there are various focus areas and geological conditions [9, 10].

Horizontal disposal in Callovo-Oxfordian clay

The objective with the proof-of-concept installation in Bure is to optimize the design of the French repository concept for high-level waste disposal. The concept consists of a high-level waste cell which in this case is an approximately 80 m long micro tunnel with a diameter of around 0.7 m. In the cell a body part, where the packages can be stored and also a cell head, are positioned. These two components are separated by a steel radiological protection plug. A swelling plug presses against a concrete plug to manage to close the cell [10, 11].

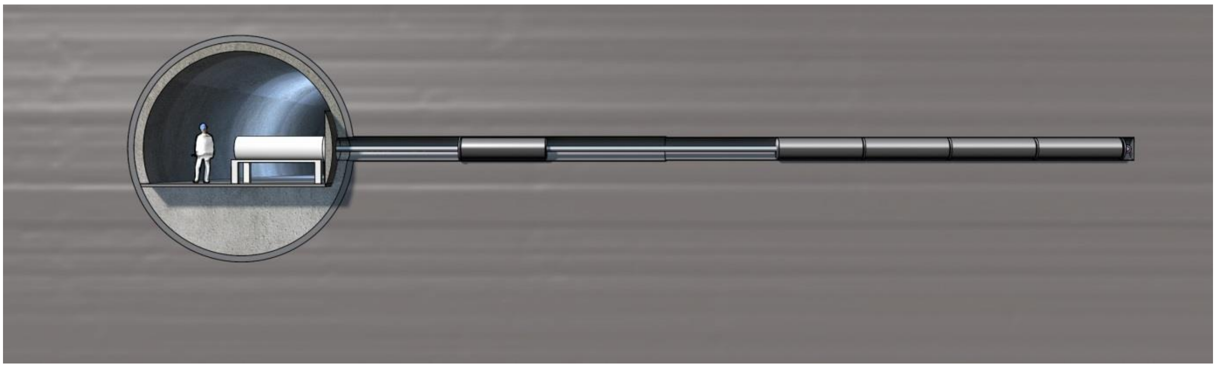

Figure 2: An illustration of the proof-of-concept installation in Bure (www.lucoex.eu)

This concept includes excavating of a cell demonstrator which can be representative of the high-level waste storage cell reference concept. Also electrical heaters are used which aim to simulate the thermal load that is induced by the waste packages. The thermal load behavior is further studied of the body part and insert and also the operation of the extension of the cell body and when it slides into the insert. Also the thermal load behavior of the rock interface and what impact it has on the linear mechanical load are being analyzed [10, 11].

Horizontal disposal in Opalinus Clay

The objective with this proof-of-concept is to confirm the sustainability of the Swiss repository concept in Opalinus Clay for high-level waste disposal. This is made in full-scale [10, 12].

This takes place in Mont Terri, Switzerland. The concept is testing how induced thermo-hydro-mechanical processes in the Opalinus Clay carry out. It also aims to verify how the emplacements techniques function under repository conditions [10, 12].

The demonstration contains construction of an emplacement tunnel, manufacturing bentonite buffer components and test equipment for buffer and waste emplacement, and also performance of the installation process [10, 12].

The Full-scale Emplacement (FE) gallery measures 2.7 m in diameter and with the length of 50 m. In NAGRA´s repository concept, the waste emplacement tunnels will be up to 800 m long [10, 12].

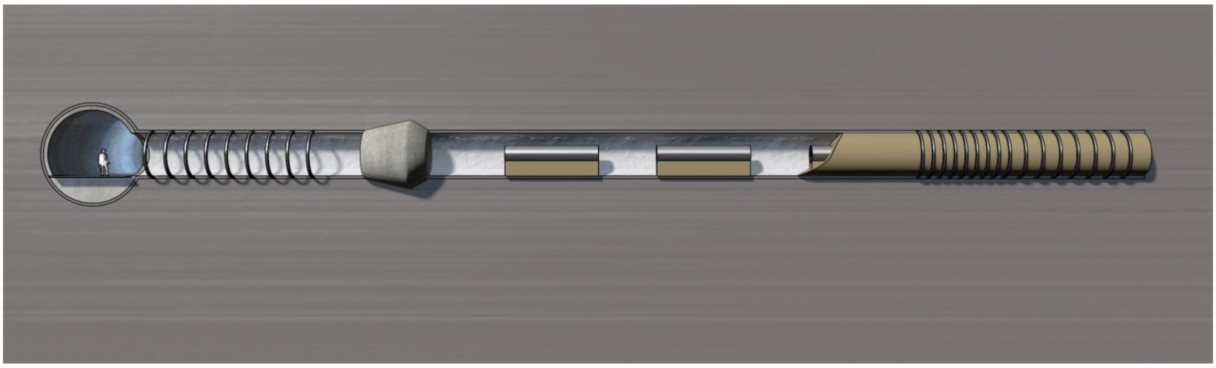

Figure 3: The illustration shows the horizontal disposal in Mont Terri. (www.lucoex.eu)

Both the demonstrators in Callovo-Oxfordian clay and Opalinus Clay aim to investigate the functionality of the repository concepts' core pieces. These are the cell excavation, emplacement techniques and backfilling. Also to explore the thermal heat monitoring effects are mutual in these two concepts [10, 11, 12].

Vertical disposal in crystalline hard rock

The objective with this proof-of-concept is to develop necessary machinery and a quality control programme. The programme includes problem management for the installation of the buffer in vertical deposition in crystalline rock. The reference concept is KBS-3V [10, 13].

The primary activities are to develop the installation technique for vertical bentonite buffer, the tools and methods for this buffer and also the required tools for problem handling if unexpected problems occur during the buffer installation [10, 13].

The demonstration takes place in Onkalo, Finland, which also will host the planned deep geological repository [10, 13].

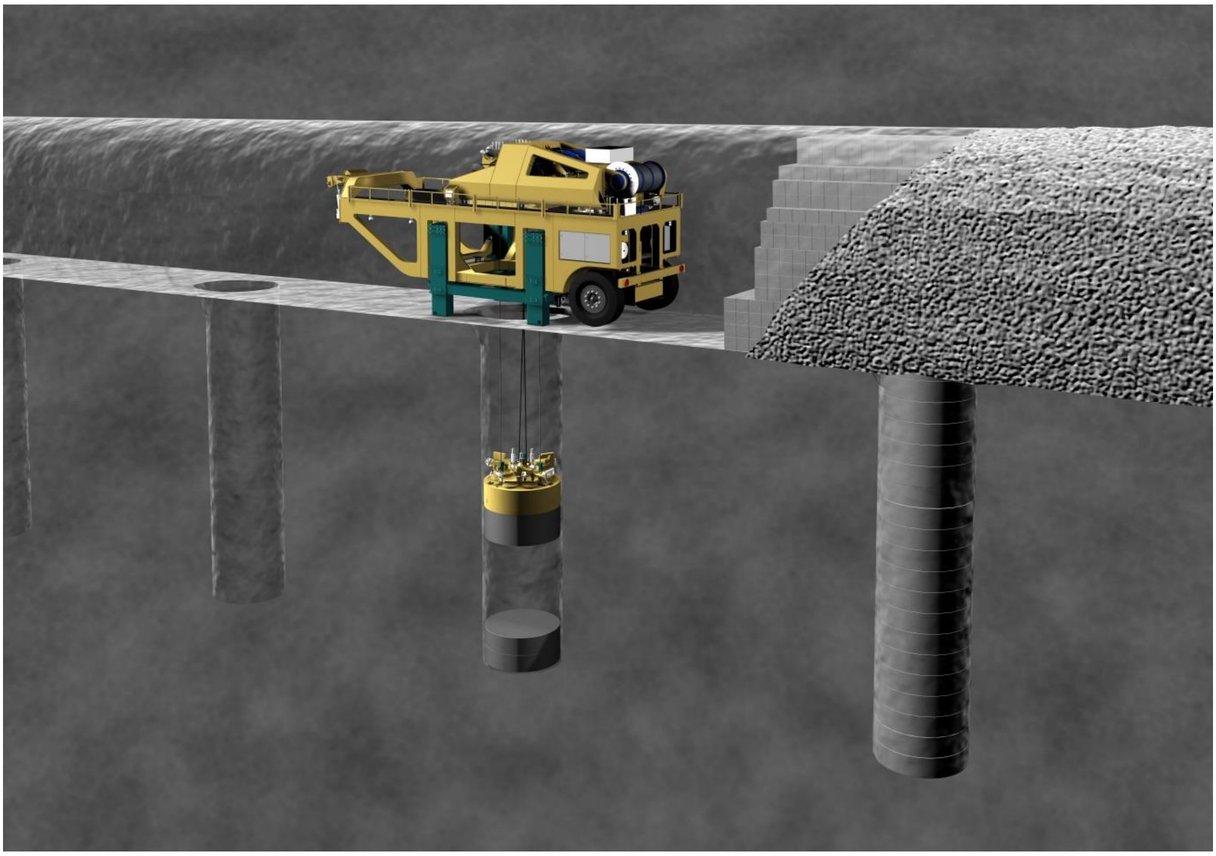

Figure 4. Vertical disposal in crystalline rock (www.lucoex.eu)

The KBS-3 repository concept means that spent fuel is encapsulated in dense canisters which are resistant to corrosion and loadbearing. These canisters are deposited in crystalline rock and several hundred meters underground. The canisters are also surrounded by a buffer. This is to protect the canisters and prohibit the flow of water. The tunnels and openings in the rock that are involved in the disposal will be backfilled and closed [14].

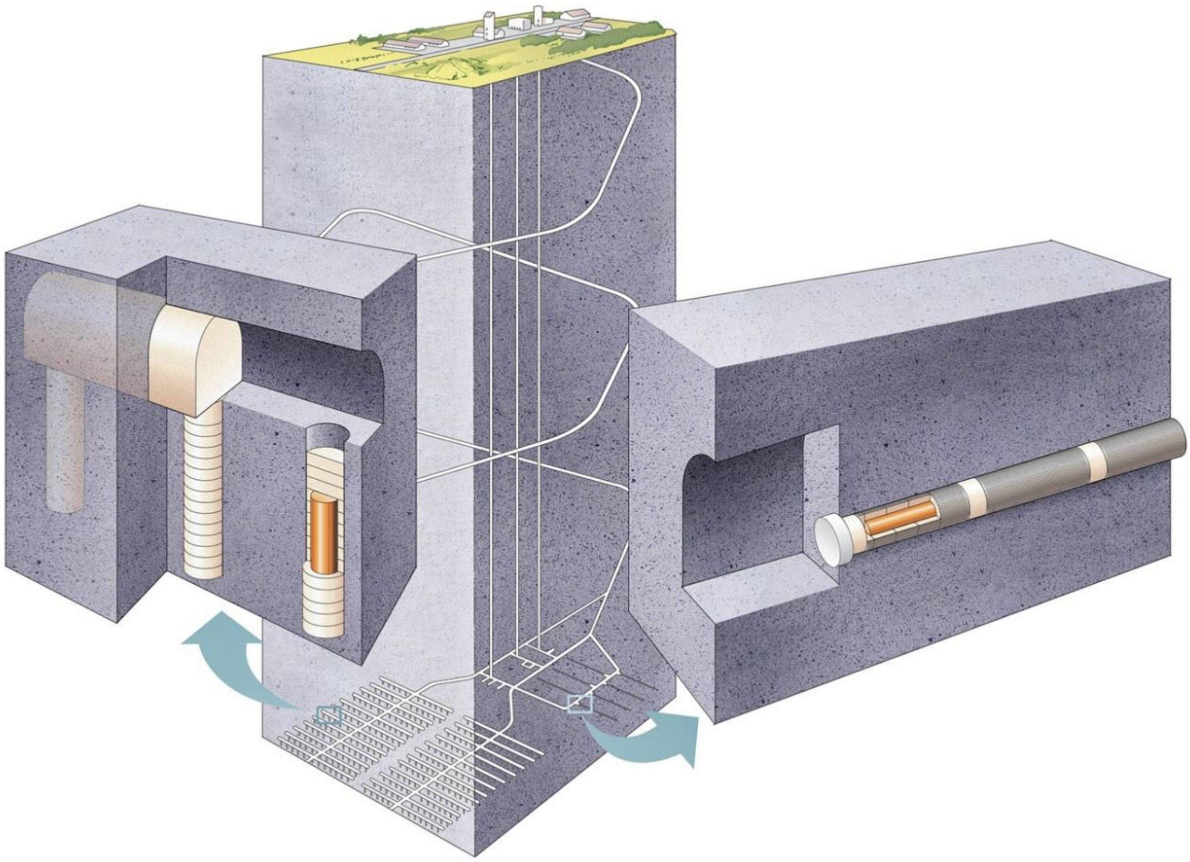

Figure 5. An illustration of the KBS-3 method. The reference design with vertical disposal, KBS-3V, is shown to the left and to the right is the alternative with horizontal disposal, KBS-3H. (www.lucoex.eu)

Horizontal disposal in crystalline hard rock

The objective with this proof-of-concept is to verify horizontal design for the high-level waste repository which is being researched. The test is based on KBS-3V as the reference concept [10, 15].

The name of the test is the Multi-Purpose test and the focus is to do full-scale tests with the system components in combination with each other. This is to verify the design implementation and component function. The main components are the super-container, distance blocks and a plug. It also contains a transition zone with a transition block and pellets. The test takes place in a 95 m long drift with a diameter of 1.85 m at Äspö, Sweden [10, 15].

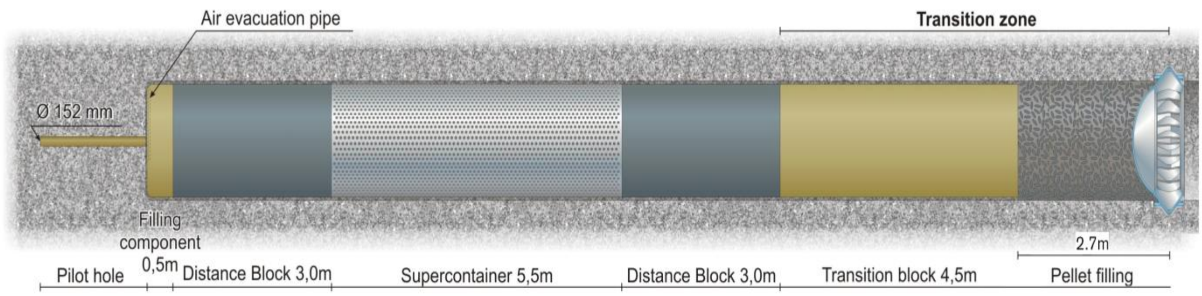

Figure 6. Horizontal disposal in the Multi-Purpose test (www.lucoex.eu)

1.2.6 Radioactive waste and spent fuel management directive

In 2011, the council of the European Union adopted the "Radioactive waste and spent fuel management directive" which requests member states to present national programmes that should include where, when and how they plan to construct and manage final repositories that should guarantee the highest safety standards. This directive was suggested by the European Commission. In 2015, the member states have to submit the first report about the implementation of their national programmes [16].

In the document, there are two statements focusing on the member states national programme:

"National programmes

1. Each Member State shall ensure the implementation of its national programme for the management of spent fuel and radioactive waste ('national programme'), covering all types of spent fuel and radioactive waste under its jurisdiction and all stages of spent fuel and radioactive waste management from generation to disposal.

2. Each Member State shall regularly review and update its national programme, taking into account technical and scientific progress as appropriate as well as recommendations, lessons learned and good practices from peer reviews." [16]

This is a step forward in EU to make all member states urged to invest and work on the implementation and progress on their national programme for the management of spent fuel and radioactive waste.

2 Situation for countries with advanced radioactive waste management programs

In a global perspective, there are several countries that have to manage hazard radioactive waste and spent fuel that they have generated. This concerns 43 countries of which 25 have made decisions that declare that deep geological disposal is the most secure and safest solution for this management. Some of the countries have made great advancement in their radioactive waste and spent fuel management programs. The European Union have several countries with severe progression in their programs. Also countries like Canada have made extensive work in the area of geological disposal and are therefore well ahead in their waste management programs [17].

In this report, focus is on the member states in the European Union plus Switzerland.

2.1 Finland

The company Posiva is responsible for the preparations and the following implementation of disposal of spent fuel in Finland [18].

At the end of 2013, about 1984 tons HM (heavy metal) spent fuel was stored in Finland. The spent fuel is stored in pools at the sites where it have been generated [18].

The construction application for construction of a disposal facility was submitted in 2012. A comprehensive research, development and design programme is ongoing to remain some open issues related to the licensing [18]. The operation license application are planned to be submitted in 2020 and the final disposal are expected to start in 2022 [19].

The reference concept for the deep geological disposal is based on the Swedish KBS-3 system. Finland is currently applying KBS-3V, which means that the canisters are placed vertical in the ground of crystalline rock [18].

Posiva has a substantial collaboration with SKB in Sweden and also with ANDRA in France, DBE in Germany and the Swiss NAGRA [18].

The producers of nuclear waste, TVO and Fortum, are according to the Nuclear Energy Act responsible for implementing the management of nuclear waste which is produced in the Olkiluoto and Loviisa nuclear power plants. They are also responsible for the costs that incurred [20].

In the 1980s, the Finnish Nuclear electricity company TVO started to focus on final disposal of spent nuclear fuel and adapted the concept of KBS-3 [21]. In 2004, an underground rock characterisation facility was started to be constructed and was finished a few years later [22].

Waste management and decommissioning costs are included in the price of the nuclear electricity. Every three years the license-holders pay contributions to a fund so the required security is provided to the state [18].

2.2 France

In 1991, the public agency ANDRA was established. ANDRA is responsible for the long-term management for radioactive waste that is produced in France [23].

In the end of 2010, there was 2700 m^3 high-level waste in France. In 2020, the amount are expected to be 4000 m^3 and in 2030, 5300 m^3 [23]. The high-level waste is today stored at its production site [24].

One of the topics for the research and studies sustainable management of radioactive materials and waste is to investigate reversible disposal in deep geological formations. This includes choosing a site and designing a disposal facility so it will be possible to file in an application in 2015 for an authorization. After this the facility can be in operation by 2025 [23].

Several studies have led to the reversibility concept. This is wider than the retrievability concept since it permits an operational stepwise disposal process which will be determined by a political decision-making process [23].

ANDRA has a research facility in form of an underground research laboratory (URL) in Bure. The aim with this facility is to study the feasibility of reversible geological disposal with respect to high-level and long-lived intermediate-level radioactive waste in Callovo-Oxfordian clay. This was licensed in 1999 and its construction was achieved in 2006. Nearby, a technical exhibition facility was built in 2007. The objective with this is to design and operate prototypes and demonstrators [23].

In 2005, ANDRA states in a report that “in principle, the feasibility of storage in clay formations is now acquired”. However, there can be obstacles since only one site being researched. This because of less flexibility compared to if there were more sites [24].

The responsibility for the financing of the radioactive waste management is held by the operators of the nuclear installations. Additional financing to basic nuclear installations have been added by a Planning Act in 2006. This is to fund the economic development scheme that involves local municipalities in the geological repository for high-level and long-lived intermediate-level radioactive waste project [23, 25].

2.3 Sweden

The Swedish nuclear fuel and waste management Co, SKB, is responsible for management of spent fuel and radioactive waste. This includes the disposal and transport [26].

The estimated amount of spent fuel that will have been produced during the existing nuclear power plants lifetime is about 12000 tons. Today, spent fuel from all Swedish nuclear power plants is stored in a central interim storage in water in storage pools [26].

In 1976, the research project KBS, nuclear fuel safety, was initiated. Seven years later, a report was published which concluded that direct disposal for spent fuel was technical feasible and that geological preconditions existed in Sweden. 1985 the interim storage facility was opened. Between 1992 and 2001, studies were made in a number of areas to investigate the feasibility for hosting a deep geological disposal. In the 1995, the research facility of geological disposal Äspö hard rock laboratory was initiated and three years later a canister laboratory was opened. Year 2002, site investigations were started in two localizations for a geological repository. One of the sites was chosen in 2009 which was Forsmark in Östhammar municipality. The bedrock is crystalline rock. Two years later, SKB submitted a license application in order to construct a disposal facility for spent nuclear fuel [27, 28]. The construction of the geological repository is planned to start 2019 and ready ten years later, year 2029 [29].

The license of a nuclear facility must contribute with a nuclear waste fee. This covers the management and disposal of nuclear waste and spent fuel. A special fee per kilowatt-hour is collected together with the other fees to a nuclear waste fond [30].

3 Radioactive waste management programs in Europe

3.1 Belgium

Belgium's National radioactive waste management organisation is named ONDRAF/NIRAS [31].

Today the spent fuel is stored near the nuclear power plants where it has been generated. The fuel is placed in special facilities where they are stored either in pools, in Tihange, or in dry storage in Doel. A total of 4691 spent fuel elements are being stored [31].

According to the inventory in 2008 and an estimated exploitation time of 40 years, the expected amount of long-lived high-level waste of the scenario of full reprocessing is taken in consideration will end up in 600 m^3. If the scenario will be with non-reprocessing, the amount will rise to 4500 m^3. If the lifetime of the three oldest reactors extends with ten years, the amounts will be 650 m^2 respective 4900 m^2 [32].

In 2003, the Belgium federal parliament decided that a law would declare that the nuclear fission for electricity production will phase-out. The operational period for the existing plants was set to be 40 years [31, 32].

A comprehensive research and development program was started in 1974 to examine the possibility to use Boom clay formations as host rock for geological disposal. This led to the construction of an underground research laboratory in Boom clay layer at the Mol-Dessel area at a depth of 220 m, in 1980 [32]. Several in situ experiments have been taken place at this site. The main areas of research has contained the geology and hydrogeology of the clay, the concept of the deep underground repository's definition, the material of the backfilling, the interaction between the host rock, the engineered barriers and the waste. Also evaluation of disposal techniques for the spent fuel and the safety and performance of the potential repository have been made. During one important experiment, close collaboration has been made with the French ANDRA. The experiment is about lining in the gallery of the future repository [31].

Year 2002, the second Safety Assessment and Feasibility Interim Report (SAFIR 2) was published. It concluded that there is no primal problem that considers the safety and feasibility of high-level waste disposal in Boom clay. In 2007, the underground laboratory was extended to contain a disposal gallery in a representative scale. The main objective with this is to study heat response of the clay. The heating test is expected to start in 2014 [31].

A first safety and feasibility case is under preparation. The aim is to gain confidence of all stakeholders in all phases of implement a geological disposal. This will support the government to begin the siting phase [31].

ONDRAF/NIRAS have created a law that command waste producers to pay the costs that the management of the produced waste requires. A fund exists where the producers pay a fee depending on how much waste they generate [31].

3.2 Bulgaria

The responsibility for the radioactive waste management is held by the State Enterprise Radioactive Wastes (SE-RAW) [33].

In the end of 2010, the spent fuel stored in Bulgaria was 910 tons of HM which was in 6024 fuel assemblies. Spent fuel used to be transported back to Russia. This was made according to contracts that were signed between 1998 and 2002 [34]. The used fuel has been stored in a pool-type storage facility. A dry storage facility was opened in 2011 and will accommodate spent fuel from the units. This allows Bulgaria to store the spent fuel in a long-term if shipping abroad wouldn't be possible [35].

Bulgaria is a member of the European Repository Development Organisation Working Group (ERDO-WG) [36]. One goal with this group is to investigate the feasibility of implementing one or more shared geological repository in Europe [37].

Bulgaria is investigating the possibilities to construct a deep geological disposal. Three interesting regions have been identified and in those, five potential areas have been localized. This has led to six potential geological blocks that can be further explored. The potential host rocks are thick clay mergels or granite [34].

The financing for the radioactive waste management is made by the operators of the nuclear installations which on a regular basis pay fees to funds [4].

3.3 Czech Republic

The Czech government adopted a radioactive waste management policy in 2002. The state organisation Radioactive Waste Repository Authority (RAWRA) is responsible for the development of the deep geological repository for disposal of high-level waste and spent fuel. Before it will be disposed, it will be stored nearby the place where it was generated or in facilities of RAWRA [38].

The current storage facilities are estimated to have enough capacity to store all expected spent fuel which will be produced in Czech Republic's two existing power plants. They will produce around four thousand tons of spent fuel during their lifetime. But plans are also to construct up to three new reactors and then the spent fuel will arise to nine thousand tons and also more storage capacity will be required [39].

The main option for Czech Republic's management is national disposal in a deep geological repository [38]. The start of operation for a deep geological disposal is expected around year 2065 [39].

The reference concept for deep geological disposal is similar to the Swedish and Finnish concept. It is based on disposal using engineered barriers with metal container and bentonite surrounded by a granite host rock. But the concept is not complete yet [39].

In the beginning of 1990, research was made on available geological data and different areas were carried out to be further investigated for the alternative to host a geological repository. A few years later, eight different locations were identified to be possibly suitable. This program also resulted in a reference project. In 1997, RAWRA took over the responsibility of the program. A new site selection study was made with six localisations in granite to be focused on as a result [39].

Czech Republic's management program is now at its first step in the site selection process [38].

The costs for the high-level waste and spent fuel management are provided by regulator instalments which come from the producers of spent fuel depending on how much they produce. This is made through a nuclear fund [38, 39].

3.4 Denmark

Dansk Decommissioning (DD) is responsible for the radioactive waste management [40].

Denmark don't have any nuclear power plant but there are a number of research reactors of which two have been fully decommissioned and one is under decommissioning [41]. The country possesses 233 kg spent uranium fuel which is stored at the facilities for storage of radioactive waste at Danish Decommissioning [42].

Denmark has searched for an international solution for its minimal amount of spent fuel. If this won't be found, the spent fuel will be disposed in a Danish low- and intermediate-level waste repository [42].

The management is financed with government bonds [4].

3.5 Germany

In Germany, the Federal Office for Radiation Protection (BfS) is responsible for radioactive waste disposal [43].

The current waste management policy for heat generating radioactive waste is formed by the modification of the atomic law, which is also known as the nuclear phase-out law, the end of reprocessing spent fuel in other countries and finally the development of disposal concepts and siting process of geological repositories [44].

The spent fuel, which is generated and will be generated in the future, is intermediately stored at the sites where it was generated before a deep geological disposal will be in operation [45]. Around 28000 m^3 conditioned heat-generating radioactive waste are expected to be produced until year 2080 [44].

A conceptual design has been considered for the repository. After several decades of interim storage, the spent fuel will be packed into containers. These will be sealed leak tight and there after disposed in deep geological formations. Prototypes for the facility that can pack the spent fuel in containers that are suitable for this disposal have been built. The goal is that the repository will be in operation around 2035. The disposal of spent fuel reference concept contains taking out the fuel rods from the fuel assemblies, pack the fuel rods casks which is self-shielded and sealed thick walled and finally emplaced in deep geological repository [45].

One site that has been investigated to host a deep geological repository for high-level waste is the Gorleben site, which is a salt dome. In 2013, a law on site selection was adopted. A commission was recently implemented with the aim to structure how the site selection procedure should progress. The proposals will be submitted in the end of 2015 [46]. Gorleben will be included as potential site. In the new site selection, adding to salt also clay and crystalline rock will be considered as options for a geological disposal [47]. The decisions of what site that will be selected for the deep geological repository are expected to be made in 2031 [45].

The financing of the waste managing in Germany is included in the price of electricity. All waste producer finance the preparation and planning of the intended waste disposal [45].

3.6 Hungary

Public Limited Company for Radioactive Waste Management (PURAM) is a company that take response for activities that relates to management and disposal of radioactive nuclear waste in Hungary [48].

The spent nuclear fuel is placed in an interim storage, near to where it has been generated, for at least 50 years. In 2013, 97.7 m^3 high-level waste was stored in the available storage. The amount of spent fuel was 9113 fuel assemblies. Adding the expected amount that will be generated in the future, including decommission, the total high-level waste will be 718.9 m^3 from the nuclear power plants and 17560 fuel assembles of spent fuel [48].

In 1993, an exploration program started to investigate if Boda Claystone was able to be suitable host rock for geological disposal. In 2000, a countrywide geological screening program was started to find a suitable host rock for a deep geological repository. The result of the program was that the Boda Claystone was the most suitable host rock [48].

Year 2015, the high-level waste conceptual design will start to be reviewed. Three years later, an underground research laboratory license application will be made and the URL is planned to be constructed in 2030. In 2055, an underground repository will be constructed and be ready for disposal nine years later [48].

Hungary has a central nuclear financial fund which is a state fund that finances the construction of the facilities for disposal of radioactive waste and spent fuel. The fund is financed by the nuclear power plants and also other institutes that generate radioactive waste in associated facilities. The government contributes also to the fund [49].

3.7 Italy

Sogin is a State company in Italy which is in charge of the safe management of radioactive waste [50].

In Italy there is a total of 1.700 m^3 intermediate and high-level waste. 20 m^3 reprocessed spent fuel will be returned from UK and about the same amount from France [51]. The spent fuel is currently stored at pool storage at one of the nuclear power plants, at a special pool storage facility and at one of the reprocessing facilities [52].

Italy has since the beginning of its nuclear programme had the option of reprocess the spent fuel abroad. However, when the political decision was made to stop all nuclear power activities, also the shipments abroad for reprocessing was adjourned. But in 2006, an agreement was signed between Italy and France which declared that the present spent fuel would be transferred to France [51].

Italy is a member of the ERDO-WG. One goal with this group is to investigate the feasibility of implementing one or more shared geological repository in Europe [36, 37].

The radioactive waste management is financed from the funds which are allocated for the decommissioning of nuclear installations [51].

3.8 Lithuania

The Radioactive Waste Management Agency (RATA) is responsible for the management and radioactive waste disposal from the country's nuclear power plant [53].

Some used fuel is being stored on the nuclear power plant site in storage pools or in a dry storage facility. The amount of spent fuel that is expected to be disposed in a geological disposal is 2510 tons of uranium and 8612 m^3 of other radioactive waste [54].

Initial studies on the possibility to establish a geological repository have been made. What option that will be used is mostly a political decision. The studies have showed that crystalline rock or clay is possible media to host the repository [54]. Some studies have been performed in corporation with Swedish experts between the year 2002 and 2005. If the host rock will be crystalline rock Lithuania has adapted the repository concept developed in Sweden, KBS-3 [55].

The site selection process will start in 2030 if no new technologies have occurred and the international practise is unmodified [35]. Lithuania is a member of ERDO-WG [36].

Financing the radioactive waste management is made from different sources. These are state budget and decommissioning funds [54].

3.9 The Netherlands

The Central Organisation for Radioactive Waste (COVRA) is responsible for the management of radioactive waste [56].

At the moment, spent fuel from the Netherlands nuclear power plants is being reprocessed. The existing radioactive waste will be stored above ground for at least a hundred years. One reason is to gain enough waste before a deep geological disposal could be sufficient economical. Another option is to share a repository with another country [56]. The Netherlands are a member of ERDO-WG [4].

Interim storage of reprocess spent fuel is made in a bunker at a COVRA-facility [35]. In 2010, 52 m^3 high-level waste was stored in the Netherlands [56].

Currently, a research program on the final disposal of radioactive waste is undergoing. In the past, the option of salt as a host rock has been well investigated. Now most focus will be on examining Boom clay, which can favor cooperation with Belgium [57].

The users of the interim storage for high-level waste and spent fuel have financed its construction according to how much waste storage they have reserved. Also the operational cost is paid by the users [4].

3.10 Poland

The responsibility for the radioactive waste management in Poland is assigned to the Radioactive Waste Management Plant (RWMP) [58].

For the spent fuel from the research reactors, Poland implemented Russian Research Reactor Fuel Return program (RRRFR). All of the high enrichment spent fuel from the former Ewa reactor and a majority of the spent fuel from the active Maria reactor has been shipped back to the country of origin. Also the additional spent fuel that will be produced is expected to be transported back to the Russian Federation. There is no commercial use of nuclear power in Poland today, but the first nuclear power plant is expected to be operational in year 2020 [58].

The Rozan site is the only repository for all radioactive waste I Poland. It is located in a former military fort and will be completely filled by 2020 [58]. In 2007, there was 200 kg of spent fuel in storage [4].

Poland is a member of the ERDO-WG. One goal with this group is to investigate the feasibility of implementing one or more shared geological repository in Europe [36, 37].

In the end of the nighties, a strategic governmental program was established to cover the aspects of radioactive waste management in the country. The localization for a new underground repository for high-level waste and spent fuel was studied. Several places were considered as suitable for the deposition. This included different types of rocks, salt deposits and clay formations. Today, there are no ongoing projects concerning the localization [58].

The financing for the radioactive management is available with state budgets through the budgets of Ministry of Economy and the National Atomic Energy Agency (NAEA). Also service activities from RWMP generate incomes [58].

3.11 Romania

National Agency for Radioactive Waste (ANDRAD) is an authority which coordinates safe management of spent nuclear fuel and radioactive waste [59].

The spent fuel is stored at a dry storage facility after being stored at the nuclear power plant a few years [60]. In the end of 2007, 131 tons of spent fuel was stored in Romania [4].

The possibilities for a deep geological repository have been investigated since 1992. Six potential geological formations have been identified [60]. The most appropriate formations are likely to be granites, green schist, salt, basalt, clay and volcanic tuff so these will be further studied. Cooperation to study the green schist has been made with the Swiss NAGRA [61]. The research is though in a very preliminary stage. Romania estimates that a geological repository can be available in the year 2055 [35, 59].

Romania has a very small nuclear energy program so if the country will construct a geological repository the cost will be proportionally very high. That's why Romania considers that disposal in an international repository would be a better solution [35]. Romania is a member of ERDO-WG [36].

The financing for the disposal of radioactive waste and spent fuel is made through a fee on the produced electricity per kWh. This is collected to a fund [4].

3.12 Slovakia

In Slovakia, JAVYS - Nuclear and Decommissioning Company are responsible for the safety of spent fuel and radioactive waste management [62].

Spent fuel is interim stored at a facility in pools. In 2010, there were 9959 fuel assemblies stored in Slovakia [63].

In 1996, Slovakia started a program for deep geological disposal. A number of localities where identified for further investigation, two in sedimentary rocks and three in granitite rocks. This program was stopped in 2001. 2008 a new strategy was outlined where the two preferred options would be either an international solution, like export or participate in an international repository, or keep the spent fuel interim stored for a non-specified time [63]. Slovakia is participating in ERDO-WG [4]. The option for a national geological repository still remains though. The next step in this process is focusing on review the past work about site investigations in order to reduce the number of proposed localities and after that undergo further studies [64].

For the financing of the radioactive waste management, there is a fund to where the producers of electricity pay a levy for the amount of sold electricity, and other contributions [63].

3.13 Slovenia

In accordance with the bilateral Slovenian-Croatian agreement on the Krško Nuclear Power Plant (NPP), the decommissioning and management of radioactive waste and spent fuel from Krško NPP is a shared responsibility between Slovenia and Croatia. This was made in 2003 [65].

The Agency for Radwaste Management (ARAO) is an organisation of the Slovenia government which handle the spent fuel and radioactive waste management [66].

The spent fuel from Krško NPP is stored in the site's spent fuel pool. In the end of 2012, 1041 fuel assemblies were stored there [66].

The planned scenario for disposal of spent fuel is following the Swedish KBS-3V concept. This consist disposal in hard rock environment at 500 m depth [67]. Also hard clays have been identified as a potentially suitable geological formation for the disposal [68].

Year 1996, the Slovenian government implemented a strategy for long-time spent fuel management. In 2004, Slovenia and Croatia approved the Programme for decommissioning of the Krško NPP and disposal of LILW and high-level waste. Here they used the Swedish concept of geological disposal as a guideline. Spent fuel will be moved to dry storage between year 2024 and 2030 and will thereafter be stored to 2065 when the deep geological repository are expected to be to be ready. The repository will operate to year 2070 and closed five years later. Also the option of export the spent fuel to another country for disposal has been considered [69]. Slovenia is a member of the ERDO-WG [36].

The financing for the spent fuel and radioactive waste management is assured trough a fund. A fee is paid for every kWh delivered by Krško NPP. Also Croatia contributes with an adequate fund [67].

3.13.1 Croatia

At the moment, there are no nuclear facilities in Croatia. A national utility in Croatia is a co-owner with a half share of a nuclear power plant that is placed in Slovenia. Croatia and Slovenia have the shared responsibility for the waste management for this nuclear power plant [70].

3.14 Spain

The radioactive waste management in Spain are a competence of the government. The body which is responsible for the radioactive waste management activities is Empresa Nacional de Residuos Radiactivos (ENRESA) [71].

Most of the spent fuel which is generated in Spain is stored on the site of the nuclear power plant, from which it's produced. It's there stored in storage pools and sometimes in dry storage systems. The total amount of high-level waste, including spent fuel, to be managed during the present nuclear power plants lifetime will rise to 6,700 tons [71].

Spain has been working with deep geological disposal as an option since 1985. The work has been divided in four basic areas. One is about the site selection plan. This has provided enough information to ensure that the required abundance of granite and clay to host a disposal installation exist. Another area is the performance of the conceptual designs in order to create a definitive disposal facility in these lithologies. Also performance of safety assessment with respect to these conceptual designs is one area. The last area is the research and development plans. This area have been evolved and adapted to the waste management program with respect to spent fuel and high-level waste [71].

Some of the ongoing work is focused on consolidation on generic design for the host rocks and the safety assessments are being revised and updated [71].

The financing for the radioactive waste management is done through a fee on the electricity bills which is paid to a fund for this purpose [71].

3.15 Switzerland

The federal government and the operators of nuclear power plant have implemented the National Co-operative for the Disposal of Radioactive Waste (NAGRA). NAGRA is responsible for carrying out permanent and safe disposal of radioactive waste [72].

Each nuclear power plant has an interim storage facility where its produced radioactive waste is stored. The radioactive waste that has been returned for being reprocessed from abroad are stored at a central storage facility [72]. With an operation time of 50 years for the existing nuclear power plants, the expected amount of high-level waste and spent fuel that will require deep geological disposal will be around 7300 m^3 [73].

Until 2006, Switzerland sent spent fuel for reprocessing to France and United Kingdom. The shipment is now prohibited because of a moratorium to the year 2016 [72].

For geological disposal of high-level waste, crystalline basement early became a prior option for host rock. 1979 an application for construction of a rock laboratory in this formation was submitted and 1984 the operation started [72].

In 2008, a new site selection process was started. It has three stages [74]. The first step identified three potential areas for high-level waste disposal and all of them were with Opalinus Clay as host rock [72]. The second stage is now undergoing and consists of concretising the different project and compering the identified areas to find the most suitable. The key focus is on safety. The last stage involves the licensing of the high-level repository and is expected in about ten years [75].

A repository for high-level waste is expected to be ready around year 2050 [76].

The producers of radioactive waste are responsible to finance the costs of the management of their waste. There is also a fund, disposal fund for nuclear power plants, to which the nuclear power plants pay trough contributions [72].

3.16 United Kingdom

The authority responsible for the nuclear sector is Nuclear Decommissioning Authority (NDA). They are responsible for implementing geological disposal for high-level waste and radioactive waste management solutions [77].

Spent fuel and high-level waste are stored at the site where it has been produced [78]. In 2013, there was 1770 m^3 of high-level waste in UK. After it has been conditioned, the volume is expected to be around 700 m^3 less [79].

The United Kingdom government have initiated a waste managing radioactive safely programme to find a solution for the high-level waste in the country. In 2008, the white paper “Managing radioactive waste safely – a framework for implementing geological disposal” was published. This was a start for a site selection process but this ended after five years. Instead, a renewed white paper was published in July 2014 by the government. This sets out a process for the siting of a geological disposal facility for high-level waste. In the process, clay, granite and salt are included as options as host rock for a geological disposal. The siting of a geological disposal is based on how willing the local communities are to participate in the process [78].

The reference conceptual design is based on the Swedish KBS-3V design. This means that the fuel assemblies will be inserted into a robust disposal canister and thereafter emplaced in deposition holes and backfilled with bentonite [80].

The producer and owners of radioactive waste are responsible for the costs of management and disposal of their own waste [81].

4 Results and conclusions

All of the countries have some kind of authority or organisation that is responsible for the radioactive waste management. They have also developed a program for this waste management.

Everyone has made a waste inventory. Some of the countries have also made estimates of how much waste that will be produced from the currently existing nuclear facilities.

Most of the countries have made some form of inventory of the geology to find a suitable host rock for deep geological repository. In Denmark, Italy and Croatia, there haven't been any concluded suitable host rock yet. The different options are presented in figure 7 and table 1.

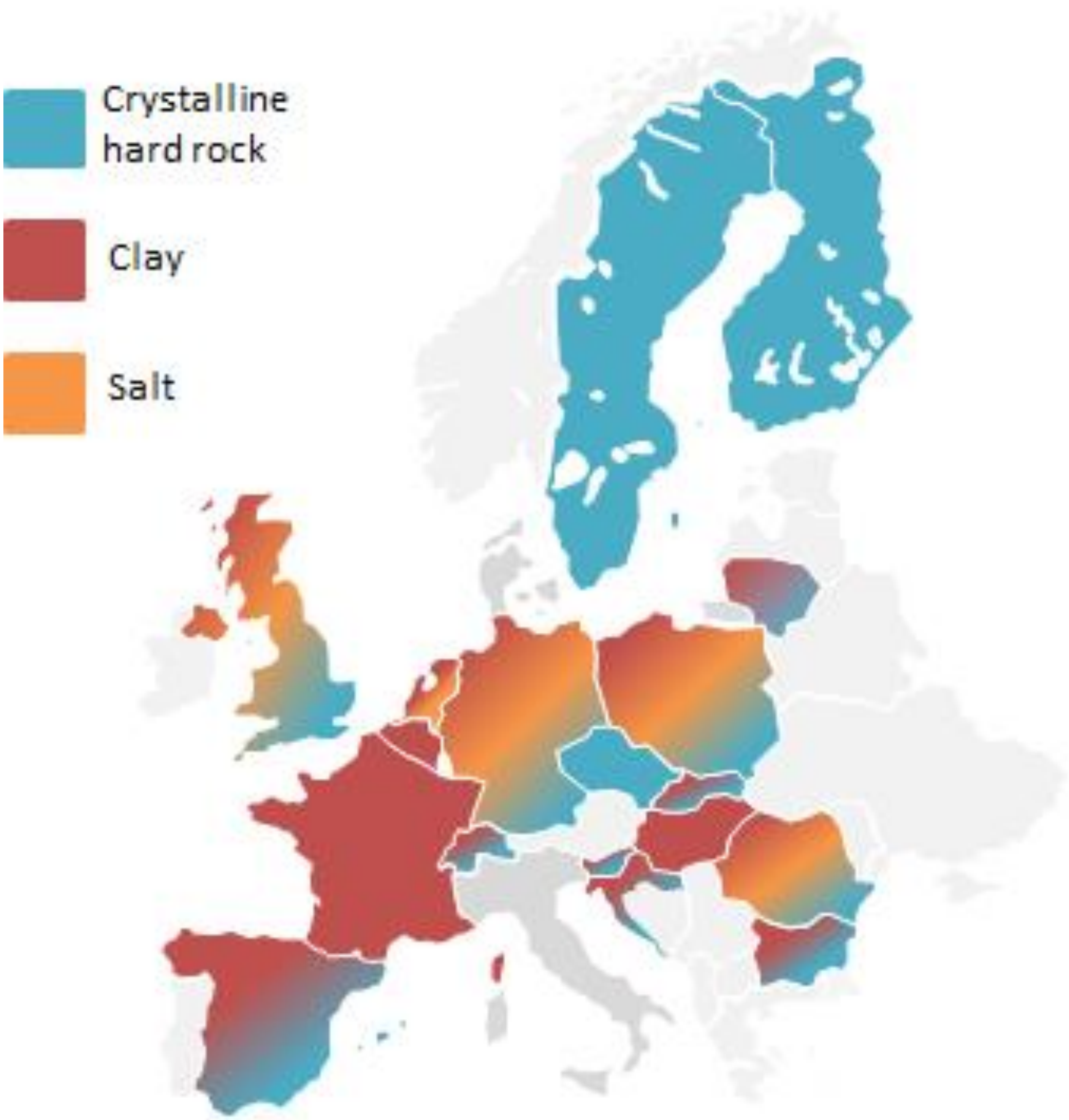

Figure 7

Table 1

Country	Geological inventory for deep geological repository
Belgium	Clay
Bulgaria	Clay, Crystalline rock
Croatia	
Denmark	
Czech Republic	Crystalline rock
Finland	Crystalline rock
France	Clay
Germany	Clay, Crystalline rock, Salt
Hungary	Clay
Italy	
Lithuania	Clay, Crystalline rock
The Netherlands	Clay, Salt
Poland	Clay, Crystalline rock, Salt
Romania	Clay, Crystalline rock, Salt
Slovakia	Clay, Crystalline rock
Slovenia	Clay, Crystalline rock
Spain	Clay, Crystalline rock
Sweden	Crystalline rock
Switzerland	Clay, Crystalline rock
United Kingdom	Clay, Crystalline rock, Salt

Some of the countries have started to develop a reference design for the deep geological repository. Of these, United Kingdom, Lithuania, Slovenia and Czech Republic have in some way considered the KBS3-3 or/and KBS-3V, which is one of the reference designs used in LUCOEX project, as an option.

Some of the countries have been in collaboration with the participated organisations of the LUCOEX project. The French ANDRA has been involved in one of Belgium's experiment of its future repository. Romania has collaborated with the Swiss NAGRA in investigation of the country's host rock.

A number of countries have set a planned year for when the repository will be constructed and in operation. They are presented in table 2.

Table 2

Country	Year for start of operation of deep geological repository
Belgium	
Bulgaria	
Croatia	
Denmark	
Czech Republic	2065
Finland	2022
France	2025
Germany	2035
Hungary	2064
Italy	
Lithuania	
The Netherlands	
Poland	
Romania	2055
Slovakia	
Slovenia	2065
Spain	
Sweden	2029
Switzerland	2050
United Kingdom	

Some of the countries declare that they prefer an international solution for the geological disposal. The main reason is that the countries possess too little waste so a national repository won't be economical enough. These countries are: Bulgaria, Denmark, Italy, Lithuania, The Netherlands, Slovakia, Romania, Slovenia and Croatia.

In terms of financing the radioactive waste management, a number of countries make the producers contribute to the financing through a fee depending on how much electricity they deliver or in other criteria's. This includes all of the countries except from Denmark, Lithuania and Poland.

The countries with the most advanced radioactive waste management programs, with respect to high-level waste and spent fuel, are Finland, Sweden and France which also are three of the participated countries in the LUCOEX project. They all plan to have a deep geological repository constructed before year 2030.

Denmark's and Italy's radioactive waste management programs, with respect to high-level waste and spent fuel, are not very advanced since they haven't concluded any suitable host rock for deep geological disposal. Neither have Croatia but Croatia have shared responsibility of the waste management with Slovenia and Slovenia has declared some options for appropriate host rock. Slovenia is in a very early step in its waste program though and so are the situation for Poland and Romania. Likewise are Bulgaria, Lithuania and the Netherlands in a primary stage in their program but a little more extensive studies have been made in these countries. Spain is also in a primary stage but has made some more work with the disposal questions. A bit more advanced is Slovakia which has made more extensive site investigations. Hungary is a little further since the country is about to review the high-level waste conceptual design and send in an application for construction of an URL in a few years. Next is United Kingdom, which have made a lot of work in the past, but are now about to do over the site selection process. Similar is Germany which also is going to redo some processes for the site selection. A bit further is Czech Republic, which has started its siting process. Also a good way ahead is Belgium which is about to begin the siting phase. The most advanced program of the less-advanced programmes in this report is Switzerland. In a few years one site for deep geological disposal will be selected and then a repository will be ready around 2050.

In figure 8, an overview of how for the member states have come in their radioactive waste program, is shown.

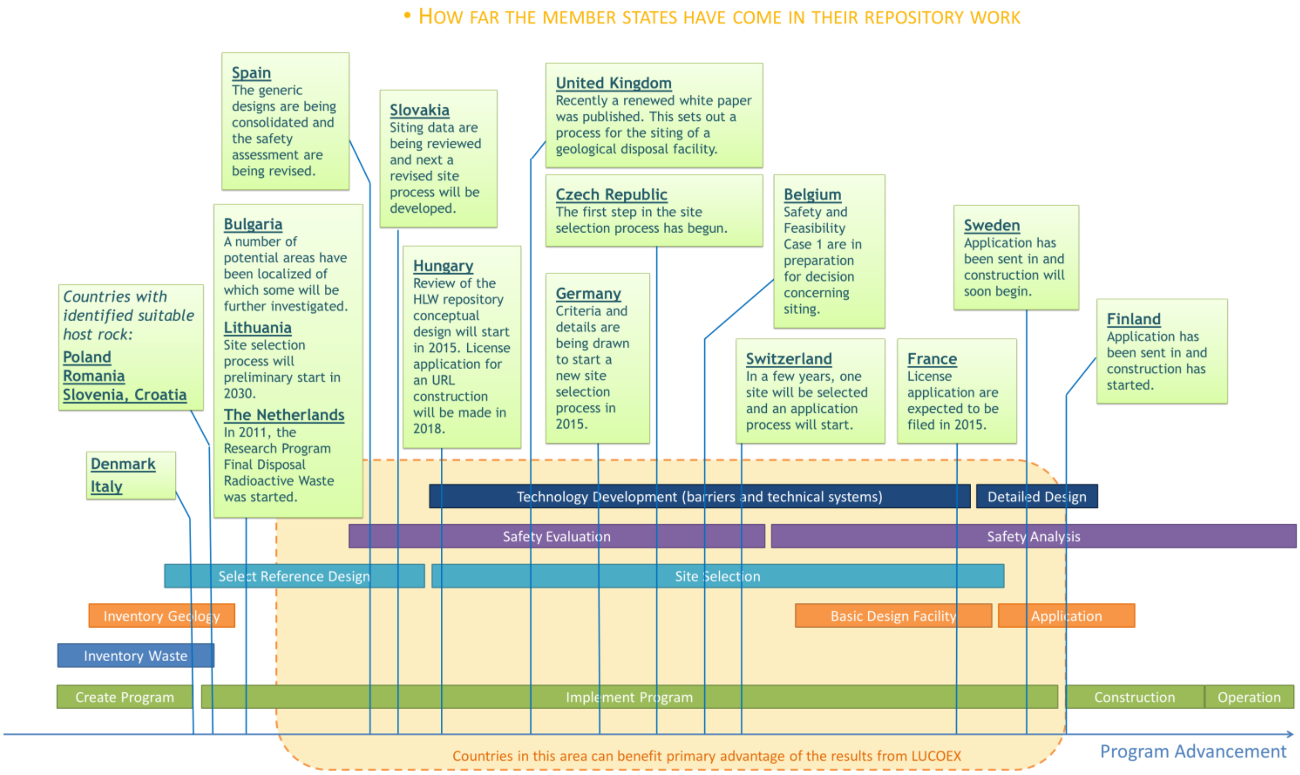

Figure 8

According to how advanced the radioactive waste management programs are for the countries, with respect to high-level waste and spent fuel, statements can be made of how well the country can utilize results from the LUCOEX project in their repository work. Since the LUCOEX project is focusing on studies on a relatively advanced level for the repository work, countries with too less advanced programs aren't current in the stage where those topics are relevant at the moment. Therefore, Denmark, Italy, Slovenia and Croatia, Poland, Romania, Bulgaria, Lithuania and The Netherlands are not now at a phase where LUCOEX findings are primarily relevant. On the other hand, the findings from LUCOEX can help to direct the less-advanced countries to get information of which concept to aim for. This is convenient if they have made a waste inventory and have concluded clay or crystalline as a potential host rock. This can be very useful for the countries to get guidelines to how they should structure their preparatory work in terms of design and long-term safety analysis so they can apply one of the concepts in the future.

The other countries though, which have a bit more advanced programs, it's more possible that LUCOEX results can be useful and all of them have either clay or crystalline rock as a possible host rock for the geological disposal.

4.1 Conclusion

All of the countries have made a nuclear waste and spent fuel inventory.

Belgium, Bulgaria, France, Germany, Hungary, Lithuania, the Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and United Kingdom consider clay as an option for suitable host rock for deep geological disposal.

Bulgaria, Czech Republic, Finland, Germany, Lithuania, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland and United Kingdom consider crystalline rock as an option for suitable host rock for deep geological disposal.

The countries that have made significant progress in their radioactive waste management programs, and therefore are in a position where results from the LUCOEX project can be utilized in a perspicuous future are Spain, Slovakia, Hungary, United Kingdom, Germany, Czech Republic and Belgium. This also concerns the participant countries of LUCOEX; Switzerland, France, Sweden and Finland.

Bulgaria, Lithuania, Poland, Romania, the Netherlands, Slovenia and Croatia can utilize the results from the LUCOEX project to get information of one concept to aim for in the future.

5 Discussion

All of the countries have made a waste inventory to gain information of how much high-level waste and spent fuel that will require future geological disposal. The amounts differ a lot between the member states. Some of the member states don't possess any of this waste or spent fuel at all or have very little like the Netherlands with 52 m^3. Compared to France with 2700 m^3 of high-level waste it's understandable that not all member state find it economical supportably to construct a national deep geological repository as against countries with a larger amount of waste. A number of the countries therefore seek the solution for a shared internationally repository. This is not an option with today's practice and plans but if the concept would change this would lead to a situation with both pros and cons. The question of which country or countries that would host the repository will probably be a difficult task. Also how the economic situation would be solved, and how the country that hosts the repository should be funded, are controversial questions.

In the LUCOEX project two concepts are tested in clay and two concepts in crystalline rock. Almost all of the member states have one of these as options in their current or upcoming site selection process. This means that potentially all of these countries can have use of the outcome of the results from the LUCOEX experiments in the aspect of parts relating to the host rock interaction. Some of the countries consider salt as an option so if they decide to use this then they won't have the same advantage.

Some of the countries have considered KBS-3 in their past or current conceptual design of the disposal of spent fuel and high-level waste. Since KBS-3V is one of the reference concepts in the LUCOEX project, findings from LUCOEX might be useful for the countries if they select to use the KBS-3 as their design. Also a horizontal disposal of the KBS-3, the KBS-3H, is investigated in LUCOEX. If this turn out to be successful also these results can be utilized by the current countries.

All of the countries have a well incorporated financing of the radioactive waste management. Many of the countries have a system where the operator of a nuclear facility pays a fee to fund the waste management organisation. In this way, the producers of the waste make the capital grow in rate with how much waste that has to be managed. This can also play a role in how much finance that is available for investments in the geological disposal work. This can be a reason to that most countries with significant amounts of high-level waste and spent fuel are ahead in the implementation work.

The countries have made different progress in how far they have come in their radioactive waste management program towards deep geological disposal. Their advancements are in some cases difficult to estimate. For example United Kingdom has made extensive studies of the site selection but has recently decided to start over with the process. Also if the country has set a planned year for when the repository should be operational can be misleading. One example is Slovenia which have planned the repository to be ready in 2065, but is in a very early stage in their program, compared to countries where more work on their program have been made, but they haven't declared a planned year yet. Therefore, an overall picture is needed to get an understanding of the situation.

To answer the main objective of this report, if any country with less-advanced radioactive waste management program can utilize the results from the LUCOEX project, it's most likely that in principle all of the countries could in some way. Even though the results cannot be used at the current phase, the situation in the future may be different. Some of the countries prefer to send their radioactive waste and spent fuel abroad and if the possibility occurs; the host repository might be able to utilize findings from LUCOEX project.

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