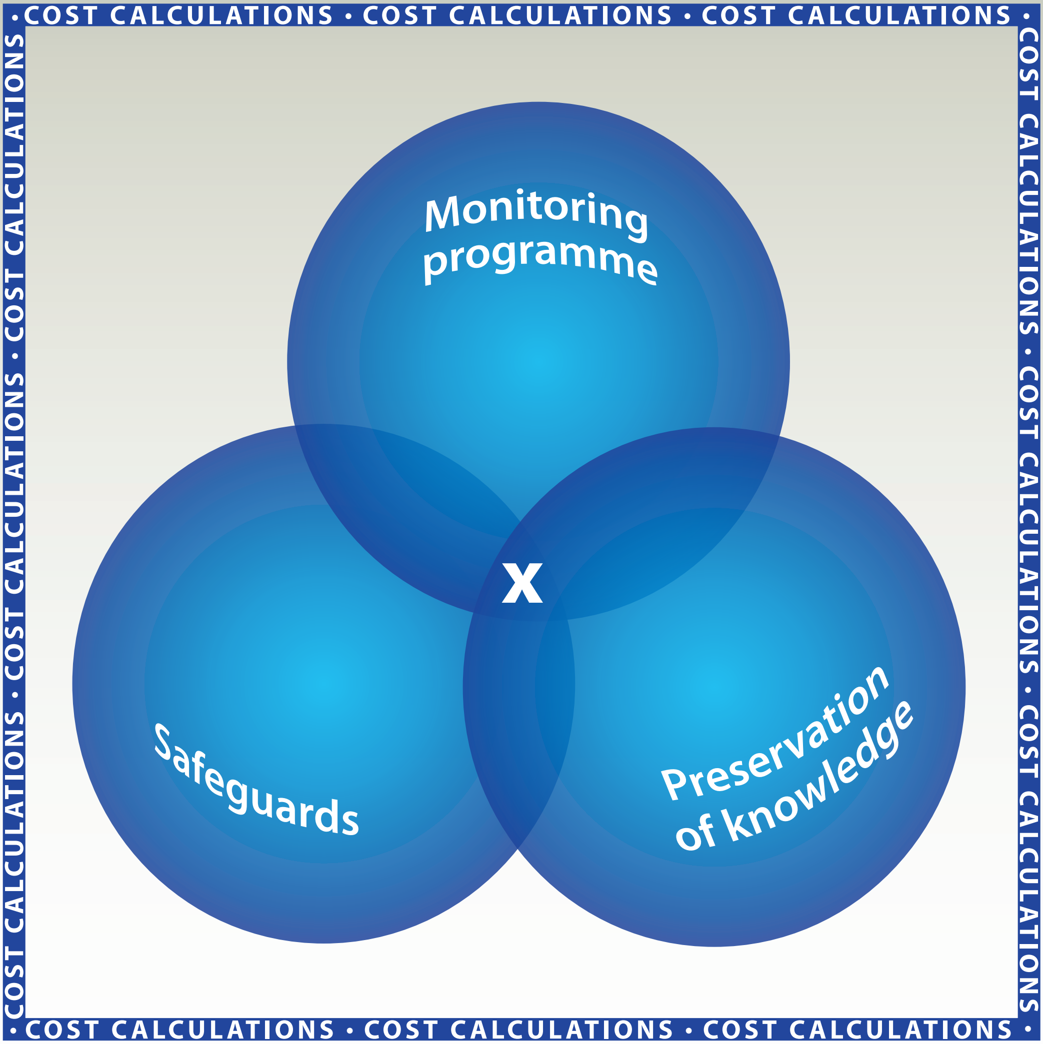


Nuclear Waste State-of-the-Art Report 2015

Safeguards, record-keeping and financing for increased safety

Report from the Swedish National Council for Nuclear Waste

KÄRNAVFALLSRÅDET
Swedish National Council for Nuclear Waste

SWEDISH GOVERNMENT INQUIRIES

SOU 2015:11

Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety

Translation of SOU 2015:11

The Swedish National Council for Nuclear Waste

Stockholm 2015

SWEDISH GOVERNMENT INQUIRIES

Swedish Government Official Reports

SOU 2015:11

This report is on sale in Stockholm at Fritzes Customer Service, which sells reports in the series Swedish Government Official Reports (SOU) and in the Ministry Publications Series (Ds). Fritzes Customer Service also distributes these reports on behalf of the Office for Administrative Affairs at the Government Offices when they are circulated for formal consultation.

Address:
Fritzes Customer Service
SE- 106 47 Stockholm, Sweden
Telefax orders: +46 8-598 191 91
Telephone orders: +46 8-598 191 90
Email orders: order.fritzes@nj.se
Online orders: www.fritzes.se

Text processing and layout: Government Offices of Sweden, Office for Administrative Affairs/Committee Service Unit

Cover: Jonas Nilsson, Miljöinformation AB.

Translated into English by Richard Nord Translation.

Printed by Elanders Sverige AB
Stockholm 2015

ISBN 978-91-38-24288-9
ISSN 0375-250X

To the minister and head of the Ministry of the Environment and Energy

The Swedish National Council for Nuclear Waste is an independent scientific committee whose mission is to advise the Government on matters relating to nuclear waste and decommissioning of nuclear facilities. In February each year, the Council publishes its independent assessment of the current state of the art in the nuclear waste field. The assessment is presented in the form of a state-of-the-art report. The purpose of the report is to call attention to and describe issues which the Council considers important and to present the Council's viewpoints on these issues.

The Swedish National Council for Nuclear Waste hereby submits to the Government this year's state-of-the-art report (the fifteenth in this series) entitled *Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety*.

English versions of the reports on the state-of-the-art in the nuclear waste field for 1998, 2001, 2004, 2007, 2010, 2011, 2012, 2013 and 2014 are also available.

Stockholm, 23 February 2015

Carl Reinhold Bråkenhielm, Chairperson acting	Anna Sanell, Administrative Director

Members of the Board

Carl Reinhold Bråkenhielm (Chairperson), Professor Emeritus of Empirical Life Philosophy Studies at Uppsala University

Karin Högdahl (Deputy Chairperson), Associate Professor, Geology, Uppsala University

Lena Andersson-Skog, Professor, Economic History, Umeå University

Sophie Grape, Researcher at the Department of Applied Nuclear Physics, Uppsala University

Mats Harms-Ringdahl, Professor, Radiation Biology, Stockholm University

Tuija Hilding-Rydevik, Professor, Land and Water Resources specializing in EIA, Swedish University of Agricultural Sciences, Director of Swedish Biodiversity Centre

Lennart Johansson, Associate Professor, Radiophysics, Norrland University Hospital

Thomas Kaiserfeld, Professor of History of Ideas and Sciences, Lund University

Mikael Karlsson, Researcher in Environmental Sciences at the Royal Institute of Technology

Jenny Palm, Professor of Technology and Social Change, Linköping University

Experts

Hannu Hänninen, Professor of Mechanical Engineering, Aalto University

Ingvar Persson, former General Counsel at the Swedish Nuclear Power Inspectorate

Secretariat

Anna Sanell, acting administrative director

Holmfridur Bjarnadottir, administrative director

Peter Andersson, administrative officer
Johanna Swedin, assistant administrative officer

Contents

1 The Swedish National Council for Nuclear Waste and national situation description

1.1 Introduction

The Swedish National Council for Nuclear Waste would like to express its heartfelt gratitude to members Willis Forsling and Clas-Otto Wene, whose appointments expired in 2014. For many years they have contributed valuable knowledge and insights to the work of the Swedish National Council for Nuclear Waste. The Council has already had the pleasure of engaging their services as independent consultants in this state-of-the-art report, since they have previously raised important questions that need to be further investigated.

The process for the Swedish Nuclear Fuel and Waste Management AB's (SKB) application to build and operate the Spent Fuel Repository (the final repository for spent nuclear fuel) is under way, and the Government will make the final decision on the permissibility of the activity under the Environmental Code and a licence under the Nuclear Activities Act.

In the opinion of the Council, there are more aspects to consider than merely the development of the technology for building a final repository for spent nuclear fuel. Nor should the societal issues be studied in isolation. What is interesting is the interaction between these aspects. The links between man, technology and organization (MTO, human factors) need to be investigated.[1]

[1] Also referred to as HTO, Human-Technology-Organization.

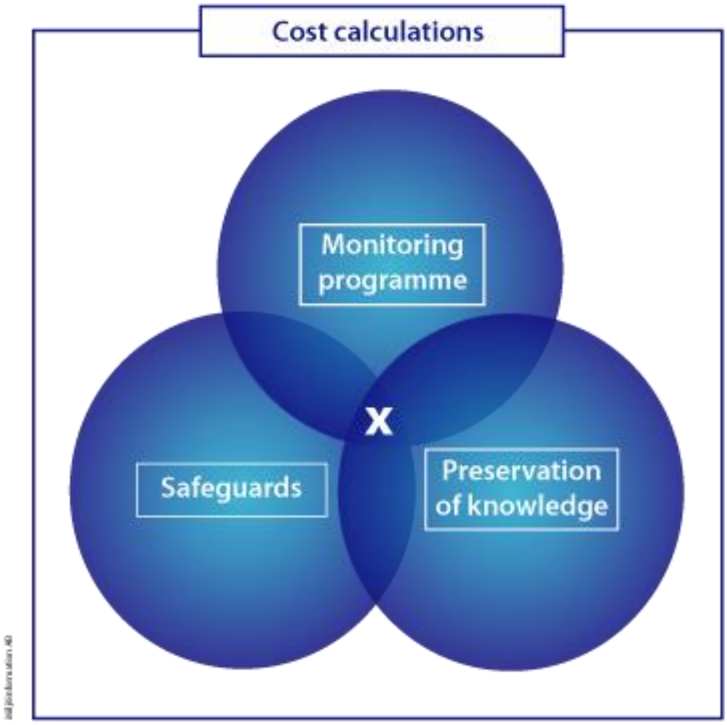
Content of this year's state-of-the-art report

The Council has already, on repeated occasions, called for social science research on the nuclear waste issue. Two chapters in this state-of-the-art report examine topics from a broader perspective. These are Chapter 4, which discusses how information on nuclear waste repositories should be passed on to future generations, and Chapter 5 about the project International Socio-Technical Challenges for Implementing Geological Disposal (InSOTEC).

The Council's mission includes following developments in other countries. The State-of-the-Art Report 2012 described the current situation for final disposal of nuclear waste in Finland, France, Germany, Switzerland and the USA. This year's report includes a follow-up of the situation in these countries. Denmark has been included because they have referred a report on final disposal of low- and intermediate-level waste to Sweden for consideration and commentary.

The topics in this report all have a point of intersection, X, at the same time as they address and describe different problem areas in a manner that can be illustrated with the aid of the following diagram, which is also featured on the cover of the report.

Figure 1.1



The cost calculation is a precondition for the final disposal project and thereby sets constraints on the other parts.

Under the topic of safeguards, the report examines technical, financial, organizational, political and ethical issues. The topic of safeguards also impinges on subjects such as supervision, monitoring and inspection of conditions in the final repository during operation and after closure; post-closure aspects include the question of monitoring programmes. The topic of safeguards also bears on record-keeping and preservation of information and knowledge, since it is based on a thorough account of the number and content of the nuclear fuel assemblies as well as of the design of the final repository. Information preservation can also be seen as an aspect of safeguards in a very long time perspective. The research project InSOTEC, along with the subject of information preservation, ties in with the social sciences aspect of the final repository project. InSOTEC deals with the relationship between technical and social challenges, based on the principle that social and political requirements also contribute to shaping technical and scientific solutions.

1.2 The work of the Swedish National Council for Nuclear Waste in 2014

State-of-the-Art Report 2014

The State-of-the-Art Report 2014 was submitted to then Environment Minister Lena Ek in March. It was also presented to the parliamentary Committee on Defence. On publication of the report, the Council met several of its target groups. The Council also held seminars in Östhammar and Oskarshamn, municipalities that figure in SKB's application, to discuss the report with politicians, local officials and the general public.

RD&D review and organization seminar

During the spring, the Swedish National Council for Nuclear Waste reviewed SKB's *RD&D programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste.* The Council has been tasked to submit an independent review statement to the Government no later than nine months after SKB has published its programme. The Swedish Radiation Safety Authority (SSM) will also submit a statement of opinion on the RD&D programme to the Government. The Government will then decide whether or not SKB's RD&D programme should be approved. Even if the programme is approved, the Government can stipulate conditions on the further research and development work if deemed necessary.

In its decision[2], the Government stipulates conditions for the continued research and development activities entailing that SKB and the reactor owners shall, prior to the presentation of RD&D programme 2016, continue to consult with SSM in matters pertaining to the development of decommissioning plans and

[2] Ministry of the Environment, Government decision I:6 (M2014/930/Ke, M2014/1495/Ke).

decommissioning studies. Furthermore, SKB shall ensure that future RD&D programmes are clearer and more structured and that they clarify how the research and development work is planned, justified and evaluated to satisfy sections 10 and 11 of the Nuclear Activities Act. The Government also stipulates the condition that the reactor owners and SKB shall carefully consider the other comments made by SSM, the Swedish National Council for Nuclear Waste and other reviewing bodies in their review of RD&D programme 2013.

One of the most important questions brought up by the Council in its statement of opinion[3] was that SKB has not started a research and development programme concerning the organization that will be responsible for building the Spent Fuel Repository (KBF). In order to further highlight this question, the Council arranged a seminar[4] in November where SKB, SSM and the Council presented their views. Representatives from the Swedish Transport Administration related their experiences from one of Sweden's largest infrastructure projects, the City Line in Stockholm.

Another important point in the Swedish National Council for Nuclear Waste's RD&D statement is that a monitoring programme should be created to monitor the water saturation of the buffer and other important processes in plugged parts of the repository. Chapter 6 in this report elaborates further on this.

Knowledge of members of parliament

The Council has been tasked to support municipal and national politicians and conducted a survey in 2014 of what the MPs know about nuclear waste. The Council held a seminar in the spring of 2014 to present the results of the survey. Following this, the report *Kunskapsläget hos Sveriges Riksdagsledamöter om kärnavfall och dess*

---

[3] SOU 2014:42 *The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2013*.

[4] Read more at www.karnavfallsradet.se/utfragningar-seminarier/seminarium-om-organisationsfragor-kring-uppbyggnad-och-drift-av-ett-slutforv (downloaded 3 February 2015, in Swedish).

slutförvar[5] ("What Swedish MPs know about nuclear waste and its final disposal", in Swedish) has been published.

Copper corrosion

One of the big questions concerning the safety of the Spent Fuel Repository is whether the copper canisters that contain the spent nuclear fuel will remain intact. The Swedish National Council for Nuclear Waste has examined this question in two seminars, the most recent one in November 2013. The report from this seminar was published in 2014, Report 2014:1e *New insights into the repository's engineered barriers – A report from the Swedish National Council for Nuclear Waste's scientific symposium.*[6] SKB submitted *Lägesrapport om kopparkorrosion i syrgasfritt vatten* ("Status report on copper corrosion in oxygen-free water", in Swedish) in September 2014 to SSM, where they say they have cleared up this matter. [7]

International activities

Members of the Council have participated in international conferences during the year. WM Symposium Phoenix in the USA had both Sweden and Finland on the agenda. The Council made presentations on "The Division of Responsibilities between the State and Power Companies in the Management of Spent Nuclear Fuel and Other Nuclear Waste in Sweden", "Ethical Principles for the Management of High Level Spent Nuclear Fuel" and "Transparency, Consent and Democracy".

In October, the Council paid a study visit to the IAEA (International Atomic Energy Agency) in Vienna, gathering information for this state-of-the-art report. The IAEA is the UN organization that handles matters relating to atomic energy. The

---

[5] www.karnavfallsradet.se/publikationer/kunskapslaget-hos-sveriges-riksdagsledamoter-om-karnavfall-och-dess-slutforvar (downloaded 3 February 2015, in Swedish).

[6] Swedish National Council for Nuclear Waste (2014), *New insights into the repository's engineered barriers; A report from the Swedish National Council for Nuclear Waste's scientific symposium on November 20–21, 2013*. Report 2014:1e.

[7] SKB (2014), *Lägesrapport om kopparkorrosion i syrgasfritt vatten.* ("Status report on copper corrosion in oxygen-free water", in Swedish).

IAEA was founded in 1957 and has 162[8] Member States. The Council met IAEA representatives from the Radioactive Waste and Spent Fuel Management Unit, the Decommissioning and Remediation Unit, the Assessment and Management of Environmental Releases Unit and the Division of Nuclear Installation Safety.

1.3 Current situation in Sweden

Final repository for spent nuclear fuel

SKB has been required to provide supplementary information to the licence applications for the Spent Fuel Repository in Forsmark and the encapsulation plant in Oskarshamn, which has delayed the timetable. On 9 January 2015, SSM received a supplement from SKB to its application for a licence to build an encapsulation plant (Clink). The facility comprises a part of SKB's proposed system for final disposal of spent nuclear fuel. At the same time, SSM has decided to extend the referral period for the application to 31 January 2016.

Extended capacity for the interim storage facility for spent nuclear fuel (Clab)

Today SKB has a licence for interim storage of 8,000 tonnes of spent nuclear fuel in Clab. To prevent Clab from getting full, SKB has supplemented its licence applications for KBF with an application for a licence to extend the capacity of Clab to 11,000 tonnes. In order to make room for the increased quantity of spent nuclear fuel in existing pools, SKB plans to relocate the core components that are currently stored in Clab. They also plan to repack the spent nuclear fuel into compact storage canisters. Today the spent nuclear fuel that arrives at Clab is loaded into compact storage canisters. The transloading operation concerns the standard storage canisters already present in Clab. SKB has previously transloaded spent fuel from standard storage canisters to compact storage canisters in connection with previous capacity increases.

[8] In February 2014.

Low- and intermediate-level waste

SKB submitted its application for extension of SFR (the final repository for short-lived radioactive waste) to the Land and Environment Court at Nacka District Court and to SSM on 19 December 2014. It is the Council's opinion that this constitutes new construction rather than an extension of the existing SFR, since both the waste categories that are stored and the activity that is pursued will be changed.[9] The new repository will primarily be a final repository for short-lived low– and intermediate-level waste, but also an interim storage facility for long-lived low- and intermediate-level waste pending the commissioning of the final repository for long-lived radioactive waste (SFL) in about 30–50 years. This is the period of time required to decommission and dismantle a nuclear power plant.

The planned activity includes other waste categories.[10] Licensing under the Environmental Code should therefore be subject to the provisions of Chap. 17 of the Environmental Code. This means that a compulsory permissibility assessment is done by the Government and that the provisions regarding the municipal veto in Chap. 17 section 6 apply.

Parallel licensing processes are pursued under the Environmental Code and the Nuclear Activities Act. The building is already regarded as new in the licensing process under the Nuclear Activities Act, and the same should apply in the environmental court process.

[9] Swedish National Council for Nuclear Waste (2011), *Kärnavfallsrådets synpunkter på SKB:s samråd om uppförande av anläggning för slutförvar för kortlivat radioaktivt avfall.* ("Swedish National Council for Nuclear Waste's viewpoints on SKB's consultations concerning construction of final repository for short-lived radioactive waste", in Swedish) (Reg. no. 60/2011) and Swedish National Council for Nuclear Waste (2014), *Uppförande av anläggning i Forsmark för slutförvar för kortlivat radioaktivt avfall (SFR)* ("Construction of facility in Forsmark for final disposal of short-lived radioactive waste (SFR)", in Swedish). (Reg. no. 16/2014).

[10] SKB (2013), *RD&D programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste* and SKB (2013), *Låg- och medelaktivt avfall i SFR. Referensinventarium för avfall 2013 ("Low- and intermediate-level waste in SFR. Reference inventory for waste 2013", in Swedish).* SKB R-13-37.

References

www.karnavfallsradet.se/utfragningar-seminarier/seminarium-om-organisationsfragor-kring-uppbyggnad-och-drift-av-ett-slutforv (downloaded 3 February 2015, in Swedish).

www.karnavfallsradet.se/publikationer/kunskapslaget-hos-sveriges-riksdagsledamoter-om-karnavfall-och-dess-slutforvar (downloaded 3 February 2015, in Swedish).

Swedish National Council for Nuclear Waste (2011), *Kärnavfallsrådets synpunkter på SKB:s samråd om uppförande av anläggning för slutförvar för kortlivat radioaktivt avfall.* ("Swedish National Council for Nuclear Waste's viewpoints on SKB's consultations concerning construction of final repository for short-lived radioactive waste", in Swedish). (Reg. no. 60/2011).

Swedish National Council for Nuclear Waste (2014), *New insights into the repository's engineered barriers; A report from the Swedish National Council for Nuclear Waste's scientific workshop on November 20–21, 2013.* Report 2014:1e. Stockholm: Fritzes.

Swedish National Council for Nuclear Waste (2014), *Uppförande av anläggning i Forsmark för slutförvar för kortlivat radioaktivt avfall (SFR).* ("Construction of facility in Forsmark for final disposal of short-lived radioactive waste (SFR)", in Swedish). (Reg. no. 16/2014).

Ministry of the Environment, Government decision I:6 (M2014/930/Ke, M2014/1495/Ke).

SKB (2013), *RD&D programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste.* Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2013), *Låg- och medelaktivt avfall i SFR. Referensinventarium för avfall 2013* ("Low- and intermediate-level waste in SFR. Reference inventory for waste 2013", in Swedish). SKB R-13-37. Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2014), *Lägesrapport om kopparkorrosion i syrgasfritt vatten. ("Status report on copper corrosion in oxygen-free water", in Swedish).* (Document ID 1448824). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SOU 2014:42 *The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2013*. Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

2 Current situation of final disposal plans in other countries

2.1 Denmark

2.1.1 Introduction

Even countries that do not use nuclear power for energy production often have radioactive waste from medical care, industry and research. Denmark does not have, and never has had, commercial reactors for energy production, pursuant to a resolution by the Folketing in 1985.[1] They have, however, had three research reactors – DR1 (Danish Reactor 1), DR2 (Danish Reactor 2) and DR3 (Danish Reactor 3) – all of which have been taken out of service, and DR1 and DR2 have been decommissioned. Decommissioning of DR3 started in 2005.[2]

2.1.2 Danish nuclear facilities

DR1

Construction of DR1 began in 1957 and the reactor was shut down in 2001. DR1 has now been completely decommissioned and dismantled. The reactor building and the surrounding area were cleared (released from regulatory control) in 2006 and can now be used for other activities. DR1 had a rated capacity of 2 kW and did not give rise to as much nuclear waste as DR2 and DR3.

---

[1] GEUS (2011), "Slutdepot for Risøs radioaktive affald", ("Final repository for Risø's radioactive waste", in Danish) *Geoviden* no. 2, 2011.

[2] Read more at www.dekom.dk/ (downloaded 3 February 2015).

DR2
Construction of DR2 began in 1959 and the reactor was shut down in 1975. A final report from its decommissioning was approved in 2008. The reactor has been decommissioned, but the building has not been cleared since the reactor hall is used to handle nuclear waste from decommissioning of the other nuclear facilities. When the fuel for DR2 and DR3 was purchased, an agreement was signed that the spent nuclear fuel would be sent back to the USA, which was also done during 2000.

DR3
Construction of DR3 began in 1960 and the reactor was shut down in 2000. Decommissioning began in 2005 and is still proceeding.

The hot cell facility
The hot cell facility was in operation from 1964 to 1989 and was used to examine irradiated nuclear fuel. Decommissioning began in 2008 and is considered to be the most complicated decommissioning of the Danish nuclear facilities. Denmark's "special waste" (233 kg of largely long-lived waste) comes from here.

Fuel fabrication facility (Technology Hall)
The fuel fabrication facility has been used for fabrication of fuel assemblies for DR3. Production ended in 2000 when DR3 was shut down. The project plan for decommissioning of the Technology Hall was approved in 2013.[3]

Waste management plant
The waste management plan receives and manages all Danish radioactive waste.

[3] Folketinget (2013), Aktstk. 14, *Aktstykke om dekommissioneringen af Teknologihallen* ("Legal document on decommissioning of the Technology Hall", in Danish). See: www.ft.dk/samling/20131/aktstykke/Aktstk.14/aktstykket.htm (downloaded 10 December 2014).

2.1.3 Responsibility

In 2003 the Danish parliament (Folketing) voted to close the research facilities at the Risø DTU National Laboratory for Sustainable Energy. Danish Decommissioning (DD) was therefore created in 2003 as an autonomous institution under the Ministry of Higher Education and Science. DD is responsible for the decommissioning of the nuclear facilities on Risø. They also receive, manage and store all Danish radioactive waste.

The Danish Ministry of Health bears overall responsibility for the construction of a final repository.

Responsibility for the preliminary studies is divided:

- DD is responsible for the final repository concept in relation to the geology of the site and the safety assessments.
- The National Institute of Radiation Protection, SIS, is responsible for transport matters.
- The Geological Survey of Denmark and Greenland (GEUS) is responsible for the geological surveys of the proposed sites.

2.1.4 Waste types

Denmark uses a classification and limit system[4] established by the IAEA, and according to this system Denmark claims it does not have any high-level waste. Waste that is interim-stored on Risø comes from the research that used to be conducted there. The waste also comes from Danish medical care, industry and research. Some of the radioactive waste also contains heavy metals and other hazardous chemical substances.

[4] IAEA (2009), *General Safety Guide No. GSG-1, Classification of Radioactive Waste.*

2.1.5 Proposed repository concepts

DD has proposed three different repository concepts:

1. a near-surface (approx. 0–30 metres depth) repository for disposing of the Danish radioactive waste,
2. a near-surface repository plus a borehole (approx. 100–300 metres depth), since the quantity of long-lived waste may be a decisive factor in the design of the repository,
3. a final repository (approx. 30–100 metres depth) for disposal of all Danish radioactive waste.

2.1.6 Consultations under the Espoo Convention

If there is a risk that an activity in one country will affect another country, the neighbouring country shall be informed in accordance with the Espoo Convention. Denmark has begun planning and scoping for a strategic environmental assessment dealing with the final disposal of low- and intermediate-level waste and has informed the neighbouring countries of Sweden, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia and the UK. Three proposals have been presented: final disposal, interim disposal or export of the waste.

At this early stage, Sweden has been given an opportunity to offer viewpoints on the scoping of the environmental assessment and on whether there is interest in continued participation in the environmental assessment process. In the material that is presented, Denmark proposes six different sites for a final repository. These six sites have been selected with the aid of the IAEA's. guidelines. Five of the sites have sedimentary rocks, while one consists of gneiss and granite. As a part of the scoping process, meetings have been held on the proposed sites.

Sweden's response

The Swedish Environmental Protection Agency (Swedish EPA) is the authority in Sweden that is responsible for consultations under the Espoo Convention.[5] The Swedish EPA's response to the Danish Ministry of the Environment (sent 16 July 2014), which is based on responses from other reviewing bodies, states that Sweden intends to participate in the continued consultations on the environmental assessment.[6]

The Swedish Radiation Safety Authority (SSM) writes in its consultation response to the Swedish EPA that Denmark needs to describe the composition and content of the waste more thoroughly and to present the different alternative designs for a final repository in greater technical detail. SSM also believes it is important that the possible environmental consequences are presented for normal function of the final repository as well as for events with low probability but with great consequences (worst case scenarios). The Swedish NGO Office for Nuclear Waste Review (MKG) summarizes its review statement by saying that the Danish plans for siting and building a final repository are so inadequate that only the proposal of continued interim storage of the waste is at all feasible. Read Sweden's response and the statements of other reviewing bodies on the Swedish EPA's website.[7]

2.1.7 Next stage in the process

In the autumn of 2014, the Danish Ministry of the Environment sent *Plan og miljøvurdering for etablering af slutdepot for dansk lav- og mellemaktiv affald*[8] ("Plan and Strategic Environmental Impact

[5] Read more at www.naturvardsverket.se (downloaded 3 February 2015).
[6] Swedish EPA (2014), *Svar från Sverige på underrättelse om plan för etablering av slutdeponi för danskt låg- och mellanaktivt radioaktivt avfall* ("Response from Sweden to notification of plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (NV-04556-14).
[7] www.naturvardsverket.se/Stod-i-miljoarbetet/Remisser-och-Yttranden/Remisser/Svar-pa-remisser/Svar-pa-remiss-om-danskt-slutforvar-av-lag--och-medelaktivt-avfall/ (downloaded 24 November 2014).
[8] Danish Ministry of Health (2014), *Plan og miljøvurdering for etablering af slutdepot for dansk lav- og mellemaktiv affald.* ("Plan and environmental assessment for establishment of final repository for Danish low- and intermediate-level waste", in Danish).

Assessment for the Establishment of a Permanent Repository for Danish Low and Intermediate Level Waste", in Danish) and *Miljørapport*[9] ("Environmental Report", in Danish) to Sweden for commentary. The Swedish EPA has sent the documents for review and commentary in Sweden, and submitted a compilation of the responses of the reviewing bodies to the Danish Ministry of the Environment on 22 January 2015.[10]

In its statement, SSM observed that the environmental report contains portions of the information requested by the authority. SSM also concludes that the requested portions that are not included in the environmental report will be provided in later stages of the consultations.[11] It is the Council's considered opinion that the responsible authorities in Denmark should consult with Sweden's SSM and Finland's Radiation and Nuclear Safety Authority (STUK), since these authorities have great experience of matters relating to final disposal.[12]

2.2 Finland

In Finland, like in Sweden, the licensing process for the planned final repository for spent nuclear fuel has taken longer than expected. The Finnish Ministry of Employment and the Economy (ANM) wanted the Radiation and Nuclear Safety Authority (STUK) to submit its statement of comment before the end of June 2014. In June 2014, STUK said that they needed about six more months than planned to assess safety for the application for a licence to build a facility for encapsulation and final disposal of

[9] Rambøll (2014), *Plan og miljøvurdering for etablering af slutdepot for dansk lav- og mellemaktiv affald, Miljørapport* ("Plan and environmental assessment for establishment of final repository for Danish low- and intermediate-level radioactive waste, Environmental Report", in Danish.

[10] Swedish EPA (2015), *Sveriges svar på dansk plan för etablering av slutdeponi för låg- och mellanradioaktivt avfall.* ("Sweden's response to Danish plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (NV-04556-14).

[11] SSM (2015), *Remiss – Dansk plan för etablering av slutdeponi för danskt låg- och mellanaktivt avfall.* ("Referral response – Danish plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (SSM2014-5566).

[12] Swedish National Council for Nuclear Waste's statement *Samråd om plan och miljörapport för danskt slutförvar.* ("Consultations on plan and environmental report for Danish final repository", in Swedish). *(*Reg. no. 2015/1).

spent nuclear fuel. The reason for the delay is that the material in the application submitted by Posiva Oy[13] to STUK at the end of 2012 was not complete. Instead, Posiva has submitted portions of the material during 2013 and 2014. Moreover, the assessment of the material that has been submitted has taken longer than STUK had estimated. In December 2013, STUK presented new safety requirements that further increased the need for supplementary information, which has also affected the timetable.[14]

2.3 France

French legislation in the area and the French process where the principle of voluntary participation has played a central role were described in the Council's State-of-the-Art Report 2012.[15]

France has 58 reactors that produce 80 percent of the country's electricity. The country is considered to be in the forefront of the effort to find a solution to the management of spent nuclear fuel. The government agency ANDRA (Agence Nationale pour la Gestion Des Déchets Radioactifs = National Radioactive Waste Management Agency) is responsible for nuclear waste management. The nuclear waste producers co-finance the work by allocating funds for future waste management, which is also financed by state subsidies.

Long-lived low-level waste

The siting process for a final repository for long-lived operational and decommissioning waste is under way. After having invited 3,115 candidate towns, the French Government narrowed the choice down to two towns in 2009: Auxon, with a population of 230, and Pars-lès-Chavanges, with a population of 75. Both are located in Aube, where two operational repositories for short-lived

[13] Responsible for developing a safe final disposal method for the Finnish spent nuclear fuel. Owned by Teollisuuden Voima Oyj (TVO) and Fortum Power & Heat Oy.
[14] Read more about the Finnish process in SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey* and at www.stuk.fi (downloaded 26 September 2014).
[15] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012.*

waste are already located. However, both towns withdrew their expressions of interest following massive protests by the inhabitants against the facilities. A repository for long-lived low-level waste of 150,000 m^3 was to have started operation in 2013. The project is currently on hold.

High- and intermediate-level waste and spent nuclear fuel

State-of-the-Art Report 2012 reported that ANDRA had built a research facility in Bure in the Meuse/Haute-Marne district in northeastern France and proposed a site as suitable for building a final repository. It was further stated that a public debate on the licence application for the construction of a final repository was planned, as is required by French law. According to the plan, construction of the final repository for high- and intermediate-level waste in Bure was to commence in 2017.

The repository for geological disposal of high- and intermediate-level waste is called "Centre industriel de stockage géologique" (Cigéo). The total storage volume there is estimated at about 100,000 m^3. The waste generated by the 58 reactors projected to be in operation up until 2052, along with new reactors, and historic waste will be disposed of there. Final disposal is planned to take place in geological clay formations at a depth of about 500 m.

Like all great infrastructure projects, this project will also be subjected to public debate in accordance with French law and the Aarhus Convention. The process for approval of a geological repository starts with submission of a licence application. The application should include a consequence analysis, a preliminary safety report, and a risk management and safety assessment. Furthermore, ANDRA has to show that the facility meets the requirements on reversibility.[16] French law imposes requirements on retrievability. This means that it must be possible to retrieve the waste during the first hundred years in the event that future generations find a better way to manage it. The state's licensing decision is made after consultation with "L'Autorité de sûreté

[16] Reversibility. The term refers to the possibility of backing up one or more steps in the planning and development process at every step of the programme (see also the English version of SOU 2012:7, p. 87).

nucléaire" (the French Nuclear Safety Authority, ASN) and only if these conditions are met.[17]

Now the public debate has been concluded. The first two public meetings had to be stopped due to noisy protests and the remaining meetings were cancelled. The debate period was extended by two months and broadened with webcast panel discussions and a conference in December 2014. Various information tools have been developed by ANDRA, such as websites, press conferences, printed matter, exhibits, open houses and school visits, participation in trade fairs, advertisements, etc. The international website is available in French, Spanish and English because international visibility is important for ANDRA and for stakeholders.[18]

The results of the debate were made public in February 2014.[19] The purpose of the debate was to inform the public about the project, give the public a chance to express an opinion, and provide the decision-maker (the state) with material on which to base a decision whether to begin construction of the facility.[20] After the results were publicized, ANDRA had three months to announce how they intended to proceed with the project.

In May 2014, ANDRA announced its intention to proceed with the Cigéo project. This decision is also based on the results of the studies in the underground laboratory in Meuse/Haute-Marne. At the same time, ANDRA announced that its research in the field of risk management will continue in cooperation with the waste producers. This research is aimed at achieving optimal management of radioactive waste and reducing its radiotoxicity and volumes.

[17] http://professionnels.asn.fr/Installations-nucleaires/Dechets-radioactifs-et-demantelement/Projet-de-centre-de-stockage-Cigeo/Calendrier-et-la-procedure-d-autorisation (downloaded 28 October 2014).
[18] Nuclear Energy Agency, Radioactive Waste Management Committee. Summary Record of the 14th Session of the Forum on Stakeholder Confidence (FSC), NEA/RWM/FSC/M(2013)2, p. 10.
[19] www.andra.fr/andramanche/index.php?id=actualite_3_3_1&art=5691 (downloaded 28 October 2014).
[20] ANDRA, 5 May 2014 *Suites données par l'Andra au débat public sur le projet Cigéo*. ("Action taken by ANDRA following the public debate on the Cigéo project", in French. See: www.cigéo.com/fr/calendrier-debat-public/suites-cigeo-debat-public (downloaded 6 February 2015).

Here is ANDRA's timetable:

- 2015: begin local construction of power supply, roads and railway tracks as well as water supply
- 2017: complete application
- 2020: begin construction of the final repository
- 2025: start of the industrial pilot phase
- 2029: the repository is put into operation, provided a licence is granted.

Under French law, spent nuclear fuel is not regarded as waste. After it has been cooled in pools it is reprocessed in La Hague. The processed, vitrified spent nuclear fuel and the intermediate-level long-lived waste from reprocessing are currently in interim storage at the reprocessing plant.

2.4 Germany and Switzerland and their site selection processes

Germany and Switzerland are both federal republics made up of states (Länder and cantons, respectively). The individual states have some autonomy, but both countries also have governments at the federal level.[21]

Decisions have been made to phase out nuclear power, in Germany by 2022 and in Switzerland by 2034. Final disposal of the radioactive waste will take place in deep geological repositories in accordance with the IAEA's recommendations.

Processes are under way in both countries to find suitable sites for final disposal of radioactive waste. A law was passed in Germany in 2013 about finding a site for final disposal of high-level waste and spent nuclear fuel, and preparations are being made for a site selection process.

In Switzerland, a site selection process is already under way to find sites for disposing of radioactive waste and spent nuclear fuel.

[21] In Germany the Federal Government and in Switzerland the Federal Council.

Furthermore, a decision in principle has been taken in Switzerland concerning an acceptable method.

The following descriptions of the situation in these two countries are not comprehensive, further information is available on the organizations' websites.[22]

2.5 Germany

2.5.1 Introduction

Classification of radioactive waste

Germany distinguishes between heat-generating waste (high-level waste and to some extent intermediate-level waste) and waste with negligible heat output (short-lived low- and intermediate-level waste).

The federal government plans to dispose of both waste categories in deep geological repositories. Like in Sweden, spent nuclear fuel is not regarded as waste until it is in a final repository. In this text, however, the categories commonly distinguished in Sweden will be used: 1) high-level waste and spent nuclear fuel, and 2) short-lived low- and intermediate-level waste.

Laws and responsibilities

The nine reactors in operation in Germany will be shut down by 2022 at the latest. Management of radioactive waste is regulated by the Basic Law (GG) and the Atomic Energy Act (AtG) from 1959, most recently amended in 2013.[23]

In Germany, the nuclear power companies bear the costs of managing all radioactive waste they create. However, actual final disposal of the radioactive waste and the spent nuclear fuel is a federal responsibility since 1976.

---

[22] English names are used, since the references usually refer to the English versions of the websites.

[23] Read more about laws: www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/legal-provisions-technical-rules/constitution-and-laws/#c18651 (downloaded 15 January 2015).

The division of responsibilities is:

- The state bears technical responsibility for the final disposal of all radioactive waste and spent nuclear fuel.24
- The nuclear power industry bears both technical and financial responsibility for interim storage of radioactive waste from nuclear facilities and the spent nuclear fuel.25

When it comes to final disposal, there is a site for low- and intermediate-level waste in Saltzgitter.[26] The state must also build a final repository for high-level waste and spent nuclear fuel. The Site Selection Law (StandAG) was therefore passed in July 2013.[27]

2.5.2 Länder and federal responsibility via BMUB, BfE and BfS

The Federal Republic of Germany consists of 16 states (Länder) with considerable autonomy. Responsibility for nuclear safety and radiation protection is divided between the federal government and the state governments based on general principles in the German Basic Law. The federal government is responsible for legislation at the federal level, while the state governments are responsible for licensing and supervision of nuclear power plants and other nuclear facilities in an open licensing and consultation process involving a number of actors.[28]

The federal government is responsible for nuclear safety and radiation protection via the Federal Ministry of the Environment, Nature Conservation, Building and Nuclear Safety, BMUB.[29]

[24] It is however the nuclear power industry that has financial responsibility, SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey* p. 87 and at www.bfe.bund.de/en/repository-site-selection-process/financing/ (downloaded 15 January 2015).
[25] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012*, p. 64 ff., p. 89 and at: www.bfs.de/en/transport/zwischenlager/einfuehrung.html (downloaded 15 January 2015).
[26] The Konrad iron ore mine is in the process of being converted.
[27] www.gesetze-im-internet.de/standag/index.html and www.bfs.de/en/endlager/standortauswahl/standortauswahl_in_deutschland/standag (downloaded 15 January 2015).
[28] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012*, p. 65 ff.
[29] Das Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB).

BMUB participates in the licensing and supervision of nuclear facilities and oversees state compliance with the federal laws.[30]

Two independent authorities work under BMUB: the newly established Federal Office for the Regulation of Nuclear Waste Management (BfE)[31] and the Federal Office for Radiation Protection (BfS)[32].

Federal Office for the Regulation of Nuclear Waste Management, BfE

The Federal Office for the Regulation of Nuclear Waste Management (BfE) started operation on 1 September 2014. The law establishing this federal authority was passed at the same time the site selection law was passed on 23 July 2013. BfE is intended to regulate the site selection process, and it also supports BMUB in its other activities relating to final disposal of radioactive waste.[33]

Federal Office for Radiation Protection, BfS

The Federal Office for Radiation Protection is both an expert organization and a regulatory authority, as well as being a project developer and in charge of building and operating facilities for final disposal of radioactive waste and spent nuclear fuel.

BfS is participating in the process for licensing of interim storage facilities (central and decentralized) and shipments of spent nuclear fuel. They are responsible for two repositories and two repository projects.

BfS repositories and repository projects

The plan in Germany today is that all types of radioactive waste will be disposed of in deep geological repositories. In the latter part of the 20th century, low- and intermediate-level waste was stored

[30] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012*, p. 65 ff.
[31] Bundesamt für kerntechnische Entsorgung (BfE).
[32] Bundesamt für Strahlenschutz (BfS).
[33] www.bfe.bund.de/en/repository-site-selection-process/tasks-of-the-federal-office/ (downloaded 15 January 2015).

in the former salt mines of Morsleben and Asse II. They are not safe as final repositories and must be remediated. Instead, the Konrad iron ore mine is being converted to a final repository for low- and intermediate-level waste.[34]

Repository for low- and intermediate-level waste

The former salt mine Asse II is in poor condition and may collapse. The law "Lex Asse" was passed in 2013 to speed up the retrieval of the radioactive waste and the decommissioning of the repository. The former salt mine of Morsleben is in the process of being decommissioned and backfilled.

The former iron ore mine of Konrad is being converted to a final repository for short-lived low- and intermediate-level waste.[35] A licence for the activity in accordance with modern nuclear energy legislation was granted in 2008. However, the project had already started in 1975 and an application was submitted in 1982. The plan that existed then to convert the mine to a final repository must now be adapted to the latest technology and to the amended legislation, which means that it will take longer than planned. According to the information in the state-of-the-art report 2012 the final repository was expected to be put into operation in 2014[36], but it has been delayed and today there is no stipulated final date.

The Gorleben Mine

The Gorleben salt mine was long considered to be the site for final disposal of the high-level waste and the spent nuclear fuel, and this was also mentioned in State-of-the-Art Report 2012. The mine is neither a licensed final repository nor an interim storage facility, and no radioactive waste has ever been stored there.

When the repository site selection law went into effect, the work at Gorleben came to a halt. However, the site has not been

[34] Read more about BfS's repositories and disposal projects at: www.bfs.de/en/endlager (downloaded 15 January 2015).
[35] The waste from Asse will probably be relocated here.
[36] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012*, p. 91.

excluded from the selection process, but remains a possible candidate.[37]

2.5.3 Interim storage facility – the nuclear power industry's responsibility

There are a number of different interim storage facilities for short-lived low- and intermediate-level waste. The competent authorities in the state where the storage facilities are located are responsible for licensing and supervision of these facilities.[38,39]

The nuclear power industry is responsible for interim storage of its radioactive waste and spent nuclear fuel. The industry's organization Society for Nuclear Service (GNS)[40] is responsible for two central interim storage facilities, one in Ahaus and one in Gorleben[41]. The nuclear power operators are also responsible for at-plant interim storage facilities.

Radioactive waste from medical care, industry and research is stored at research institutions and in federal collection depots located in the Länder.[42]

2.5.4 Site selection process for final repository for high-level waste and spent nuclear fuel

In 1963, the federal government recommended the use of salt formations for geological disposal of radioactive waste, and plans for a national final repository began to be drawn up in 1973. The

[37] www.bfs.de/en/endlager/einfuehrung.html and www.endlagerung.de/language=de/6721/aktuelle-situation (downloaded 15 January 2015).
[38] www.bfs.de/en/transport/zwischenlager/dezentrale_zwischenlager/einfuehrung.html (downloaded 15 January 2015).
[39] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012*, p. 68 f.
[40] Gesellschaft für Nuklear-Service mbH (GNS). The following companies are stakeholders in GNS: E.ON Kernkraft (48 percent), RWE Power (28 percent), EnBW with subsidiaries consisting of German nuclear waste companies (18.5 percent) and Vattenfall Europe (5.5 percent). Read more about GNS: www.gns.de/language=en/24394 (downloaded 15 January 2015).
[41] The interim storage facility does not belong to the BfS final disposal project in Gorleben.
[42] For an overview of interim storage facilities for low- and intermediate-level waste (waste with negligible heat output) see: www.bfs.de/en/transport/zwischenlager/zwl_vern_waerme.html (downloaded 15 January 2015).

Atomic Energy Act was amended in 1976, and the federal government was made responsible for final disposal.

Today the federal government is responsible, via the Federal Office for Radiation Protection (BfS), for building and operating final repositories for high-level waste and spent nuclear fuel. BfS has worked for more than ten years to keep the process of finding a site for a final repository for spent nuclear fuel open in a number of respects. Many different groups are encouraged to participate to assure a democratic process. Several sites will be investigated to find the safest one. Several repository concepts will be investigated based on the latest technology. Other materials besides salt that may be suitable for a final repository are shale and crystalline rock.

Site Selection Law (2013)

In 2013, the federal government and the Länder agreed on the Site Selection Law.[43] The goal is to find a site with the "best possible safety" for a final repository for high-level waste and spent nuclear fuel. The site selection decision shall be taken in national consensus between the federation, the Länder and the citizens.

The site selection process shall proceed in stages with stepwise decisions:

- identification of eligible regions for the site and exploration on the surface,
- development of criteria for requirements on the sites,
- site investigations both on the surface and underground,
- selection and decision for exploration on the surface,
- in-depth investigation of e.g. geology,
- concluding comparison of sites and site proposal, as well as
- decision on a site.

[43] Standortauswahlgesetz (StandAG). Read more about the site selection process: www.endlagerung.de/language=de/17142/standortauswahl-verfahren and www.bfs.de/en/endlager/standortauswahl (downloaded 15 January 2015).

The decision on a site for the final repository is followed by the licensing procedure for construction, operation and decommissioning of the repository.[44] A description of the actors and their duties follows below.

The Commission

In accordance with the Site Selection Law, the Commission for High Level Waste Disposal[45] (the Commission) has worked since May 2014. The Commission considers how the process for site selection should proceed and plans to submit its final report with recommendations to the federal government and the German parliament before July 2016.[46]

The Commission consists of representatives of different scientific and societal groups as well as members of the county administrative boards and the Bundestag (federal parliament).

The site selection process can begin when the Commission has completed its work and it has been established in law what criteria must be met in order to select a site.[47]

BfS and BfE

The Federal Office for Radiation Protection (BfS) is the project developer. They lead the search for sites and will then build the repository. BfE is the regulatory authority and leads the selection process. The Ministry of the Environment, BMUB, exercises technical oversight of both BfS and BfE.

Before the Commission has finished its work, BfE focuses on the financing of the site selection process. They will then take

---

[44] www.bundestag.de/bundestag/ausschuesse18/a16/standortauswahl och www.bfs.de/en/endlager/standortauswahl/standortauswahl_in_deutschland/standag/oeffent lichkeit och www.bfe.bund.de/en/repository-site-selection-process/the-process/ (downloaded 15 January 2015).
[45] Kommission Lagerung hoch radioaktiver Abfallstoffe.
[46] www.gesetze-im-internet.de/standag/__3.html (downloaded 15 January 2015).
[47] www.endlagerung.de/language=de/18217/kommission-lagerung-hoch-radioaktiver-abfallstoffe-endlagerkommission (downloaded 15 January 2015).

charge of the process of site selection and approve BfS's geological investigations of a suitable site once the process is under way.[48]

The parliament must approve all important steps in the process, under the terms of the law. The law requires participation of the public in order to gain broad acceptance of the decisions made.

2.6 Switzerland

2.6.1 Introduction

Classification of radioactive waste

In Switzerland the radioactive waste is divided into three categories:[49]

1. High-level waste (spent nuclear fuel and vitrified waste from reprocessing of spent nuclear fuel)
2. Long-lived intermediate-level waste
3. Short-lived low- and intermediate-level waste

Laws and responsibility

There are five reactors in operation in Switzerland, which are planned to be decommissioned by 2034 at the latest and will not be replaced with new ones.[50]

Radioactive waste management is regulated in the Nuclear Energy Act (Kernenergiegesetz) from 2003 and the Nuclear Energy Ordinance (Kernenergieverordning) from 2004. They entered into effect in 2005, replacing the Atomic Act from 1959.[51] Switzerland decided in 1978 that a producer had to guarantee that the radioactive waste can be managed safely in order to obtain a licence to operate a nuclear power plant. The producers were

[48] www.bfe.bund.de/en/standortauswahlverfahren/aufgaben-des-bundesamtes/ och www.bfe.bund.de/en/repository-site-selection-process/the-process/ (downloaded 15 January 2015).
[49] Read more at: www.ensi.ch/en/topic/waste-management/ and www.nagra.ch/en/types.htm (downloaded 15 January 2015).
[50] www.bfe.admin.ch/themen/00526/00527/index.html?lang=en (downloaded 15 January 2015).
[51] www.nagra.ch/en/legalframework.htm (downloaded 15 January 2015).

responsible for management and disposal of the radioactive waste they generated.[52] The division of responsibilities is as follows:

- The nuclear power industry (the reactor owners) are responsible for managing spent nuclear fuel and radioactive waste from nuclear facilities.
- The state is responsible for the radioactive waste from medical care, industry and research.

2.6.2 Nagra and the final repositories

Since both the nuclear power industry and the state are responsible for managing waste, they jointly formed the National Cooperative for the Disposal of Radioactive Waste (Nagra)[53] in 1972.[54] Nagra is responsible for creating and building deep geological repositories for all categories of radioactive waste arising in Switzerland from both the nuclear power plants and the use of radioactive substances in medical care, industry and research.

Nagra investigates suitable sites for geological repositories, and a site selection process is under way. After a site has been selected, Nagra will submit applications for the licences that are required, and after a licence is obtained they will build and operate the final repositories.[55] Examples of other duties are that they inventory all radioactive waste and are in charge of the Grimsel research laboratory.[56]

[52] www.ensi.ch/en/waste-disposal/deep-geological-repository/regulatory-requirements/the-history-of-waste-management/ (downloaded 15 January 2015).
[53] Die Nationalen Genossenschaft für die Lagerung radioaktiver Abfälle (Nagra).
[54] The members of Nagra Cooperative are: Swiss Confederation (represented by the Department of Home Affairs), BKW FMB Energie AG, Bern (Mühleberg NPP), Kernkraftwerk Gösgen-Däniken AG, Däniken (Gösgen NPP), Kernkraftwerk Leibstadt AG, Leibstadt (Leibstadt NPP), Axpo Power AG, Baden (Beznau I and II NPPs), Alpiq Suisse SA, Lausanne och Zwilag Zwischenlager Würenlingen AG, Würenlingen.
[55] www.nagra.ch/en (downloaded 15 January 2015).
[56] www.nagra.ch/en/grimselrocklaboratory.htm (downloaded 15 January 2015). (See Chapter 6).

2.6.3 Federal responsibility: DETEC, SFOE and ENSI

The Swiss Confederation consists of 26 cantons. The Federal Department of the Environment, Transport, Energy and Communications (DETEC)[57] issues licences for nuclear power plants, research reactors and final repositories for nuclear waste disposal, together with the Federal Council and the parliament. The Swiss Federal Office of Energy (SFOE)[58] prepares these licensing decisions and is subordinate to DETEC.

SFOE also licenses shipments of nuclear fuel and radioactive waste, and enforces the legal provisions regarding decommissioning of nuclear facilities. SFOE deals with legal matters and is responsible for legislation in the field of nuclear energy. SFOE has been responsible for the process[59] for selection of sites for the deep geological repositories.[60]

Swiss Federal Nuclear Safety Inspectorate, ENSI

The Swiss Federal Nuclear Safety Inspectorate (ENSI)[61] is an independent federal regulatory body.[62] ENSI oversees and regulates radiation protection and is responsible for supervision of the Swiss nuclear power plants. They also regulate shipments of radioactive material to and from nuclear facilities.

ENSI provides technical support, assesses expert reports and evaluates applications from Nagra. The Federal Council and SFOE base their licensing decisions on ENSI's work.

---

[57] Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK (DETEC).
[58] Bundesamt für Energie BFE (SFOE).
[59] The Sectoral Plan for Deep Geological Repositories (SGT).
[60] www.bfe.admin.ch/themen/00511/00512/index.html?lang=en (downloaded 15 January 2015).
[61] Eidgenössisches Nuklearsicherheitsinspektorat (ENSI).
[62] www.ensi.ch/en/topic/waste-management/ (downloaded 15 January 2015).

2.6.4 Interim storage today

Switzerland has interim storage facilities for operational radioactive waste and spent nuclear fuel both centrally and decentralized at the nuclear power plants.

There are two central interim storage facilities in Würenlingen where all categories of waste are processed and stored: an industrial interim storage facility operated by ZWILAG[63], and the federal interim storage facility located on the same site, where waste from medical care, industry and research is stored.[64]

2.6.5 The site selection process for the geological repositories

Two final repositories

Two deep geological repositories are planned to be built in Switzerland for all radioactive waste:

- a final repository for high-level waste, spent nuclear fuel and long-lived intermediate-level waste,
- a final repository for short-lived low- and intermediate-level waste.

A combined repository is also possible, with two physically separate storage areas for the two categories of waste. In that case they can use a common facility on the surface.[65]

In 2002, Nagra submitted a report to the Federal Council stating that it is in principle possible to dispose of all spent nuclear fuel, high-level waste and long-lived intermediate-level waste in Switzerland.[66] The Federal Council approved the report in 2006 and

[63] The Swiss nuclear power operators own the company Zwilag Zwischenlager Würenlingen AG, founded in 1990. Read more: www.zwilag.ch/en/home.html (downloaded 15 January 2015).
[64] Read more at: www.nagra.ch/en/interimstorage.htm och www.ensi.ch/en/topic/interim-storage-facilities/ (downloaded 15 January 2015).
[65] Which of the repositories category 2 (long-lived intermediate-level waste) will be emplaced in will be determined later in the process.
[66] Nagra (2002), TECHNICAL REPORT 02-05 *Project Opalinus Clay – Safety Report – Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate-level waste (Entsorgungsnachweis).*

found that the important technical questions had been answered when it came to designing safe deep geological repositories.

Nagra is responsible for creating the final repositories. They propose siting areas, conduct site investigations and submit licence applications for building and operating the repository.

The Sectoral Plan for Deep Geological Repositories

How the process works and which criteria a potential site has to fulfil are defined in *The Sectoral Plan for Deep Geological Repositories* (SGT).[67] SFOE has developed the site selection process and they are in charge of the process approved by the Federal Council in April 2008. SFOE then leads and coordinates the process, which proceeds in three steps and will take at least ten years.

ENSI formulates guidelines for specifying requirements on the deep geological repositories and evaluates investigations and applications from Nagra. The Swiss population and neighbouring countries are also entitled to participate. The Swiss Federal Council will then make a decision.[68] The process is divided into three stages:

- Stage 1: Selection of geological siting areas (concluded – took place during the period 2008–2011).
- Stage 2: Selection of at least two sites (currently in progress).
- Stage 3: Selection of a site.

Stage 1: Selection of geological siting areas from 2008 to 2011

The purpose of stage 1 was to identify areas in Switzerland that could be suitable sites for deep geological repositories. Nagra

[67] Sachplan geologische Tiefenlager (SGT). Sectoral plans are usually used as tools in physical and regional planning to organize the collaboration between the Federal Council and the cantons.
[68] Read more about the site selection process:
www.nagra.ch/en/siteselection.htm
www.ensi.ch/en/waste-disposal/deep-geological-repository/sectoral-plan-for-deep-geological-repositories-sgt/
www.bfe.admin.ch/radioaktiveabfaelle/01277/05192/index.html?lang=en
(downloaded 15 January 2015).

presented proposals[69] in 2008 which were reviewed and evaluated by the regulatory authority, ENSI. In this stage, the selection of sites was mainly based on safety criteria.

The Federal Council decided to continue with all the proposed siting areas in step 2. The first stage in the process was thereby finished at the end of 2011.

Stage 2: Selection of at least two sites from 2011

The second stage of the process is currently in progress. Nagra is working together with the selected regions and the responsible authorities. For example, regional representative participate in determining where the surface installations for the final repository are to be positioned.

The potential sites are further investigated and compared with each other to narrow down the choice to at least two sites for each of the two final repositories.[70] Besides safety criteria, social and economic aspects are further examined in this stage.

Latest news about stage 2 during 2014

ENSI is of the opinion that the method described and the geological knowledge possessed by Nagra are sufficient to perform the preliminary safety assessment corresponding to stage 2 in the selection process. In other words, Nagra can notify the regulatory authority SFOE of its site proposals.[71] The preliminary safety assessment will then be vetted by the authority and sent to a public hearing. At the end of stage 2, the Federal Council will decide which site areas remain, which is planned to take place in 2017. The final site selection(s) are then carried out in stage 3.

---

[69] Nagra proposed 6 sites for low- and intermediate-level waste and three sites for high-level waste and spent nuclear fuel.

[70] Two sites for high-level waste and spent nuclear fuel plus long-lived waste. Two sites for short-lived low- and intermediate-level waste.

[71] ENSI confirmed in a letter to SFOE that Nagra will soon be ready to submit its proposals for at least two sites per type of disposal. Nagra is expected to announce its recommendations in early 2015. Read the news: www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=de&msg-id=54232 (downloaded 15 January 2015). (BFE is a German abbreviation for SFOE).

Stage 3: Selection of a site

In the third stage, the remaining sites will undergo another, more thorough and detailed comparison. Site-specific geological knowledge must be further verified by e.g. drilling. Social and economic consequences must also be further investigated. Based on the results, the repository sites will be proposed. The Federal Council and the parliament make decisions on the general licence applications, and a national referendum may also be needed.

A long way to go to a geological repository

The search for suitable sites takes time, and even when suitable sites have been selected there is still a long way to go before a geological repository can be built and closed. Milestones along the way are different steps in the licensing process including construction, operation, observation and closure.

2.7 Developments in the USA during the past year

The nuclear waste issue in the USA is still developing in the shadow of the Obama administration's decision in January 2009 to cut off funding of a planned final repository for high-level waste and spent nuclear fuel in Yucca Mountain in the state of Nevada. A "Blue Ribbon Commission on America's Nuclear Future" (BRC) was appointed in 2010. Its final report was published in 2012 and included recommendations to develop one or more geological disposal facilities.

A decision has not yet been made regarding BRC's recommendations, and several legal processes are being pursued in the wake of the decision to abandon the Yucca Mountain project. The congressional election of 4 November 2014 may have created new premises for the fate of the project, since the Republican party now has a majority in both the Senate and the House of Representatives. The Yucca Mountain project could thereby be revived. Funding could be made available so that the NRC (Nuclear Regulatory Commission) and DOE (Department of Energy) can complete the licence application process. Given these premises and the granting of a licence application, a final repository could be opened for waste disposal in about 2030. However, President Obama could still halt this process by presidential veto.

Radioactive waste from the U.S. Armed Forces is disposed of in WIPP (Waste Isolation Pilot Plant) 700 metres beneath the surface in a salt formation in the southeastern part of the state of New Mexico. Disposal operations began in 1999 and are still proceeding. Two accidents occurred in February 2014 down in the repository. A truck caught fire on 5 February, and the fire was quickly extinguished. A more serious radioactive release occurred on 14 February. The subsequent investigation has not succeeded in determining the exact cause of the event and has revealed a number of deficiencies related to e.g. the ventilation system and the plant's safety culture.

References

Denmark

Folketinget (2013), Aktstk. 14, *Aktstykke om dekommissioneringen af Teknologihallen* ("Legal document on decommissioning of the Technology Hall", in Danish) See: www.ft.dk/samling/20131/aktstykke/Aktstk.14/aktstykket.htm (downloaded 10 December 2014).

GEUS (2011), "Slutdepot for Risøs radioaktive affald" ("Final repository for Risø's radioactive waste", in Danish), *Geoviden* no. 2, 2011. Geological Survey of Denmark and Greenland.

IAEA (2009), *General Safety Guide No. GSG-1, Classification of Radioactive Waste*. Vienna: International Atomic Energy Agency.

Swedish National Council for Nuclear Waste (2015), *Yttrande Samråd om plan och miljörapport för danskt slutförvar* ("Statement Consultation on plan and environmental report for Danish final repository", in Swedish) (Reg. no. 2015/1).

Danish Ministry of Health (2014), *Plan og miljøvurdering for etablering af slutdepot for dansk lav- og mellemaktiv affald.* ("Plan and environmental assessment for establishment of final repository for Danish low- and intermediate-level waste", in Danish).

Swedish EPA (2014), *Svar från Sverige på underrättelse om plan för etablering av slutdeponi för danskt låg- och mellanaktivt radioaktivt avfall* ("Response from Sweden to notification of plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (NV-04556-14).

Swedish EPA (2015), *Sveriges svar på dansk plan för etablering av slutdeponi för låg- och mellanradioaktivt avfall.* ("Sweden's response to Danish plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (NV-04556-14).

Rambøll (2014), Plan og miljøvurdering for etablering af slutdepot for dansk lav- og mellemaktiv affald, Miljørapport ("Plan and environmental assessment for establishment of final repository for Danish low- and intermediate-level radioactive waste, Environmental Report", in Danish).

SSM (2015), *Remiss – Dansk plan för etablering av slutdeponi för danskt låg- och mellanaktivt avfall.* ("Referral response – Danish plan for establishment of final repository for Danish low- and intermediate-level radioactive waste", in Swedish). (SSM2014-5566). Swedish Radiation Safety Authority.

www.naturvardsverket.se/Stod-i-miljoarbetet/Remisser-och-Yttranden/Remisser/Planer-i-vara-grannlander---Esbokonventionen/Samrad-om-plan-och-miljorapport-for-danskt-slutforvar-/ (downloaded 10 December 2014).

Finland

SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey*. Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

France

ANDRA, 5 May 2015 *Suites données par l'Andra au débat public sur le projet Cigéo.* ("Action taken by ANDRA following the public debate on the Cigéo project", in French).

http://professionnels.asn.fr/Installations-nucleaires/Dechets-radioactifs-et-demantelement/Projet-de-centre-de-stockage-Cigeo/Calendrier-et-la-procedure-d-autorisation (downloaded 28 October 2014).

SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

Summary Record of the 14th Session of the Forum on Stakeholder Confidence (FSC), NEA/RWM/FSC/M(2013). See: www.oecd-nea.org/html/rwm/docs/2013/rwm-fsc-m2013-2.pdf (downloaded 2 February 2015).

www.andra.fr/andra-manche/index.php?id=actualite_3_3_1&art=5691 (downloaded 28 October 2014).

www.andra.fr/index.html (downloaded 2 February 2015).

Germany

www.bmub.bund.de/en (downloaded 15 January 2015).

www.bundestag.de/bundestag (downloaded 15 January 2015).

www.bfe.bund.de/en/(downloaded 15 January 2015).

www.bfs.de/en/bfs (downloaded 15 January 2015).

www.endlagerung.de/ (downloaded 15 January 2015).

www.gesetze-im-internet.de/standag/index.html (downloaded 15 January 2015).

www.gesetze-im-internet.de/standag/__3.html (downloaded 15 January 2015).

www.gns.de/language=en/24394 (downloaded 15 January 2015).

SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

Switzerland

Nagra (2002), TECHNICAL REPORT 02-05 *Project Opalinus Clay – Safety Report – Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate-level waste (Entsorgungsnachweis)*.

"Geologische Tiefenlager: ENSI beurteilt Kenntnisstand für den Einengungsvorschlag in Etappe 2 als ausreichend" ("Deep geological repository: ENSI judges the state of knowledge for the proposed restriction in Stage 2 to be sufficient", in German) See: www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=de&msg-id=54232 (downloaded 15 January 2015).

www.bfe.admin.ch/themen/00526/00527/index.html?lang=en (downloaded 15 January 2015).

www.bfe.admin.ch/themen/00511/00512/index.html?lang=en (downloaded 15 January 2015).

www.bfe.admin.ch/radioaktiveabfaelle/01277/05192/index.html?lang=en (downloaded 15 January 2015).

www.ensi.ch/en/ (downloaded 15 January 2015).

www.nagra.ch/en (downloaded 15 January 2015).
www.zwilag.ch/en/home.html (downloaded 15 January 2015).

3 Safeguards and final disposal of spent nuclear fuel

3.1 Introduction

After the Second World War there was great optimism regarding the peaceful use of atomic power. Sweden was an early adopter, and the Atomic Committee was formed in November 1945. In its first report in 1946, they write: "that a new and powerful energy source could be harnessed in the service of peaceful progress."[1]

In 1957, the world's first nuclear power plant is put into operation, with four Magnox reactors of initially 60 MWe each (Calder Hall in England). The nuclear power plant also produced plutonium for British nuclear weapons. The International Atomic Energy Agency (IAEA) was founded the following year. The purpose was to develop and operate a system of safeguards to prevent nuclear material from being diverted from the civilian nuclear fuel cycle to military use. The Nuclear Proliferation Treaty (NPT), aimed at preventing the spread of nuclear weapons, came into being in 1968[2]. The nuclear weapon states pledge to pursue nuclear disarmament, and other countries without nuclear weapons but with an interest in developing civilian nuclear power pledge to submit to safeguards. An important role is assigned to the IAEA, which has often taken centre stage in global politics. The ongoing discussions of Iran's nuclear power programme provide the most recent example. The Non-Proliferation Treaty strengthened the

---

[1] See *Kärnkraftens historia* ("The history of nuclear power", in Swedish), www.stralsakerhetsmyndigheten.se

[2] Treaty in London, Moscow and Washington on prevention of the proliferation of nuclear weapons, 1 July 1968 (SÖ 1970:12). Sweden ratified the non-proliferation treaty in 1970, see Gov. Bill 1969:164.

IAEA's position, but it was not until the 1990s that the IAEA could realize a safeguards system worthy of its name.[3]

Today there are a total of 437 nuclear reactors in operation, and they account for about 11 percent of total global electricity production. 66 nuclear power reactors are under construction. In 2010, the IEA (International Energy Agency) published a study of the consequences of a global 50 percent reduction in greenhouse gases by 2050 (Blue Map Scenario)[4] and estimates that about 24 percent of global energy production will be nuclear-generated at that time. This would entail a tripling of nuclear power capacity.[5] Since the IEA's 2010 study, the economic feasibility of nuclear power has been increasingly called into question. The IAEA estimates that the rate of growth of nuclear power will in reality be lower. It is also worth noting that even in the most unlikely event that global nuclear power operation were to cease immediately, safeguards would still be vital for managing all the nuclear material that already exists. In any event, very high demands will be made in the coming decades on the maintenance of effective nuclear safeguards.

3.1.1 The interface between safeguards and final disposal

This chapter will deal with the interface between the question of a future final repository for spent nuclear fuel in Sweden and the regulatory framework surrounding safeguards. Of course, the question of safeguards extends far beyond that of a final repository – and the final repository involves much more than preventing the proliferation of spent nuclear fuel for military purposes. But the issues intersect, and many measures associated with the disposal of the spent nuclear fuel are aimed at compliance with the international system of safeguards.

---

[3] Håkansson, A. & Jonter, T. (2007), *Icke-spridning och kärnämneskontroll.* ("Non-proliferation and safeguards", in Swedish). SKI-rapport 2007:45, Chap. 2.

[4] Blue Map Scenario. See: www.iea.org/publications/freepublications/publication/etp2010.pdf (downloaded 2 February 2015).

[5] OECD/IEA & OECD/NEA (2010), *Technology Roadmap: Nuclear energy*.

3.1.2 Purpose

Why is it important to bring up this question in this context? There are three reasons. Firstly, compliance of the final repository with the international regulatory framework for safeguards is of central importance for the credibility of the entire final repository project. According to the Council, the importance of this has been underestimated in the ongoing discussion. Secondly, issues relating to safeguards impinge upon other issues relating to monitoring and inspection of conditions in the final repository during operation and closure. These issues are dealt with in Chapter 6. Thirdly, the issue of safeguards in connection with a future final repository also brings up the issue of record-keeping and knowledge preservation. Safeguards are based on a thorough accounting of the number and content of the fuel assemblies and of the construction of the final repository. There is an important interface between these issues and other reasons for information storage, which is dealt with in another chapter.[6]

Issues concerning safeguards bring up other technical, financial, organizational, political and ethical issues. The Swedish National Council for Nuclear Waste's multidisciplinary composition makes it particularly qualified to deal with these questions.

3.2 The international regulatory framework

3.2.1 IAEA

The ranking of different safety standards issued by the IAEA is of importance for an understanding of the international regulatory framework. Of normative importance are the Safety Fundamentals adopted by the IAEA in 2006, with the support of numerous other international organizations.[7] These Safety Fundamentals are clarified in Safety Requirements and Safety Guides. These

[6] See Chap. 4 in this report. In their response to demands for supplementary information by Östhammar Municipality, SKB writes: "SKB agrees that forms for the preservation of information are a regulatory question. It is also a question of international interest to enable future nuclear safeguards." (see SKB (2013), *Application under the Environmental Code – supplement II – April 2013* (in Swedish). Appendix K3, pp. 34 and 134).

[7] IAEA (2006), *Safety Fundamentals. No. SF-1. Fundamental Safety Principles.*

standards reflect the international consensus on the safety level when it comes to protection against harmful radioactive radiation.[8]

3.2.2 Euratom

Euratom[9] was founded the same year as the IAEA, 1958. The organization is subordinate to the European Commission and is regulated in the Euratom Treaty, which has remained relatively unchanged since it entered into force in 1958. An important part of Euratom's mission is safeguards. This mission is clarified as follows:

> Nuclear materials such as uranium and plutonium can be used both for peaceful and military purposes. Nuclear safeguards were established as a guarantee that nuclear materials would not be diverted to purposes other than those for which they were originally declared.
>
> Nuclear safeguards are measures that:
>
> - oblige users of nuclear material to keep a system of records and to make declarations about the nuclear material they hold and process to the European Commission
> - mandate the European Commission to verify these declarations with regard to their correctness and completeness in order to assure citizens, supplier states and the international community that the nuclear material remains in use only for peaceful purposes.[10]

The Euratom Treaty with clarifications and recommendations contains far-reaching specifications of measures, methods and verifications of nuclear materials at nuclear facilities in Europe. Euratom has some 160 inspectors at their disposal, and their activity is described in annual reports.[11]

Many of Euratom's regulations are also applicable to safeguards at facilities for final disposal of spent nuclear fuel. This particularly

---

[8] See further Håkansson, A. & Jonter, T. (2007).

[9] The treaty establishing the European Atomic Energy Community (Euratom) was signed on 25 March 1957, the same date as the treaty establishing the European Economic Community (the EEC Treaty). The Euratom Treaty comprises a part of the legislation of the Member States and applies in Sweden in accordance with the Act (1994:1500) on Sweden's Accession to the European Union.

[10] See further http://ec.europa.eu/energy/nuclear/safeguards/safeguards_en.htm (downloaded 2 February 2015).

[11] See e.g. European Commission (2014), *Report on the Implementation of Euratom Safeguards in 2013*.

includes a document stipulating obligations for those who are in charge of the construction and operation of final repositories.[12] The standards – which are also Swedish law – are a detailed account of e.g. the nuclear materials records which an operator (in Sweden SKB) is obliged to present to Euratom and the inspections they are obliged to receive. What is still lacking, however, is a more detailed EU regulation of safeguards in connection with final disposal of spent nuclear fuel.

Euratom and IAEA safeguards complement each other and coordinate, for example, their inspections of nuclear installations. Euratom's requirements can be interpreted as more precisely defined versions of the IAEA's.

3.3 Safeguards

3.3.1 Safeguards and physical protection

First, a simple terminological clarification is in order. Safeguards and physical protection are two fairly closely related concepts, but are nevertheless usually distinguished. By *safeguards* is meant that the nuclear material (uranium, plutonium or other radioactive substance that can be used to produce nuclear energy) that is stored or used must be subjected to a legally accepted and well-functioning system for verification of correctness and completeness. *Physical protection* involves more concrete measures to (1) prevent unauthorized intrusion and sabotage at a facility that could lead to radiological damage, and (2) prevent illicit trafficking in nuclear materials that could lead to the proliferation of nuclear weapons.[13] It could be said that physical protection is the most tangible and visible part of safeguards. It involves alarms, fences, barriers, guards, surveillance, floodlights, etc. Nuclear power plants are the main target of physical protection, but also facilities for disposal of radioactive material.[14] A future final repository for high-level

---

[12] Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards.

[13] Håkansson, A. & Jonter, T. (2007), p. 70.

[14] SSM (2012)*Översyn av tillståndshavarnas och samhällets förmåga att skydda kärntekniska anläggningar och transporter av kärnämnen mot antagonistiska hot* ("Survey of licensees' and

nuclear waste has special physical protection needs, which should also be noted in SKB's 2011 application (and to which we will return towards the end of this chapter).

3.3.2 Purpose of safeguards

Safeguards are regulated in a number of different IAEA regulatory documents. These documents are ranked in a defined value hierarchy, where Fundamental Safety Principles is a top-ranked normative document. Next come various Safety Requirements, which in turn provide guidance for different Specific Safety Guides and Technical Reports. It should be emphasized that neither Specific Safety Guides nor Technical Reports are legally binding on IAEA Member States.[15]

Safeguards do not receive much attention in either *Safety Fundamentals* (2006) or *Specific Requirements* (2011), but are thoroughly dealt with in the latest version of a *Specific Safety Guide* (2011) on management of spent nuclear fuel and a *Technical Report* (2010) on geological disposal facilities.

Specific Safety Guide No. SSG-14 (2011) states the fundamental objective of safeguards as follows:

> The objective of IAEA nuclear safeguards is the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown and the deterrence of such diversion by the risk of early detection. Geological disposal provides long term passive nuclear security, consistent with the objective of IAEA nuclear safeguards.[16]

The concluding sentence in this quote is of crucial importance. It entails that a geological repository with passive barriers (i.e. barriers that do not require active monitoring) – of the type which SKB has applied for a licence to build – complies with the IAEA requirement on long-term safeguards. But such a geological

society's ability to protect nuclear facilities and shipments of nuclear material from hostile threats", in Swedish. (SSM 2010-2632). Appendix 2, p. 3.

[15] Bäckblom, G. & Almén, K-E. (2004), *Monitoring during the stepwise implementation of the Swedish deep repository for spent fuel.* SKB R-04-13, p. 23.

[16] IAEA (2011), *Specific Safety Guide No. SSG-14. Geological Disposal Facilities for Radioactive Waste,* p. 47.

repository is of course not a sufficient prerequisite for effective safeguards. The IAEA has specified a number of different measures that are necessary to prevent the spent nuclear fuel from being used for illicit purposes. These measures are not restricted merely to an accounting of all spent nuclear fuel that is actually deposited in the repository, but also include a number of other measures. According to current requirements, the entire nuclear fuel cycle from mine to repository has to be accounted for and subjected to safeguards.[17]

3.3.3 The three phases of safeguards

Specific Safety Guide No. SSG-14 (2011) and other IAEA standards differentiate between safeguards:

1. during the pre-operational phase prior to the actual deposition of nuclear fuel,
2. during the operational phase when the spent nuclear fuel is being deposited in the final repository, and
3. during the post-closure phase of the repository.

The final repository is unique insofar as the facility is in the pre-operational phase and the operational phase at the same time. Construction of new tunnels, deposition of canisters and backfilling of tunnels take place at the same time in different parts of the repository. Since the different phases entail different types of safeguards, it can be fruitful to distinguish between them.

Safeguards in the pre-operational phase

According to the IAEA's technical report *Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste* (*Technical Report*, 2010)[18], the pre-operational phase begins after a specific site has been selected. It begins with a

[17] Håkansson, A. & Jonter, T. (2007), p. 46.
[18] IAEA (2010), *Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste.* Technical Report. NW-T-1.21.

site characterization which, along with a repository concept, delivers data to the safety assessment. The purpose of this work is described in the following manner:

> The objectives of this work are to establish the baseline information for the site, to provide a comprehensive understanding of the nature and properties of the geological and surface environments and to support the safety case and the basic repository system design.[19]

Technical Report No. NW-T-1.21(2010) adds that such site characterization will include test drilling, which can also be useful for the purposes of safeguards. Effective safeguards may require consultations between the IAEA, the operator, and state and regulatory authorities regarding the special conditions on the selected site and the safeguards that may be needed.[20]

The IAEA's safeguards authority may also request information on the design of the final repository so that it can propose various modifications that could facilitate the inspection of the spent nuclear fuel.[21]

The second stage in the pre-operational phase is initial excavations of the repository's shafts, ramps and galleries. The IAEA would during this phase be able to carry out Design Information Verification (DIV) to ensure there are no undeclared underground chambers where the fuel canisters could be opened and the spent nuclear fuel could be reprocessed for weapons use.[22] During this phase, the IAEA may also want to install various types of instruments to verify the design and to calculate different values for comparison with other values later on.[23]

Safeguards in the operational phase

The operational phase starts when the encapsulated nuclear waste begins to be delivered to the final repository.[24] Safety is fundamental for both the working environment and safeguards and

[19] IAEA (2010), *Technical Report*, p. 9.
[20] IAEA (2010), *Technical Report*, p. 12, 14 f.
[21] IAEA (2010), *Technical Report*, p. 13 f.
[22] IAEA (2010), *Technical Report*, p. 12.
[23] IAEA (2010), *Technical Report*, p. 15.
[24] IAEA (2011), *Specific Safety Guide*, p. 5.

entails accounting and recording of the spent nuclear fuel, and in particular fuel that could be used for the manufacture of nuclear weapons. Anni Fritzell has clarified the implications of this requirement in SKI's technical journal *Nucleus*:

> From a safeguards perspective, two aspects in particular must be considered: That the spent fuel has the expected characteristics and that material that is supposed to be at a given place at a given time is in face there at that time. The most important fuel characteristics in the safeguards work are those that influence how the fuel could be used in nuclear weapons production and those that show how the operators have handled the fuel. For these reasons, it is important to have information on the proportion of uranium and plutonium isotopes, i.e. the material in the spent fuel that could be used in nuclear weapons /translated from the Swedish/.[25]

Of central importance in these contexts are material accountancy measures, or what is known as C/S (containment and surveillance). This is described as follows in *Technical Report No. NW-T-1.21* (2010):

> The C/S measures may include visual observation, camera surveillance, safeguards seals, radiation (neutron and gamma ray) monitors and motion detectors. A system of radiation monitors and surveillance cameras is expected to be used to verify declared transfers of spent fuel casks from the surface buildings to the underground facility. These monitors and cameras would likely be located at the entrance to the transport shaft or ramp.[26]

In other words, very extensive measures are required. Other requirements also come into play when the encapsulated spent nuclear fuel has been deposited in the repository. The purpose of the IAEA recommendations on this point is to ensure that the nuclear waste that is supposed to be in a particular place at a particular time is in fact there at that time. This is to prevent nuclear waste being returned to the surface via fan ducts or other routes. Surveillance equipment and seals are among the measures

---

[25] Fritzell, A. (2007), "Safeguardperspektiv på slutförvaret. Kontroll av bränslets egenskaper lika viktigt som att kontrollera antalet element" ("Safeguards perspectives on the final repository. Verification of fuel characteristics as important as verification of the number of fuel assemblies", in Swedish), *Nucleus* SKI 1, 2007, p. 11. See also Fritzell A. (2006), *Concerns when designing a safeguards approach for the back-end of the Swedish nuclear fuel cycle*. SKI Report 2008:18. Swedish Nuclear Power Inspectorate.

[26] IAEA (2010), *Technical Report*, p. 12.

used to prevent this. Design Information Verification (DIV) is of fundamental importance in this work.[27]

Safeguards in the post-closure phase

Finally, safeguards are also applied to the post-closure phase of the repository. During this period, safeguards can be maintained by satellite surveillance, aerial photography or different kinds of electronic equipment that provide information on conditions in the final repository (Chapter 6).

Some conflict can be noted in the regulatory framework between one line that emphasizes the function of the passive barriers and another line that emphasizes active post-closure safeguards. An important safety standard states for example that:

> The operator shall evaluate the site and shall design, construct, operate and close the disposal facility in such a way that safety is ensured by passive means to the fullest extent possible and the need for actions to be taken after closure of the facility is minimized.[28]

But later on, the same document stresses that institutional controls can nevertheless contribute to preventing human intrusion that could compromise the safety of the geological disposal facility. Institutional controls can also contribute to increasing public acceptance of a geological repository.[29]

The design of safeguards in conjunction with the construction and operation of geological repositories is overseen by an expert group at the IAEA (Application of Safeguards to Repositories, ASTOR).

3.4 The Swedish regulatory framework

The point of departure for the Swedish regulatory framework with regard to safeguards is the Nuclear Activities Act. Section 3 of this Act states:

---

[27] IAEA (2010), *Technical Report*, p. 12 f.
[28] IAEA (2011), *Specific Safety Requirements. No. SSR-5. Disposal of Radioactive Waste*, p. 21.
[29] IAEA (2011), *Specific Safety Requirements*, p. 42.

> Nuclear Activities shall be conducted in such a manner that safety requirements are met and the obligations entailed by Sweden's obligations under treaties aimed at preventing the proliferation of nuclear weapons and unauthorized dealings with nuclear material and nuclear waste consisting of spent nuclear fuel are fulfilled.

The Swedish Radiation Safety Authority (SSM) is the authority that issues regulations so that these obligations are fulfilled. This is evident from the document SSMFS 2008:3.[30]

3.4.1 Important points in SSM's regulations

The regulations initially refer to Commission Regulation (Euratom) No. 302/2005 on the application of Euratom safeguards. The regulation is directly applicable in the Member States. This means that it is not permitted to introduce any additional national rules so that the regulation will apply in Sweden. The regulation applies directly to the facility owners, which means that it is the facility owner who is responsible to the Euratom Community with regard to safeguards. It is also punishable under Section 27 b of the Nuclear Activities Act to violate the provisions of the regulation.

Furthermore, inspectors employed by the European Commission are entitled to have access to all data and all sites covered by the safeguards. The Commission carries out its inspection in close cooperation with the IAEA. This cooperation is closely regulated in the protocol additional to INFCIRC/193 and the Approach for Integrated Safeguards.

Section 3 of SSM's regulations on safeguards etc. (SSMFS 2008:3, in Swedish) include requirements with respect to organization, leadership and management of the nuclear activities. As far as safeguards are concerned, Section 9 of the regulations refers to the IAEA's requirements on facility description, nuclear material safeguards and inventory. A special appendix contains a form for

[30] SSM (2008), *Strålsäkerhetsmyndighetens föreskrifter om kontroll av kärnämne mm. och Strålsäkerhetsmyndighetens allmänna råd om tillämpningen av föreskrifterna om kontroll av kärnämne m.m.* ("The Swedish Radiation Safety Authority's regulations concerning nuclear material safeguards etc. and the Swedish Radiation Safety Authority's general advice on the application of the regulations concerning nuclear material safeguards", in Swedish). (SSMFS 2008:3).

the information that is to be communicated to SSM when the spent nuclear fuel is relocated to the final repository.

3.4.2 Important points in SSM's general advice

The general advice regarding the regulations is initially reminiscent of the international regulatory framework.[31] Of particular interest in view of the Council's seminar on organizational matters in the autumn of 2014 is the assertion that the organization should be designed and manned so that it supports satisfactory safeguards at the facility.[32]

It should not be too narrow, but should include all measures required in connection with safeguards. The general recommendations further add the following:

> Well-functioning procedures should exist for continuous experience feedback and regular competency development within all parts of the organization that have duties of importance for safeguards.[33]

In comments on sections 5 and 6, further recommendations are given on procedures in conjunction with the IAEA's inspections and the need for prepared information. Of particular interest in this context is the general advice in SSMFS 2008:21 to Section 8 in the regulations, which are in agreement with the provisions of SSMFS 2008:37[34]:

> Measures can be adopted during construction and operation for the possible monitoring of a repository's integrity and its barrier performance after closure. Such measures can also be adopted to maintain safeguards. Measures can also be adopted during construction and operation with the primary aim of facilitating the retrieval of deposited nuclear materials and nuclear waste from the repository, either during the operating period or after closure. Furthermore, measures can be adopted to make intrusion into the repository difficult or to warn against intrusion. The safety analysis report for the facility in accordance with Section 9 should show that these measures

[31] Note that the general advice on SSM's regulations is only indicative and not binding on either the plant owner or SSM.
[32] SSMFS 2008:3, p. 4.
[33] SSMFS 2008:3, p. 4.
[34] SSM (2008), *The Swedish Radiation Safety Authority's regulations concerning the protection of human health and the environment in connection with the disposal of spent nuclear fuel and nuclear waste.* SSMFS 2008:37.

> either have a minor or negligible impact on repository safety, or that the measures result in an improvement of safety, compared with the situation if the measures had not been adopted. These provisions are in agreement with the Swedish Radiation Safety Authority's regulations SSMFS 2008:37.[35]

In SR-Site, the Swedish Nuclear Fuel and Waste Management Co (SKB) comments on the need for post-closure monitoring and makes the following assessment:

> The intention is not to monitor the engineered barrier systems – i.e. canister, buffer and backfill – for deposited waste, since deployment of the instrumentation and the necessary cabling to sensors will probably degrade the safety functions of the engineered barriers (translated from Swedish).[36]

The Swedish National Council for Nuclear Waste discussed this question in its State-of-the-Art Report 2010[37] and in its viewpoints on the need for supplements to SKB's application.[38]

It can be observed as a general comment on these regulations and advice that they have mainly been framed with a view to safeguards for nuclear power plants and are not clearly linked to the requirements imposed by nuclear materials safeguards in conjunction with the construction, operation and closure of a final repository for spent nuclear fuel.

3.5 Safeguards in SKB's application

The issue of safeguards is briefly touched upon in the so-called "top document" in SKB's application under the Nuclear Activities Act.[39] Reference is made there to one of the main appendices,

---

[35] SSM (2008), *The Swedish Radiation Safety Authority's general advice on the application of the regulations concerning safety in connection with the disposal of nuclear material and nuclear waste.* SSMFS 2008:21, p. 4.
[36] SKB (2011), *Redovisning av säkerhet efter förslutning av slutförvaret för använt kärnbränsle.* ("Long-term safety for the final repository for spent nuclear fuel at Forsmark", in Swedish). *Main report of the SR-Site project. Part I*, p. 207.
[37] SOU 2010:6 *Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme.*
[38] *The Swedish National Council for Nuclear Waste's viewpoints regarding the need for supplementary information in applications for licences for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333-11).* (Reg. no. 43/2012).
[39] SKB (2011), *Ansökan om tillstånd enligt lagen (1984:3) om kärnteknisk verksamhet till uppförande, innehav och drift av en kärnteknisk anläggning för slutförvaring av använt*

SR-Operation, which in turn makes reference to the document *Nuclear material safeguards in the KBS-3 system* (both documents in Swedish).[40] The question is also dealt with in *SR-Site*.[41] Finally, the question of safeguards is also dealt with in *Application for encapsulation plant (Clink)*.[42]

Generally speaking, it would be an advantage if issues relating to safeguards were given a coordinated treatment in SKB's application, for example in a special appendix. In the document *Nuclear material safeguards*, however, a brief summary is presented of the safeguards which the final repository project and the encapsulation plant require. There it is asserted that a well-functioning system for safeguards requires a holistic view of the entire fuel handling chain from reception to deposition of the canisters in the final repository.

3.5.1 Safeguards in the pre-operational phase according to SKB's application

Safeguards in the initial period of the pre-operational phase are discussed briefly in *Nuclear material safeguards*.[43] The document also contends that safeguards are facilitated if the need for equipment rooms, measurement equipment, cameras and instruments for monitoring according to the viewpoints of the international and national regulatory bodies is taken into account in the layout of the facilities in the design phase, and if the facility is made as transparent as possible. SKB adds that a room has already been reserved in Clink's encapsulation building for the regulatory authorities' safeguards. It is also asserted there that:

---

kärnbränsle och kärnavfall. ("Application for a licence under the nuclear Activities Act for construction, ownership and operation of a nuclear facility for the final disposal of spent nuclear fuel and nuclear waste", in Swedish. Top document, p. 39.

[40] SKB (2011), *Säkerhetsredovisning för drift av slutförvarsanläggning för använt kärnbränsle (SR-Drift) kapitel 4 – Kvalitetssäkring och anläggningens drift.* ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 4 – Quality assurance and operation of the facility", in Swedish), p. 19. See further SKB (2009), *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish) – here abbreviated *Nuclear material safeguards*.

[41] SKB *SR-Site*, p. 207.

[42] SKB (2009), *Ansökan om inkapslingsanläggning (Clink). Pärm 2. Chapter 4. Kvalitetssäkring och anläggningens drift* ("Application for encapsulation plant (Clink). Volume 2. Chapter 4. Quality assurance and operation of the facility", in Swedish), p. 7.

[43] SKB (2009) *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish), p. 4 f.

> SKB will, in good time before the start of operation of Clink (encapsulation) and the final repository submit "Basic Technical Characteristics" (BTC) to Euratom and "Design Information Questionnaire " (DIQ), which will be sent to the IAEA by Euratom or the Swedish Radiation Safety Authority (translated from Swedish).[44]

Another measure in a later stage of the pre-operational phase is referred to in *SR-Operation*, namely the activity that falls under the concept Design Information Verification (DIV). SKB writes in *SR-Operation*, Chapter 4 (under heading 6 Safeguards) that there shall be:

> a clear layout and clear description showing what has been built so that there are no roads out from the facility that have not been indicated and no underground spaces with other activities than that indicated (translated from Swedish).[45]

It could be added that the IAEA will want to install different types of instruments and seals during this stage in order to verify the design.

In the transition between the pre-operational and the operational phase, the spent nuclear fuel is transported from Clab (the interim storage facility for spent nuclear fuel) to Clink (the encapsulation plant) in special transport casks. The regulatory body will establish certain Key Measurement Points (KMPs), for example at the fuel handling pool and at the point before the lid is put on and in the lock before the canister is transported out of the facility.

3.5.2 Safeguards in the operational phase according to SKB's application

When it comes to safeguards, the emphasis in SKB's application is on the operational phase. Of particular importance is the aforementioned document *Nuclear material safeguards*. Particular attention is devoted to the reporting and documentation (with marking and recording) of the canisters that are transported from Clab to Clink and from Clink to the final repository. Each canister

[44] SKB (2009) *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish), p. 4.

[45] SKB *SR-Drift* ("SR-Operation", in Swedish), Chapter 4, p. 19. See also SKB (2009) *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish), p. 7.

will have a unique identity that can be checked visually. Prior to transport from Clink to the final repository, the canisters are placed in special transport casks, which are sealed. On arrival at the final repository, the regulatory authority's inspection body can verify that the transport cask has arrived in unchanged condition.

At the final repository, the canisters' disposal location is then documented in a reliable manner. A universal basic principle is "Continuity of Knowledge" (CoK), which entails that the safeguards cover the entire transport chain from Clab to the final repository and that each move is documented.

If it is necessary to retrieve deposited canisters during the operational phase, the same principles are applied as during deposition of the canisters.

The document *Nuclear material safeguards* states that:

> SKB's ambition is that the system for safeguards shall be credible and reliable and have as little impact as possible on the facility and its operation, while at the same time being easy to check for the regulatory body.[46]

3.5.3 Safeguards in the post-closure phase according to SKB's application

The post-closure phase is not dealt with further in the document *Nuclear material safeguards*. The introduction to *SR-Operation* contains the following definition of the term "safeguards": "System for determining the quantity of nuclear material in a facility for the purpose of preventing illicit proliferation", (translated from Swedish).[47] It is noted in *SR-Operation* that safeguards will not cease after the spent nuclear fuel has been deposited and the final repository has been closed, but will continue for as long as the Non-Proliferation Treaty is in effect.[48] However, the question of what measures safeguards will require after closure is not further dealt with in this document, but in *SR-Site*.[49] There it is stated that

[46] SKB (2009) *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish), p. 8.
[47] SKB (2011), *SR-Drift* ("SR-Operation", in Swedish), Chapter 1, Introduction, p. 17.
[48] SKB (2009) *Kontroll av kärnämne inom KBS-3-systemet* ("Nuclear material safeguards in the KBS-3 system", in Swedish), p. 3.
[49] SKB 2011, *SR-Site* ("SR-Operation", in Swedish), p. 207 (section 5.8.4. Monitoring after deposition of the waste)

the intention is not to monitor the engineered barrier system, since deployment of the instrumentation and the necessary cabling to sensors will probably degrade the safety functions of the engineered barriers. Furthermore, according to SR-Site, no legal requirements are made on post-closure monitoring. This is confirmed by reference to an SKB report written by Göran Bäckblom and Karl-Erik Almén,[50] which however says that safeguards may require surveillance in the form of monitoring even after closure and adds:

> The extent of the post-closure monitoring programme will essentially be given by the decisions made at closure and it is appropriate that any decisions on post-closure monitoring are taken by the generation that is the decision-maker at the time of closure. When responsibility for the repository is transferred to the State after closure it is then also necessary to clarify where responsibility for execution of the post-closure monitoring lies.[51]

The difficulty with this assessment is, however, that a decision must be made on post-closure monitoring much earlier, since the measurement equipment needed for safeguards must be prepared during the pre-operational phase and installed during the operational phase.

3.6 Requirements on supplements to the Land and Environment Court and SKB's reply

The Land and Environment Court at Nacka District Court has invited public authorities and organizations to submit proposals for supplementary information to supplement SKB's application. The Swedish National Council for Nuclear Waste submitted several proposals for supplementary information in October 2012. There the Council asserted the following:

> Safeguards against nuclear non-proliferation entail international control to ensure that nuclear fuel is not used to produce nuclear weapons. An international agreement between the IAEA (International Atomic Energy Agency), Euratom and the EU's Member States regulates how this control is to take place. The agreement also applies to geological repositories, even though it is not adapted to this type of facility.

[50] Bäckblom, G. & Almén, K-E. (2004).
[51] Bäckblom, G. & Almén, K-E. (2004), p. 7.

> Discussions are still being conducted on how the international requirements on safeguards should be designed for a geological repository. In a policy document in 1988, an advisory group to the IAEA said that safeguards for a final repository should be maintained as long as a safeguards agreement is in force. How such safeguards are to be designed is not specified in the application.[52]

In its reply to the Swedish National Council for Nuclear Waste's viewpoints on the need for supplementary information, SKB did not respond to these viewpoints, but they did provide a more detailed response to similar viewpoints from the Swedish Society for Nature Conservation and the Swedish NGO Office for Nuclear Waste Review (MKG). The associations say that applicants must describe how monitoring for the purpose of safeguards is to take place after closure of the final repository. Furthermore, the associations demand "that applicants describe how monitoring for the purpose of safeguards is to take place after closure of the final repository." SKB responds to these viewpoints in the following manner:

> SKB believes that the final repository should be designed so that no equipment will be needed to monitor the status and integrity of the canisters after closure and decommissioning of the facility. The requirement on safeguards remains, however. The application of safeguards will require a level of monitoring that permits the early detection of movements of fissionable material. A probable indicator of unpermitted movements could be unexpected excavation of engineered or natural barriers. Such activity can be detected by means of inspections, aerial photography, satellite imagery and microseismic surveys (IAEA-TECDOC-1208, translated from Swedish).[53]

SSM has requested supplementary information from SKB regarding the international regulatory framework and SKB has replied:

> SR-Operation will undergo revision, resulting documents in that will be included in a preliminary safety analysis report, PSAR, that will be

[52] SOU 2013:11 *Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures*, p. 138. See further SOU 2010:6 *Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme*, p. 39, where it is stated that the possibility of retrieval of deposited nuclear waste after closure warrants continued safeguards.
[53] See *Ansökan enligt miljöbalken – komplettering II – april 2013. Bilaga K3* ("Application under Environmental Code – supplement II – April 2013. Appendix K3", in Swedish), p. 133.

> approved by SSM before construction of the final repository can begin (translated from Swedish).[54]

In the autumn of 2014, SSM published a report with information on fuel assemblies in Clab and at the nuclear power plants.[55] The purpose of the study is:

> to determine what information is available on the spent nuclear fuel that is to be disposed of. The intention is to investigate whether the information is sufficient to fulfil Sweden's obligations with respect to nuclear non-proliferation.[56]

The study shows that:

> For fuel unloaded before 1980, most data can be retrieved, but all data are not stored electronically and some effort is required to retrieve them.

3.7 Concluding reflections

Safeguards may at first glance appear to be complicated and difficult, but actually concern essential aspects of the final repository project. It might even be said that they offer an inroad to nearly all parts of the final disposal question and the entire nuclear fuel cycle, from extraction of nuclear fuel to its final disposal. Vital ethical issues are involved in each step, and a careful balance must be struck between different values. A central question is the balance between openness and safety, i.e. between how much information can be made available to the public and how much must be kept confidential. This important question would require a more detailed analysis. As already mentioned, the purpose of this chapter has been to point out the interface between the safeguards issues on the one hand and considerations pertaining to monitoring and documentation on the other, which are dealt with in other chapters of this state-of-the-art report.

[54] SKB (2013), *Svar till SSM på begäran om komplettering rörande kärnämneskontroll.* ("Reply to SSM on request for supplementary information regarding safeguards", in Swedish).
[55] Lindahl, H. (2014), *A Study of Availability of Fuel Data for Sweden's Spent Nuclear Fuel.* Technical Note. SSM 2014:50.
[56] Lindahl, H. 2014, p. 5.

References

Bäckblom, G. & Almén, K-E. (2004), *Monitoring during the stepwise implementation of the Swedish deep repository for spent fuel.* SKB R-04-13. Stockholm: Swedish Nuclear Fuel and Waste Management Co.

Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards.

European Commission (2014), *Report on the Implementation of Euratom Safeguards in 2013.* April 2014 Ref. Ares(2014)1534607 – 14/05/2014. See: www.iea.org/publications/freepublications/publication/etp2010.pdf (downloaded 2 February 2015).

Fritzell A. (2006), *Concerns when designing a safeguards approach for the back-end of the Swedish nuclear fuel cycle.* SKI Report 2008:18. Swedish Nuclear Power Inspectorate.

Fritzell, Anni (2007), ”Safeguardperspektiv på slutförvaret. Kontroll av bränslets egenskaper lika viktigt som att kontrollera antalet element” (“Safeguards perspectives on the final repository. Verification of fuel characteristics as important as verification of the number of fuel assemblies”, in Swedish), *Nucleus* SKI 1, 2007, pp. 10–13.

http://ec.europa.eu/energy/nuclear/safeguards/safeguards__en.htm (downloaded 2 February 2015).

http://ec.europa.eu/energy/en/content/annual-report-commissions-nuclear-safeguards-activities-2013.

Håkansson, A. & Jonter, T. (2007), *Icke-spridning och kärnämneskontroll* (“Non-proliferation and safeguards”, in Swedish). SKI Rapport 2007:45.

IAEA (2006), *Safety Fundamentals. No. SF-1. Fundamental Safety Principles*. Vienna: International Atomic Energy Agency.

IAEA (2010), *Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste.* Technical Report. NW-T-1.21. Vienna: International Atomic Energy Agency.

IAEA (2011), *Specific Safety Requirements. No. SSR-5. Disposal of radioactive waste.* IAEA. Vienna: International Atomic Energy Agency.

IAEA (2011), *Specific Safety Guide. No. SSG-14. Geological Disposal Facilities for Radioactive Waste.* Vienna: International Atomic Energy Agency.

History of nuclear power. See: www.stralsakerhetsmyndigheten.se/Global/Publikationer/SKI_import/050215/a3f256e53422eeb15e8084c81328db82/ppk_kap5_6.pdf (downloaded 15 January 2015).

Lindahl, Henrik (2014), *A Study of Availability of Fuel Data for Sweden's Spent Nuclear Fuel*. Technical Note. SSM 2014:50. Swedish Radiation Safety Authority.

OECD/IEA & OECD/NEA (2010), *Technology Roadmap. Nuclear energy.* See: www.iea.org/publications/freepublications/publication/nuclear_roadmap.pdf (downloaded 15 January 2015).

SKB (2009), *Ansökan om inkapslingsanläggning (Clink). Pärm 2. Chapter 4. Kvalitetssäkring och anläggningens drift. ("Application for encapsulation plant (Clink). Volume 2. Chapter 4. Quality assurance and operation of the facility", in Swedish).* Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2010) *Kontroll av kärnämne inom KBS-3-systemet.* ("Nuclear material safeguards in the KBS-3 system", in Swedish). SKBdoc 1172138. Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2011), *Ansökan om tillstånd enligt lagen (1984:3) om kärnteknisk verksamhet till uppförande, innehav och drift av en kärnteknisk anläggning för slutförvaring av använt kärnbränsle och kärnavfall.* ("Application for a licence under the Nuclear Activities Act for construction, ownership and operation of a nuclear facility for the final disposal of spent nuclear fuel and nuclear waste", in Swedish). Top document. Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2011), *Säkerhetsredovisning för drift av slutförvarsanläggning föranvänt kärnbränsle (SR-Drift) kapitel 1 – Introduktion.* ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 1 – Introduction", in Swedish). (Document ID 1091960). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2011), *Säkerhetsredovisning för drift av slutförvarsanläggning för använt kärnbränsle (SR-Drift) kapitel 4 – Kvalitetssäkring och anläggningens drift.* ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 4 – Quality assurance and operation of the facility", in Swedish). (Document ID 1091959). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2011), *Redovisning av säkerhet efter förslutning av slutförvaret för använt kärnbränsle. Huvudrapport från projekt SR-Site Del I.* ("Long-term safety for the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project, Part I", in Swedish). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2013), *Ansökan enligt miljöbalken – komplettering II – april 2013.* ("Application under the Environmental Code – supplement II – April 2013", in Swedish). Bilaga K:3 Frågor och svar per remissinstans ("Appendix K:3 Questions and answers by reviewing body", in Swedish). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SKB (2013), *Svar till SSM på begäran om komplettering rörande kärnämneskontroll*. ("Reply to SSM in response to request for supplementary information regarding safeguards", in Swedish). (Document ID 1371905). Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SOU 2010:6 *Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

SOU 2013:11 *Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

SSM (2008), *Strålsäkerhetsmyndighetens föreskrifter om kontroll av kärnämne mm. och Strålsäkerhetsmyndighetens allmänna råd om tillämpningen av föreskrifterna om kontroll av kärnämne m.m.*

("The Swedish Radiation Safety Authority's regulations concerning nuclear material safeguards etc. and the Swedish Radiation Safety Authority's general advice on the application of the regulations concerning nuclear material safeguards", in Swedish). SSMFS 2008:3.

SSM (2008), *The Swedish Radiation Safety Authority's general advice on the application of the regulations concerning safety in connection with the disposal of nuclear material and nuclear waste.* SSMFS 2008:21.

SSM (2008), *The Swedish Radiation Safety Authority's Regulations Concerning the Protection of Human Health and the Environment in Connection with the Final Disposal of Spent Nuclear Fuel and Nuclear Waste.* SSMFS 2008:37.

SSM (2012), *Översyn av tillståndshavarnas och samhällets förmåga att skydda kärntekniska anläggningar och transporter av kärnämnen mot antagonistiska hot.* ("Survey of licensees' and society's ability to protect nuclear facilities and shipments of nuclear material from hostile threats", in Swedish). (SSM 2010-2632). Swedish Radiation Safety Authority.

www.iea.org/publications/freepublications/publication/etp201.pdf (downloaded 2 February 2015).

4 Information and knowledge preservation in connection with final disposal of spent nuclear fuel

4.1 Introduction

Traditionally, one of the most important prerequisites for a successful final repository for spent nuclear fuel is the prevention of human intrusion into the repository. It is therefore necessary to isolate the final repository and its contents from other human activities. At the same time, this isolation entails a risk that society's collective memory of the repository's characteristics and function will be lost. Hence, it would seem that there is a risk associated with the construction of final repositories for spent nuclear fuel that future generations will, at least in the long term, lose important information and knowledge regarding why the repository was built, what it contains and what risks could be associated with intruding into it. In other words, there is a fundamental conflict between the generally accepted goal of disposing of spent nuclear fuel and the chances of preserving knowledge of this disposal.

In view of this, it is scarcely surprising that attention is being given to information, knowledge and memory aspects as final repositories for spent nuclear fuel are planned and eventually built at more and more places in the world. For some years now, recommendations have been issued for what records management systems should contain and how they should be handled, what techniques can be used and how access to the information can be facilitated. The International Atomic Energy Agency (IAEA) in particular has developed methods for recording and preserving information and knowledge. These methods have however often been fundamental and have had a distinct instrumental perspective.[1]

Broader perspective

In recent years, new research approaches have begun to be used more seriously in order to obtain broader perspectives on knowledge preservation and how information can be secured for future generations, not least by the use of semiotics, history of knowledge and experience from preservation of memory. In other words, the regulatory perspectives on records management and preservation plans have been broadened to include all kinds of institutional perspectives on the preservation of records, knowledge and memory.[2] Altogether, this has led to the inclusion of cultural interpretation and comprehension contexts in the preservation work in order to improve the prospects of success in these efforts. At present, research is being pursued on how facilities can be designed from a records and preservation viewpoint in a number of fields: archaeology, architecture, archival science, philosophy, history, art history, semiotics, etc.

Purpose

This chapter makes no claim on providing a comprehensive overview of the area. The purpose is rather to shed light on some central themes and insights that have emerged in recent years within the interdisciplinary field of study that is investigating whether it is desirable to preserve and communicate knowledge of a final repository for spent nuclear fuel to future generations, and if so how this can be done in a reliable manner. In all known cases so far, the basic strategy of different types of final repositories for spent nuclear fuel is to isolate the repository from human activity and impact, in many cases (such as the Swedish one) by the use of

[1] See for example IAEA (1999), *Maintenance of records for radioactive waste disposal.*
[2] IAEA (2001), *Waste inventory record keeping systems (WIRKS) for the management and disposal of radioactive waste*. p. 29.

multiple engineered and natural barriers, where different kinds of bedrock are often an important element. However, the construction of these different barriers as components in a final repository should be combined with methods for preserving documentation and knowledge concerning the contents of the final repository and why it is important not to try to open it. Also of importance are questions concerning the possibilities of surveillance[3] and monitoring of final repositories, and whether (and if so how) the site of a final repository should be marked in the terrain, on maps and in other representations of the site.

Different time perspectives

When it comes to preservation of knowledge and memory of final repositories for spent nuclear fuel, the time aspect is of very great importance. The outline of this chapter follows the time frames proposed by the OECD/NEA's Expert Group on Preservation of Records, Knowledge and Memory (RK&M) across Generations, which proposes that records, preservation and memory matters be dealt with from three time perspectives:

1. the short term, which applies to the period during which a final repository is built, a few decades,
2. the medium term, which extends from a finished final repository until continuous oversight ceases, typically a few centuries, and
3. the long term from the end of continuous oversight, typically millennia.

Each time horizon poses its own challenges for investigating the problems of preserving knowledge of a repository.[4]

The Expert Group on Preservation of Records, Knowledge and Memory in the OECD/NEA has just concluded the first phase of its work of re-examining record-keeping and preservation management aspects and creating standards and other common

---

[3] Read more about this in Chapter 6.
[4] See also IAEA (2001), *Waste inventory record keeping systems (WIRKS) for the management and disposal of radioactive waste*, p. 1 f.

resources in the area. This work has proceeded between 2011 and 2014 has involved thirteen Member States, including Sweden.

Now the work is proceeding into a second phase from 2014 to 2017 which includes twelve countries along with the IAEA. The Expert Group is adopting a dual-track strategy. This strategy involves using both traditional methods for record-keeping and preservation while also discussing complementary methods such as the use of symbols (tokens) and decorations at the repository, or site-specific markers to warn or inform future humans on what the site has been used for.

4.2 Basic principles

Distinction between information and knowledge

Ordinarily, information refers to data without a context, for example, information can be concealed in dead written languages that can no longer be interpreted or understood. Knowledge entails information in a context where it can be interpreted and understood. Knowledge of a dead written language entails that it has been brought back to life so that the hidden information can be processed and interpreted.

Direct and indirect knowledge transmission

Another important distinction is the one between direct, non-mediated knowledge transmission between generations and indirect, mediated knowledge transmission.

Direct, non-mediated knowledge transmission entails that information is recorded and preserved for transmission directly to future generations without any processing or alteration. In such contexts it is of course important to ensure as far as possible that both information and knowledge is preserved in such a manner that it can be used by future generations. Markers at the final repositories may be a method for direct knowledge transmission, for example by means of narrative structures, perhaps conveyed by decorations or specially designed monuments.

When it comes to mediated and indirect knowledge transmission, it is possible to edit and alter both information and knowledge to increase the chances that future generations will be able to understand it. Traditional archive management, involving culling and transferring information from one medium to another, may be a way of transmitting information from generation to generation.[5]

Examples of how information can be lost

An important consideration is how information can be lost. Information may be lost simply because it has never been preserved or even been accessible. A decision to preserve information always involves some measure of immediate culling, which means that some information is not recorded. Furthermore, information may be lost due to a lack of resources or inadequate or poorly formulated record-keeping rules and practices. It can also happen due to legal or illegal handling as well as unavoidable accidents. The records may be accessible, but the information in them may be incorrect or corrupted.[6] Information may also be difficult or impossible to retrieve from records, since knowledge of how to handle them has been lost (for example because a certain medium technology is not available and cannot be recreated) or because knowledge is lacking on how to interpret and understand the information correctly. Additional difficulties with information preservation may arise in situations when both the information and the knowledge concerning it are accessible, but it is nevertheless not sought or used for various reasons, such as indifference.

RK&M conference in Verdun in September 2014

To mark the end of the first phase and the start of the second phase, RK&M organized a conference in Verdun in September 2014 with 190 participants from 17 countries, including Swedish

[5] Bowen-Schrire, M., Jander, H. & Waniewska, K. (2007), *Kunskapsbevarande för framtiden – Fas 1* ("Knowledge preservation for the future – Phase 1", in Swedish). SKB Report P-07-220.
[6] IAEA (2007), *Retrieval, Restoration and Maintenance of Old Radioactive Waste Inventory Records.*

organizations such as the Swedish National Archives, the Swedish National Council for Nuclear Waste, the Swedish NGO Office for Nuclear Waste Review (MKG) and SKB. Here it was concluded that there are numerous mechanisms besides traditional record-keeping and preservation that can be used to preserve the memory of the final repository for spent nuclear fuel. It was further concluded that there is a large body of literature on short- and long-term RD&M preservation, but much less when it comes to the medium term, perhaps due to uncertainties concerning how oversight will be managed and what technologies will be available, since this is an area currently undergoing rapid development. Furthermore, RK&M claims that the regulation of long-term perspectives requires greater systematics and more careful formulations of various problems so that the discussions and analyses will be more pregnant and more stringent. Moreover, the group also asserts that the long-term perspective requires more standardized terminology, a project which was already started during the first phase.

4.3 RK&M preservation in the short term, during the period the repository is being built – decades

Practical questions concerning preservation of information and knowledge arise and must be answered even before the construction of a final repository begins. Such questions include what type of information should be preserved and in what form it should be preserved.[7]

Multiple methods for information preservation

The US Department of Energy (US DOE) has proposed that information and knowledge should be preserved in multiple ways using multiple methods and in multiple contexts in order to increase the chances that it will be able to be interpreted by future generations. A special unit, the Office of Legacy Management,

[7] Bowen-Schrire, M. et al. (2007).

works to find ways to preserve records and information on e.g. nuclear facilities for the purpose of protecting human health and the environment after closure, including combining multiple methods for information preservation that also include conditional alternative uses for closed facilities. The goal is to make records available, maintain knowledge and retrieve memories of the facilities and the activities pursued there.

In a similar manner, the IAEA has contended that each body that manages nuclear waste should establish its own records management system.[8] To improve the chances of mediated information transmission, it may also be worthwhile to establish special interpretation and translation centres where the information is continuously revised so that it can be preserved in an up-to-date fashion. The importance of drawing up a plan for regular review and revision of information and continuously developing this plan to meet changing requirements and conditions is something that is emphasized by the IAEA as crucial in order to successfully not only preserve records, but also make the information in them accessible and usable in the short term.[9]

The importance of and problems with the short-term perspective

It has been observed within RK&M that the short-term perspective of decades or up to a century or so is actually relatively long-term, at least from the individual's perspective, since it corresponds roughly to a lifetime. RK&M preservation is important during this period, since that which is lost here is presumably lost forever. A great deal can happen in the short-term perspective as well and processes can be quite dynamic, but nevertheless important from a record-keeping, preservation and memory viewpoint.

At the same time, the group claims that not much analysis effort is being devoted to these matters, creating problems with inadequate institutional frameworks, including regulatory frameworks and follow-up. There is far too little interest in short-term

[8] IAEA (2005), *Methods for Maintaining a Record of Waste Packages during Waste Processing and Storage.* Technical Report Series No. 434, p. 9.
[9] IAEA (2008), *Long Term Preservation of Information for Decommissioning Project.* Technical Report Series No. 467, p. 54 ff.

information preservation in the international nuclear waste management industry, since attention is often focused on licence applications, where these matters are seldom of any crucial importance. In these licensing processes, the applicants do what they need to do to get a licence, but seldom more than that, which does little to promote processes and systems in support of record-keeping and information and knowledge preservation. A common practical problem is that requirements are often made on preserving all "relevant" records without a satisfactory definition of the term "relevant". The result is uncertainty concerning what should be preserved and what can be culled at an early stage.

Another concrete consequence is problems with division of roles and responsibilities for RK&M preservation, which can in turn create problems when short-term activities affect how RK&M preservation is managed in the medium and long term. Another problem is that, despite various financing programmes, repositories must be built within given budget constraints, which necessarily entails resource limitations. When different activities have to compete for funding within the same budget, record-keeping and knowledge preservation often get the short end of the stick when compared with the costs of construction work or surveillance.

The Expert Group on Preservation of Records, Knowledge and Memory has made certain efforts to contribute to solutions of these problems and others. One such effort is the creation of a reference work with definitions of different terms for Preservation of Records, Knowledge and Memory (RK&M), a so-called wiki where various participants can write articles that can then be edited by other members. The point is that the document is dynamic and is continuously edited and changed to keep up with changing requirements. The wiki is not yet public, but will be made public when it has become more reliable. Another initiative involves creating a standard for metadata, OECD/NEA Radioactive Waste Repository Metadata Management (RepMet). Here the goal is to increase understanding for the identification and administration of metadata (information on information). The basic idea is that all work done within the framework of different national final disposal programmes for spent nuclear fuel and other nuclear waste creates quantities of information that can be shared between different organizations so that duplication of work can be avoided.

At the same time as potential problems with records and preservation can be identified already in a short-term perspective, networks and institutional resources are available that could be better utilized than is currently the case. For example, the international geological research community and other international geological societies can be utilized to share and disseminate information on different types of geological conditions. Within the environmental movement there are opportunities to disseminate information on methods for environmental protection. Within cultural heritage management, research and practically oriented record-keeping and preservation activities are being pursued with established information exchange in international networks and organizations such as UNESCO World Heritage or initiatives such as "Memory of Mankind".

The Expert Group on Preservation of Records, Knowledge and Memory also proposes that short-term record-keeping and preservation matters be handled by several different actors and interest groups at several different levels: locally, regionally, nationally, internationally and globally. It is important that the activity be organized so that it is value-creating. This means that there is a plan for how the work of record-keeping and knowledge and memory preservation can be pursued with the aim of creating value for interest groups at several different levels in the process. This increases the chances that the work will be enduring and sustainable, at the same time as it will be easier to attract the necessary long-term funding. Value-creating measures may entail keeping records of ecological systems on the site of the final repository and how they change during the construction process. Other value-creating processes may involve creating artistically or architecturally interesting designs.

Involving more stakeholders increases the chances of redundancy in information knowledge preservation. At the same time, redundancy and parallel processes involving multiple actors makes it particularly important to have standardized methods and common terminology. In order to ensure uniformity and perhaps also funding, the question of international mechanisms has been raised. Here there is thus room for initiatives that could improve the potential for successful internationally coordinated parallel record-keeping and preservation processes.

Organizational and legal matters

Other aspects that must be dealt with in the short term are organizational and legal matters. Very little energy has been devoted to determining which legal entities and organizational forms are suitable for handling preservation of records, knowledge and memory. The British Nuclear Decommissioning Authority (NDA) has formed a subsidiary to take charge of archiving of records. In the USA, an important actor for RK&M preservation management in the nuclear sector is a not-for-profit organization, the Nuclear Information & Records Management Association (NIRMA), which also arranges annual conferences in the field.

In Sweden it is of course a matter of great importance who will own the records of the construction of a final repository and what laws and ordinances will apply to the owner's management of information and knowledge. According to the Swedish Radiation Safety Authority's regulation 2008:38, the archive from a nuclear facility that has ceased operating shall be turned over to the National Archives or a provincial archive in signed and ordered condition.[10] In spite of this, records management is given relatively short shrift in SKB's licence application, where it is nevertheless made clear that the project will be concluded with the handover of all final documentation to SKB's operating function, and there is room for more exhaustive accounts.[11] The Swedish Radiation Safety Authority has for example requested supplements of SKB's licence application regarding organizational matters, among other things.

Regardless of how record-keeping is planned to be managed and organized, it is an extremely important question where a balance must be struck between, on the one hand, awaiting the development of systems and techniques for records management, and on the other hand finalizing record-keeping methods in good time before the construction of a final repository in order to avoid

[10] SSM (2008), *Strålsäkerhetsmyndighetens föreskrifter om arkivering vid kärntekniska anläggningar* ("The Swedish Radiation Safety Authority's regulations concerning archiving at nuclear facilities", in Swedish). SSMFS 2008:38.

[11] SKB (2011), "Verksamhet, ledning och styrning – Uppförande av slutförvarsanläggningen" VU ("Activity, leadership and management – Construction of the final repository", in Swedish), Open Report, 4, p. 4. Appendix to *Application under the Nuclear Activities Act (KTL) to build, own and operate the final repository for spent nuclear fuel (in Swedish)*.

unclear owner relationships and unnecessary transfers and reallocations of important and sensitive material. Today SKB has a wait-and-see attitude to this question.

4.4 RK&M preservation in the medium term, from a finished repository until continuous oversight ceases – centuries

In the USA, the United States Nuclear Regulatory Commission (USNRC) has formulated clear requirements on descriptions of a method for records management and preservation in order to grant a licence to build a final repository for spent nuclear fuel. The same agency has also, together with many other actors in the nuclear fuel management field, made a clear distinction between:

- active control
- passive control

Active control (or active protection) during the construction of a final repository includes continuous social and technical measures to protect the facility, such as a fence to keep out unauthorized persons, maintenance of protection against the spread of radioactive material or monitoring of the repository by means of various surveillance methods.

Passive control (or passive protection) may be instituted after the facility has been built and closed, which means that the design of the facility renders human intrusion more or less impossible. The passive protective measures are thus maintained without active human interventions or oversight. This may involve preventing land use that could impact the function of the repository, but also preserving information.[12]

Note that the differences between active and passive protective mainly lie in the time dimension. Active measures are created and maintained in real time, while passive measures have been designed so that they maintain control over time without continuous active human interventions. In both cases it is thus a question of applying

[12] IAEA (1999), *Maintenance of records for radioactive waste disposal*, p. 1.

a combination of social and technical controls in order to exclude human activity from the area where a final repository has been created. In one case this is accomplished by continuous social and technical measures. In the other case it is accomplished by social and technical measures that have been instituted at a given time and will function over a longer period. From an archive management perspective, this means that record-keeping aspects are central in the short term, while preservation aspects are more important in the medium and long term, since activities at the repository first decrease and later on cease completely.

Criticism of passive protection

The strategy of letting the long-term protection of spent nuclear fuel be based on passive protection has also been criticized. Advocates of development programmes for nuclear energy claim that spent nuclear fuel could be reprocessed and serve as fuel in future generations of nuclear reactors, something which could moreover significantly reduce both the quantity of spent nuclear fuel and the time it needs to be kept isolated before the radiation levels are harmless to human health. Others have questioned passive protection as an absolute prerequisite for safe disposal spent nuclear fuel, since the functions are still questioned. In recent years, the idea of a final repository for spent nuclear fuel with passive protective measures has moreover lost rather than gained in legitimacy. In general, the criticism stems from the fact that even though the repository can be designed to provide the spent nuclear fuel with long-term protection, the repository itself still exists in a changing cultural context. This means that the freedom of action of future generations is limited in a way that they may perceive negatively. As an alternative principle, a better balance has instead been proposed between active and passive controls.[13] Such a balance can be achieved by means of greater reversibility in decision processes, with the option of retrieval of spent nuclear fuel, at least during a limited period. The French, for example, are working with such a solution.

[13] Schröder, J. (2014), ”Acting for passive safety”, *Work Package 2 – Topic: Reversiblity and Retrievability.* InSOTEC Working Paper.

Example: The French facility in Manche (ANDRA)

At the RK&M conference in Verdun, ANDRA (the French National Radioactive Waste Management Agency) reported that they have detailed information archived in 11,000 documents at their facility in Manche for short-lived low- and intermediate-level waste, which is stored in concrete-lined ditches covered by layer upon layer of different materials. The facility was closed in 1994, and since 2003 an information preservation plan is being applied there whereby records are regularly examined, simplified and renewed to enhance accessibility without losing information. One of the problems has namely been the large amount of information, which has had adverse effects for accessibility. In addition to this plan for what ANDRA calls passive preservation, they have also created a plan for active preservation where guided tours are organized at the facility together with exhibitions, collaborations with other interest groups, etc. In addition, "reflection groups" meet three to four times a year to develop the RK&M work and the preservation plan. Moreover, different kinds of dynamic works of art and decorations have been discussed, together with more durable markers with colour schemes that change over time to reflect the process of decay, etc.

Projects for a medium-term perspective

Other interesting projects for information and knowledge preservation in the medium term have involved creating extremely detailed digital records with photographs and maps which, together with other representations, can be made exceptionally detailed while at the same time providing a very comprehensive and accessible overview of a facility. In addition, three-dimensional images can be created, and different representations can be associated with images and stories that can explain why things turned out the way they did on a detailed level. This has not yet been tried in practice, but there are numerous systems and hardware that permit this type of massive digital documentation. Such methods can be very useful, not least for those who choose to preserve information in accordance with the simple principle "as much as possible for as long as possible", an idea that also has its advocates despite the obvious risk of huge resource requirements. The goal of the aforementioned RepMet (Radioactive Waste Repository Metadata Management) is to create metadata libraries within relevant areas based on tried and recognized methods ("best practices"). With a well-functioning system for metadata in the field of nuclear waste management, it is hoped that a great deal of work can be saved in the different national programmes with these resources.

4.5 RK&M preservation in the long term, without continuous oversight – millennia

Few future projects have been as inspiring to the imagination as the prospect of having to build a final repository for spent nuclear fuel that must be protected against both human intrusion and the forces of nature for hundreds of thousands of years or more. Many minds have pondered how such repositories can and should be designed so that the memory of their importance and associated risks can be preserved over what are, from the individual's perspective, very long periods of time. The proposals have ranged over a whole spectrum of problems and ideas, from calculations of the erosion of granite markers to futuristic visions bordering on science fiction.[14] Many people have tried to design different types of fixed or changing markers able to communicate danger regardless of cultural context. Others have stressed the importance of not using markers, since history shows that they attract interest rather than repelling it. When it comes to knowledge and memory preservation, the ideas have ranged from information etched on discs of virtually indestructible ceramic material to the creation of social institutions with the sole purpose of preserving and transmitting knowledge on the content and risks of the final repository, not wholly unlike religious orders.

[14] Heaney, C. (2013), "The 'forever problem': Nuclear waste as information", *iConference 2013 Proceedings, poster abstracts, Fort Worth,* Texas, February 12–15, 2013.

When it comes to long-term RK&M preservation, however, certain principles are particularly deserving of attention:

- avoiding the long-term perspectives
- high risk that information will be lost or distorted
- impossible to predict memory systems.

In the *first* place, there seem to be certain preferences for trying to completely avoid the long-term perspective by prolonging the continuous oversight of the repositories and thereby extending the medium-term perspective on information preservation. One drawback of this strategy is that the operating costs are shifted to future generations in a way that is not covered by the current cost calculations of the nuclear power industry. Alternatively, long-term perspectives can be transformed into medium-term ones by resuming oversight on the basis of education, access to metadata and cooperation between different facilities for the purpose of reconstructing knowledge and information. This approach also opens the way for reversible decision processes and the possibility of retrieval, and a better balance between active and passive protective measures as already discussed above.

In the *second* place, the assumption has widely been held that there is a very great, even imminent, risk that information and knowledge will be lost in a long-term perspective. There are however different scenarios here: that the loss is limited; that the loss is extensive and that information and knowledge will be distorted. The last scenario is regarded as the most alarming one. In order to prevent information from being lost or distorted, different methods have been discussed to enable information and knowledge to be reconstructed. There is, however, a consensus that the most effective option is to ensure if possible that information is not lost. This can be done by creating redundancy in the records and by creating several different parallel systems for information preservation.

In the *third* place, there seems to be a relatively widespread notion that it is virtually impossible to predict how information and knowledge should be preserved to ensure that it will be accessible even in very long-term perspectives. Instrumental approaches and strategies seldom seem convincing in this context.[15] If record-keeping systems are of primary importance in the short term and preservation systems in the medium term, there is much to indicate that memory systems adapted for information and knowledge transmission across many generations are the most appropriate in the long term. This may involve establishing and transmitting traditions and customs, images and stories, across generations rather than maintaining and preserving different types of mediated information. Since repositories for spent nuclear fuel have a fixed place in the landscape, many people have pointed out the importance of associating memories to the landscape, whether by means of markers or not.

In other words, memory and landscape appear to be key concepts for the long-term preservation of information and knowledge. Peter C. van Wyck, professor of Communication Studies, has spun further on this theme in his explanation of how humans have left their mark on the Earth.[16] Civilization has always left traces behind. Ever since the dawn of agriculture, man has altered the landscape to suit his activities. The term "Anthropocene" was launched in 2000 to denote the era when human activity began to make an irreversible impact on the Earth. At the same time, we see how the human impact on the Earth and the atmosphere seems to be accelerating. The ozone layer was under threat in the 1980s, but at least for the time being it seems to have been preserved in such good condition that the sun's ultraviolet rays are being attenuated. Today the most hotly debated issue is the greenhouse effect, another irreversible result of human activity. Yet another example is the swarm of geostationary satellites that encircle the Earth as a reminder of man's ambitions to use not only the Earth's resources, but also the space in the immediate vicinity of our planet.

Another example is the various species and life forms that have already been exterminated due to human activities. The pattern repeats itself almost endlessly. van Wyck's point is that all of these human traces comprise a kind of archive or record of mankind's

[15] van Wyck, P. C. (2004), *Signs of Danger: Waste, Trauma, and Nuclear Threat*.
[16] van Wyck, P.C. (2012), "An Archive of Threat", *Future Anterior* 9:2, 53–80.

ability to reshape the environment for its own purposes. From this perspective, repositories for spent nuclear fuel offer one of many examples of how human activities have left traces in the landscape, a kind of archive of human life on Earth. In this case the traces are of a less innocent kind than many other similar remains, not least due to the awareness that lies behind these traces of resource utilization as well as the risks that they may pose for future generations.

Another aspect of the relationship between the long-term perspective on the one hand and memory and landscape on the other is the fact that the area around facilities for the disposal of spent nuclear fuel – already in the short-term perspective and to an even greater extent in the medium- and long-term perspectives – seems to be abandoned for all types of human activities than those associated with oversight or management of the facility. It is difficult to judge today what this tendency may mean for the memory of facilities. In general, there is always a risk that areas abandoned by humans will be forgotten and after a number of generations resettled without any awareness of the hazards this may entail.

There are also information scientists who have pointed out that the spent nuclear fuel itself comprises an information carrier due to the regular disintegration of atomic nuclei that proceeds at a steadily declining pace. With this in mind, a number of mechanisms have been proposed for transmitting information on the fuel's age, state, composition, location etc. With modern monitoring and transmission technology, this type of information can be made available more or less anywhere and anytime.[17] At the same time, media historians have observed that the availability of these present-day information technologies is questionable in a long-term perspective, since the technology needed to access the information appears to be more transient and short-lived than ever. Technologies for information preservation have existed for many tens of thousands of years, as witnessed by cave paintings as well as millennia-old inscriptions in stone and clay tablets. Information preserved on parchment, papyrus or paper is seldom as durable, usually only a few hundred years, even though older examples also

[17] Heaney, C. (2013), "The 'forever problem': Nuclear waste as information".

exist. By comparison, it is not clear how long different forms of digitized information can be preserved.

When it comes to the long-term perspective, it has been repeatedly pointed out that it is not possible to extrapolate so far into the future when it comes to interpretation and comprehension. The archaeologists Holtorf & Högberg at Linnaeus University recently pointed out that there are nevertheless certain trends and tendencies that should be useful in at least trying to get an idea of how future generations might possibly view the repositories that are being built today, at least from shorter-term perspectives.[18]

The importance of social contexts

Holtorf & Högberg have noted in other contexts as well that long-term memories of final repositories are promoted by social contexts and groupings where questions of preservation of information, knowledge and memory are regularly discussed and debated. Continuous discussions of the nuclear waste problem thus favour the preservation of information, knowledge and memory. The most important results of such discussions of the future are not necessarily an instrumental solution to a concrete waste problem. In fact, discussions of the future seldom or never lead to any definitive conclusions and or plans of action. But the discussion in itself can be at least as important. Often perhaps even more important. From this perspective, the primary value of meetings and conferences concerning RK&M preservation in relation to repositories for spent nuclear fuel is not the actual content, but rather the forms of the activities and practices that are developed and communicated here between the scientific community, industry, public authorities and regulatory bodies, environmental movements, politicians and other stakeholders. The very creation of social contexts as institutions for discussions of RK&M matters can prove to be the enduring contribution to the preservation and transmission of knowledge of repositories for spent nuclear fuel to future generations.

[18] Holtorf, C. & Högberg, A. (2014), "Communicating with Future Generations", *European Journal of Post-Classical Archaeologies* 4, pp. 315–330.

4.6 The alternatives

This chapter of the state-of-the-art report began by contrasting the idea of a closed repository for spent nuclear fuel, isolated from human activities, and the possibilities of collectively remembering its properties and functions. From this perspective, it was observed that preservation of RK&M (records, knowledge and memory) was particularly relevant and important in ensuring a safe final repository. However, our review of the state-of-the-art has strengthened the impression of difficulties in combining a successful final disposal with a long-term memory of it. Nevertheless, it is the combination of passive safety and long-term preservation of records documentation that is still the primary plan for managing high-level waste in most countries, including Sweden.

The main alternative is to reject the idea of exclusively passive safety in the long term. One consequence could be not only reversibility and the possibility of retrieval, but also better prospects for information and knowledge preservation as well as strong memory traditions. From this perspective, continuous and regular revisions of information management, as well as memory institutions, have been advocated as the most effective way to preserve knowledge of repositories for spent nuclear fuel. In order to further strengthen the preservation culture, such methods can also be linked to the site and the landscape.

The other alternative, to rely on long-term passive protection while rejecting ideas of preservation of information and knowledge – in other words, "out of sight, out of mind" – has not yet been put forward as a serious solution, however. The idea of creating a final repository whose function is exclusively based on passive safety while actively destroying all records and knowledge would appear quite bizarre in our information- and knowledge-oriented democratic culture. And yet it is perhaps just such a solution that future generations would like us to choose. Our problem is that we can never know anything for sure about what future generations will want, no matter how much we would like to.

References

Bowen-Schrire, M., Jander, H. & Waniewska, K. (2007), *Kunskapsbevarande för framtiden-Fas 1* ("Knowledge preservation for the future – Phase 1", in Swedish). SKB Rapport P-07-220. Stockholm: Swedish Nuclear Fuel and Waste Management Co.

Heaney, Chris (2013), "The 'forever problem': Nuclear waste as information", *iConference 2013 Proceedings, poster abstracts, Forth Worth*, Texas, February 12–15, 2013, Association for Computing Machinery: Digital Library (ACM DL) pp. 659–661.

Holtorf, C. & Högberg, A. (2014), "Communicating with Future Generations", *European Journal of Post-Classical Archaeologies* 4, pp. 315–330.

IAEA (1999), *Maintenance of records for radioactive waste disposal.* IAEA-TECDOC-1097. Vienna: International Atomic Energy Agency.

IAEA (2001), *Waste inventory record keeping systems (WIRKS) for the management and disposal of radioactive waste.* IAEA-TECDOC 1222. Vienna: International Atomic Energy Agency.

IAEA (2005), *Methods for Maintaining a Record of Waste Packages during Waste Processing and Storage.* Technical Report Series No. 434. Vienna: International Atomic Energy Agency.

IAEA (2007), *Retrieval, Restoration and Maintenance of Old Radioactive Waste Inventory Records.* IAEA-TECDOC 1548. Vienna: International Atomic Energy Agency.

IAEA (2008), *Long Term Preservation of Information for Decommissioning Project.* Technical Report Series No. 467. Vienna: International Atomic Energy Agency.

Schröder, Jantine (2014), "Acting for passive safety", *Work Package 2 – Topic: Reversiblity and Retrievability.* Working Paper – International Socio-Technical Challenges for Implementing Geological Disposal. InSOTEC/ EU/Euratom.

SKB (2011), ”Verksamhet, ledning och styrning – Uppförande av slutförvarsanläggningen” VU (“Activity, leadership and management – Construction of the final repository”, in Swedish), Open Report, 4. Appendix to *Application under the Nuclear Activities Act (KTL) to build, own and operate the final repository for spent nuclear fuel (in Swedish).* Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SSM (2008), *Strålsäkerhetsmyndighetens föreskrifter om arkivering vid kärntekniska anläggningar* (“The Swedish Radiation Safety Authority’s regulations concerning archiving at nuclear facilities”, in Swedish). SSMFS 2008:38.

van Wyck, Peter C. (2004), *Signs of Danger: Waste, Trauma, and Nuclear Threat.* Minneapolis: University of Minnesota Press.

van Wyck, Peter C. (2012), “An Archive of Threat”, Future Anterior 9:2, pp. 53–80.

5 The research project InSOTEC

5.1 Introduction

One of the broadest and most successful research projects ever on the management of radioactive waste was concluded in 2014. The project, called International Socio-Technical Challenges for Implementing Geological Disposal (InSOTEC)[1], was funded by the European Commission via Euratom between 2011 and 2014 and was mentioned already in the state-of-the-art report for 2014.[2]

The main purpose of InSOTEC has been to investigate the relationships between technical and social challenges with regard to high-level waste management, particularly in relation to geological disposal. The reason this particular method was viewed so favourably is a consensus that has developed over the past decade or so between the IAEA and the European Commission, among others, that geological disposal is the most suitable solution for high-level waste and spent nuclear fuel. Despite this, considerable criticism has been levelled at the project and different national programmes exhibit a wide range of solutions and disparate methods gathered under the heading of "geological disposal".

The basic principle for InSOTEC is that social and political demands shape technical solutions just as much as technical and scientific values and judgements shape social, legal and political processes.

Any long-term solution to the nuclear waste problem arrived at by such an approach must therefore be regarded as a socio-technical solution whose value and characteristics are arrived at by negotiation where the evaluation criteria are necessarily value-laden

---

[1] www.insotec.eu/ (downloaded 2 February 2015).
[2] SOU 2014:11 *Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making*. p. 67 f.

and not neutral. Additional support for this approach is provided by the seemingly simple observation that safety aspects have been the single most important challenge in designing geological repositories. The design of such repositories has also undoubtedly been improved and concretized since this solution to the nuclear waste problem was first proposed in the late 1950s.

However, it cannot be denied that the very long-term aspects of geological disposal are such that the safety offered by these repositories is based solely on socio-technical assumptions which, while they can be supported by means of naturalistic tests and experiments as well as model simulations, nevertheless cannot be tested on a full scale for the length of time required for total risk elimination. In view of the fact that no geological repositories for spent nuclear fuel are in existence today, the method cannot be regarded as a proven technology developed to solve a specific problem, but is rather to be regarded more as a socio-technical hypothesis formulated to improve safety surrounding one of the negative aspects of nuclear power.[3]

5.2 Socio-technical challenges

Within the project, these points of departure have resulted in the perspective that the analyses should deal with "the social within the technical" rather than "the social around the technical". In keeping with this reasoning, the project participants have focused on the role of researchers in the social sciences and the humanities as critical experts rather than as mediators in deliberations or as specialists in social processes and achieving collective acceptance. This means that the objective of the project has been no less than to improve the processes of technical change by including other areas of expertise than the traditional ones of technology and science. A number of different activities are included in InSOTEC in order to investigate technical and social perspectives on nuclear waste management both nationally and internationally. A cornerstone has been fourteen studies of different national decision-making processes related to nuclear waste management, as well as a

[3] InSOTEC (2014), *InSOTEC Project Final Report*.

compilation of the results. The countries that have been studied are: Belgium, Canada, the Czech Republic, Finland, France, Germany, Hungary, the Netherlands, Slovenia, Spain, Sweden, Switzerland, the UK and the USA. All of these reports are available on the project's website.[4]

In the country reports, the investigations have studied how the different final repository programmes have integrated social factors such as safety requirements with political and economic factors. The reports also describe the environmental, technical and legal premises for designing geological disposal in the different countries. The synthesis report, which is based on the various country reports, deals with factors that are regarded as being particularly distinctive for the nuclear waste problem. It is pointed out here how discussions of retrieval of spent nuclear fuel have influenced views of geological disposal in different countries, even where such requirements do not exist today. Another observation has to do with how long-term political and other control of final disposal has become a very urgent research area as different geological repositories are planned in a number of countries.[5]

Based on the different country studies, a number of topics were selected for international comparisons. They were:

- the possibility of reversibility and retrievability of waste,
- site selection processes,
- demonstration of management methods and final disposal of spent nuclear fuel
- and technology transfer.

Within each topic, between three and five studies were conducted, resulting in thirteen topical reports where practices, aspects or situations of relevance to a given topic were dealt with based on international comparisons.[6]

[4] http://www.insotec.eu/publications/file-cabinet (downloaded 2 February 2015).
[5] InSOTEC D1.2 "Socio-technical Challenges to Implementing Geological Disposal".
[6] www.insotec.eu/publications/topical-reports (downloaded 2 February 2015).

5.3 InSOTEC from a Swedish and an international perspective

Within the framework of InSOTEC, and from a Swedish perspective, it is particularly interesting to note an exhaustive account of the socio-technical challenges when it comes to geological disposal of spent nuclear fuel.[7] Two challenges in particular are identified here:

1. The first is upholding an arrangement where political values are given priority over geological considerations in the site selection process.
2. Another has to do with the financing of a final repository, a challenge that has also attracted the attention of numerous other actors and has been given particular coverage in the media.

Two other highly relevant studies of Swedish conditions conducted within the framework of InSOTEC have to do with how SKB's KBS-3 method has been transferred to and used in Finland, as well as the processes behind the formation of SKB International 2001 and what this has meant for the internationalization and marketification of the nuclear waste issue. The fact that funds from the Nuclear Waste Fund have been used to create a global for-profit company in the nuclear waste management sector is perhaps not surprising, but entails at the same time that the confidence that has been created in the KBS-3 method in a national Swedish context has now become a sales argument on an international market characterized by a demand for corporate responsibility. Sebastian Svenberg and Mark Elam, who authored the report, contend that this responsibility has thereby become an equally vital part of the KBS-3 method as copper canisters and bentonite clay.[8]

Added to this synthesis of the different country cases is a summary and study of the different international initiatives and

[7] Daoud, A. & Elam, M. (2012), *Identifying remaining socio-technical challenges at the national level: Sweden (WP 1 – MS 11).*
[8] InSOTEC, "Swedish Nuclear Waste Management on the Move: From the Finnish Uptake of KBS-3 to the Rise of SKB International".

programmes during the past ten years, for example from Euratom, the OECD and the IAEA.[9]

Here there is also a case study of a European technology platform called IGD-TP where important conclusions are that the development work within the platform is for the most part influenced by the Swedish, Finnish and French programmes. Another important conclusion is that despite ambitions, it has proven difficult to involve different stakeholders in the work of the platform. The main reason is that it has not been elucidated why stakeholders should be involved, what the IGD-TP can offer to them and what stakeholders can offer to the platform, in order to understand clearly the benefits and drawbacks of participation. While channels for dissemination of information have been established, it remains for the platform to show how the efforts can engage stakeholders in innovation and technical change. In order to be able to better formulate why the platform wants to engage stakeholders and what the platform can offer them, there is a proposal here to also involve social scientists in the platform's research and development work, something which has so far only been realized to a limited extent.[10] This observation also fits in very well with other more general conclusions concerning the importance of involving social scientists in the work of developing better methods and technologies for final disposal of spent nuclear fuel, as well as ensuring that this work is conducted effectively. The biggest independent Swedish social science research project concerning management of nuclear waste, which moreover involved numerous international researchers in the field, observed how social science experts have been mobilized in different ways in recent decades. However, in important respects it was yet another unutilized potential for improving both process and results when it comes to developing technologies for management of high-level waste.[11] In a contemporary Swedish context, the lack of competence

[9] InSOTEC D1.1 "Review of initiatives addressing sociotechnical challenges of RWM & geological disposal in international programmes".
[10] InSOTEC D3.1 "Reflecting on the Implementing Geological Disposal Technology Platform as a knowledge network and potential scenarios for stakeholder involvement".
[11] Solomon, B.D., Andrén, M. & Strandberg, U. (2010), "Three Decades of Social Science Research on High-Level Nuclear Waste: Achievements and Future Challenges", *Risks, Hazards & Crisis in Public Policy* 1:4, pp. 13–47.

in the social sciences and humanities that characterizes the Swedish Radiation Safety Authority can also be mentioned.

5.4 The contributions of the social sciences

When it comes to more concrete tasks, the results from InSOTEC indicate that the contributions of the social sciences to the development of geological repositories for spent nuclear fuel could be extended beyond their usual range today to encourage the participation of various stakeholders in deliberations regarding, for example, site selection in order to increase the legitimacy of the political decision-making process and show that these decision-making processes are fair and representative in order to gain greater social acceptance for the decisions. These types of instrumental tasks can thus be expanded by making an effort early in the processes to involve alternative perspectives on fundamental issues such as problem formulation, knowledge building and potential solutions for the management of spent nuclear fuel.

If the planning of geological repositories for spent nuclear fuel involves from the start different areas of competence than just technical and scientific ones, multiple perspectives will be able to contribute to acceptable and sustainable solutions.[12] In particular, this promotes a more heterogeneous innovation process. At the same time, competence and experience are of course needed to lead this broader development effort, something which social scientists could irrefutably assist with.

5.5 Conclusions, proposals and recommendations

Together, the fourteen country studies and the international topical comparisons with the studies of international initiatives and programmes have also resulted in a number of practical recommendations for the development and realization of geological repositories of spent nuclear fuel as a socio-technical practice. In order to be able to realize the ambition of opening up the

[12] InSOTEC D3.3 "Investigating the potential for integrating social aspects in technical research and development (R&D) in geological disposal".

development processes on which the design of geological repositories is based from the start, it is proposed here that participation not be limited to chosen existing groups already active in an established institutional context, but that the invitations to participation be made more open.

Nor should opportunities for open participation be limited to certain parts of the development process, but rather apply without exception throughout the process. Another important prerequisite for being able to open up the development processes is not to regard differences of opinion or conflicts as a result of a lack of information or knowledge that can be overcome by providing what is lacking.

Instead, tensions that arise in the development process are regarded as an asset, since they can be used to identify weaknesses in the proposed method and to improve it. In concrete terms, this insight can be expressed in a recommendation that every organization involved in development of methods for management of spent nuclear fuel should allocate a portion of its research and development budget to research on questions and problems proposed by the public.

Another conclusion is that development processes for the creation of safe geological repositories should be flexible in the sense that they should be open for changes, corrections and adaptation to new circumstances or findings. Against this background, InSOTEC proposes that the implementation of geological disposal be regarded as a scientifically controlled, open investigation process with one possible solution as a goal, even if it takes several generations to achieve. What they object to is a traditional project organization with a clear start and end date.

It is important to emphasize that InSOTEC's recommendations also have a bearing on the Swedish effort to develop a geological repository for spent nuclear fuel, even though the process has come farther than in many other countries. Even though a licence application has been submitted in Sweden, many decisions remain to be made, as indicated by the large number of comments on SKB's licence application. The Swedish development process could also be improved by taking the results from InSOTEC to heart and translating them into practical action.

References

Solomon, B.D., Andrén, M. & Strandberg, U. (2010), "Three decades of social science research on high-level nuclear waste: Achievements and future challenges", *Risk, Hazards & Crisis in Public Policy, Vol. 1,* No. 4, pp. 13–47.

SOU 2014:11 *Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

InSOTEC (2011−2014), International Socio-Technical Challenges for Implementing Geological Disposal. InSOTEC/ EU/Euratom. See: www.insotec.eu/publications/topicalreports (downloaded 2 February 2015).

- D1.1 "Review of initiatives addressing sociotechnical challenges of RWM & geological disposal in international programmes".
- D1.2 "Socio-technical Challenges to Implementing Geological Disposal".
- D3.1 "Reflecting on the Implementing Geological Disposal Technology Platform as a knowledge network and potential scenarios for stakeholder involvement".
- D3.3 "Investigating the potential for integrating social aspects in technical research and development (R&D) in geological disposal".
- "Swedish Nuclear Waste Management on the Move: From the Finnish Uptake of KBS-3 to the Rise of SKB International".

InSOTEC (2012), *Identifying remaining socio-technical challenges at the national level: Sweden (WP 1 – MS 11).* Working Paper – International Socio-Technical Challenges for Implementing Geological Disposal. Daoud, A. & Elam, M. InSOTEC/ EU/Euratom.
See: http://curie.ornl.gov/system/files/documents/SEA/ WP1_MS11_CR_Sweden_Final.pdf (downloaded 28 January 2015).

InSOTEC (2014), *InSOTEC Project Final Report* – International Socio-Technical Challenges for Implementing Geological Disposal. InSOTEC/ EU/Euratom. See: www.insotec.eu/publications/final-report (downloaded 28 January 2015).

6 Monitoring programmes for sealed areas

6.1 Background

Monitoring programmes for following developments in closed repositories have been discussed in the international project Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn). The Swedish National Council for Nuclear Waste and Östhammar Municipality[1] have also focused attention on monitoring programmes in different contexts. Reasons for establishing a monitoring programme in sealed areas can be gathered under four headings: safety assessment, transparency, operations oversight and knowledge building. The Swedish Nuclear Fuel and Waste Management Co (SKB) proposes staged closure, which entails that tunnels are backfilled and plugged as deposition there is finished. Under certain conditions, a monitoring programme could be utilized in the *safety assessment.* For the municipality and the region, a monitoring programme entails increased transparency, which is an important prerequisite for citizen confidence in the deposition process. From the viewpoint of the operating organization, measurements in backfilled and plugged tunnels are a part of the regular monitoring programme, where detection of serious problems can necessitate opening and repairing plugged tunnels. From an international perspective, the monitoring will provide important new knowledge on repository processes, since SKB's timetable makes it one of the first projects of its kind. Transparency and knowledge building are presumably the most important arguments for continuing measurements for as long as possible after the

[1] Land and Environment Court, M1333-11. Case file appendix 139, Östhammar Municipality.

repository has been closed, which is expected to take place around the turn of the next century.

The question of post-closure monitoring is also taken up by the International Commission on Radiological Protection (ICRP), which writes in its description of the post-closure phase: “it is expected that monitoring of baseline environmental conditions will continue for a period of time”.[2] It is thus regarded as more or less self-evident that the monitoring of environmental factors that has been started during the operational phase will continue after closure as well, for as long as possible.

A monitoring programme requires extensive preparations. This includes technology development for sensors, data transmission and power supply of equipment in sealed areas. Measurement, data transmission and power supply must take place without disturbing the barrier functions. Strategies are required for data analysis and for how this analysis should guide decisions.

The purpose of this chapter is to shed light on how the issue of monitoring programmes in sealed areas is being dealt with in Europe outside of Sweden, particularly in terms of technology and strategy development. The point of departure is an EU project within the Seventh Framework Programme called Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn). The project is studying monitoring of all phases of the final repository, including: “staged closure, as well as a post-closure institutional control phase.”[3] Two of the project’s work packages are of special interest. One work package involves in-situ demonstration of innovative monitoring techniques for measurement and data transmission in sealed areas in five projects. Another work package presents three case studies for repository monitoring with monitoring programmes for sealed areas.

Water saturation of the buffer is an example of an important process to monitor. Several of the innovative monitoring techniques focus on the buffer and its water saturation. The following sections therefore recapitulate why this barrier and its water saturation are

---

[2] Weiss, W., Larsson, C-M., McKenney, C., Minon, J-P., Mobbs, S., Schneider, T., Umeki, H., Hilden, W., Pescatore, C., Vesterlind, M. (2013), *Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste ICRP.* Publication 122.

[3] MoDeRn, NDA et al. (2010), *Site Plans and Monitoring programmes report*, p. 6.

important. The results from MoDeRn are presented in the following two sections.

The Council intends to continue following developments in the area. At the end of this chapter there is a summary of the Council's positions as expressed in review statements on SKB's RD&D programmes and in the supplementary opinion to the Land and Environment Court regarding SKB's application for a licence to build a final repository in Forsmark.

6.1.1 From initial state to target state with complications

The copper canister with the spent nuclear fuel will be emplaced in a bored deposition hole with compacted blocks and pellets of bentonite clay. Bentonite is a natural product consisting of a number of different minerals, of which at least 75 percent is montmorillonite, which can absorb groundwater and swell. At the time of deposition the bentonite contains 17 percent water and is not water-saturated. The canister with the unsaturated bentonite constitutes the initial state of the waste package.

The safety requirement on the KBS-3 method is that the nuclear fuel shall be kept isolated from the geosphere for at least 100,000 years. To guarantee this, the only completely tight barrier, the copper canister, must be protected from corrosive substances in the groundwater and mechanical stresses for such a long time that the total time taken for transport through the remaining barriers, the bentonite clay and the rock, is sufficient to meet the safety requirements. The rock has been chosen after comprehensive geological and geophysical investigations, and a buffer of bentonite clay has long been the main alternative for embedding the copper canister in the deposition hole. The rock is expected to have such properties that it undergoes little change during the repository's operating period, while the bentonite buffer must undergo change to acquire optimal properties as a protective barrier. By far the most important change undergone by the buffer is that it becomes water-saturated, i.e. absorbs groundwater from the surrounding rock and swells.

The bentonite buffer and the backfill are thus the only barriers in which post-closure changes are necessary to achieve important barrier functions. The buffer must be water-saturated in order to guarantee the chemical and microbiological environment around the copper canister and to protect it from shear forces in the event of an earthquake. The barrier functions require a uniformly water-saturated buffer. With the chosen design and site, water saturation in a backfilled and plugged deposition tunnel takes a long time, up to several hundred years. The problems surrounding water saturation are reflected in SKB's difficulties in formulating verifiable design premises regarding the buffer and its water saturation.

If sorption of groundwater takes place roughly simultaneously and uniformly in the bentonite along the entire 5 m long copper canister, the buffer will be very tight and meet high standards as a functioning protective barrier. The target state has been achieved when the density of the buffer has reached its optimal value at about 2 kg/dm^3, the hydraulic pressure on the canister is high and uniform, and the oxygen has been consumed by reactions with impurities in the bentonite and with the surface of the copper canister.

In practice, the water saturation process is very complicated. Radioactive decay inside the copper canister generates heat during a period of about 800–1,000 years and γ radiation during the first 100 years.

If the rate of water transport from the surrounding rock is slow due to the fact that the rock is dry, the buffer will dry out and lose some of its thermal conductivity and mechanical strength. There is also a risk for mineral alteration and illitization, which can adversely affect the buffer's absorbing and retarding properties. A rapid and plentiful supply of water through e.g. fractures can cause erosion and loss of buffer material and degrade barrier function.

An uneven water saturation of the bentonite along the length of the copper canister leads to varying pressure and creates conditions for e.g. stress corrosion cracking and creep in the copper material.

All water transport through the buffer will take place against a temperature gradient between canister and rock, which leads to mineral alteration and mineral transport in the buffer ("cementation").

In a new research report by Digby D. Macdonald and others published on the Swedish Radiation Safety Authority's (SSM) website, the authors summarized their most important results in a number of conclusions that underscore the importance of the bentonite buffer for long-term safety. The summary begins with the following conclusion:

> In the case when the bentonite buffer between the copper canister and the granitic rock is not damaged, we can neglect the possibility of general corrosion damage being a threat to canister integrity over a 100,000 year storage period.[4]

The authors go on to describe a number of consequences for the repository if the buffer does not act as an adequate engineered barrier for the copper canister. Recent years' research on the barriers in the final repository has demonstrated with increasing clarity that an optimally functioning buffer is an essential factor for long-term safety.[5]

In fact, the uncertainties associated with water saturation of the buffer alone are enough to warrant a monitoring programme to follow the situation in the deposition holes. On an international level, the problem has been addressed by the MoDeRn project. One of the tasks of the work package for the in-situ demonstration of innovative techniques is the following:

> Demonstrate the capability to monitor events inside sealed and inaccessible repository areas, including the behaviour of the swelling clay plug.

6.2 MoDeRn introduction

MoDeRn, a project in the EU's Seventh Framework Programme, was carried out during the period 2009–2013. The project had 18 partners from 17 countries, including the USA and Japan. Sweden was represented by SKB and the Department of Sociology at the University of Gothenburg (GU). According to the project's website[6] , SKB participated in all work packages except the third

---

[4] Macdonald, D.D., Engelhardt, G.R., & Sharifi-Asl, S. (2014), *Issues in the Corrosion of Copper in a Swedish High Level Nuclear Waste Repository: Phase III. Role of Sulphide Ion in Anodic and Cathodic Processes.* SSM 2014:57 Technical Note.

[5] Swedish National Council for Nuclear Waste (2014), *New insights into the repository's engineered barriers; A report from the Swedish National Council for Nuclear Waste's symposium on November 20-21, 2013.* Report 2014:1e.

[6] www.modern-fp7.eu/ (downloaded 23 January 2012).

one (WP3), which dealt with innovative techniques for non-intrusive monitoring in closed parts of the repository. In 2012, GU arranged a seminar within the project in Gimo with participants from e.g. Östhammar Municipality, SKB, SSM and the Swedish National Council for Nuclear Waste.

MoDeRn deals with the entire chain of measurements and analysis for monitoring of all phases of a final repository programme, from site investigation, construction and operation to staged closure and post-closure institutional control.

Of particular interest for the discussion of monitoring programmes for sealed parts of a repository are work packages three and four (WP3 and WP4), which will be described below. In five projects, WP3 deals with the development of innovative monitoring techniques and wireless transmission of data, while WP4 describes three case studies involving monitoring of planned repositories in Germany, France and Finland.

6.2.1 WP3 – Innovative non-intrusive monitoring techniques: five projects

The overall goal of WP3 was to contribute to the development of technical systems for monitoring of changes, especially in the engineered barriers after the nuclear waste has been isolated.[7] A demonstration of monitoring systems is also planned for lay stakeholders to get their views on how the results of the monitoring can best be communicated.

Table 6.1 summarizes the five in-situ studies (the projects) in WP3.[8] They were carried out in underground rock laboratories in Belgium, France and Switzerland by organizations from Belgium, France, the Netherlands, Switzerland, Spain and the UK. The demonstrations cover a combination of monitoring technologies tested in a variety of bedrocks using existing infrastructures in

[7] ”The overall aim of Monitoring Demonstration Programme is to progress, through further development, demonstration and analysis, the capability to provide an effective range of reliable and validated monitoring systems to monitor the changes occurring, particularly in those phases following isolation of the radioactive waste and the evolution of the engineered barrier system.” (MoDeRn, Deliverable 3.1.1, p. 8).

[8] References to the reports from the five projects are included in the list of references under the heading “MoDeRn”.

TEM and ZigBee in Grimsel, Switzerland, Praclay in Hades, Belgium, and a mock-up disposal cell in Bure, France. Most of the experiments are done in mock-up disposal cells to test the effectiveness of the different monitoring technologies and determine their limitations. Together, the five projects address three important and specific problems for monitoring in sealed spaces containing deposited nuclear waste: non-intrusive monitoring, data transmission and power supply. Monitoring equipment must fulfil many other requirements, such as long-term reliability and robustness, but these requirements are not specific for application in a repository. An explicit requirement for the Bure project is that the monitoring system for the steel liner must be able to withstand the construction procedures.

Development of sensor technology

The projects are investigating two monitoring techniques that are assumed to cause negligible or minor disturbances in the engineered barriers. In projects 1 and 3, seismic technology is being developed for monitoring conditions in the bentonite buffer and the near-field around the tunnel, and in projects 3 and 5, optical fibre is being used to measure temperature distribution and deformations.

The project in Grimsel, Switzerland, is of special interest because the goal is to follow water saturation in a bentonite barrier by means of a seismic technique. The development work began during an earlier EU programme (ESDRED, 2004–2008) and has resulted in two doctoral projects at the Swiss Federal Institute of Technology, Zürich (ETHZ). The bentonite's water saturation and pressure influence its elasticity, and laboratory experiments show that seismic data are dependent on water content and pressure in a very clear manner. The results point towards possibilities for developing technology to monitor the evolution of conditions in the buffer without disturbing this engineered barrier. However, further development of, for example, microphones and computer algorithms for tomography is required in order for the technique to become operational. With the present-day technique, sensors and microphones must be placed in boreholes near deposition tunnels and deposition holes, which can disturb the near-field.

Table 6.1 Field studies carried out within MoDeRn WP3

Report	Goal	Sensors	Data transmission	Power supply
1. Seismic Tomography at Grimsel Test Site	Development of non-intrusive monitoring techniques. Focus: the buffer	Seismic matrix (including sparker and microphones in boreholes around plugged tunnel)	(Cable transmission)	–
2. Wireless sensor network demonstrator report (Grimsel Test Site)	Demonstrate and analyze HFW network embedded in engineered barriers	Five measurement nodes for pore pressure, total pressure, water saturation in buffer, plug and surrounding rock	Wireless transmission from measurement nodes to control unit outside plugged tunnel	Measurement nodes with lithium batteries. Expected lifetime 1–25 years, depending on application
3. HADES demonstrator report	Test fibre-optic sensors for measuring temperature distribution and tunnel expansion. Investigate potential for micro-seismics	Scattering and interferometry in optical fibres. Micro-seismic technique to monitor the near-field	(Cable transmission)	–
4. Wireless Data Transmission Demonstrator: from the HADES to the surface	Demonstrate the possibilities for data transmission from a geological repository to the surface	–	Wireless transmission via low-frequency magnetic fields through 225 m of clay with an electrical conductivity of 0.02–0.05 S./m	Energy-efficient data transmission: < 1 mJ/bit for a repository in granite
5. Disposal cell monitoring system installation and testing demonstrator in Bure Underground Research Laboratory	Demonstrate monitoring of a disposal cell: inside, liner surface and near field. Prove robustness of monitoring system during construction	Testing optical fibre to monitor thermomechanical behaviour and vibrating wire to monitor hydraulic pressure	(Cable transmission)	–

HFW: High Frequency Wireless.

In Bure (project 5), an overall monitoring strategy has been developed including distribution and design of monitoring units, research and development to adapt, complete and qualify the sensing devices and specific tests and large-scale experiments in underground research laboratories. The programme includes measurements of pore pressure, temperature and displacements in the cell near-field to determine the impact hydromechanical pressure and how water content and temperature influence the conditions. External and internal optical fibres were installed to monitor thermomechanical processes and possible rock breakout. The effects on the casing of pressure from water and surrounding rock will be evaluated, along with the effects of the excavations. The work has provided important insights, but definitive conclusions cannot yet be drawn regarding operational use.

Development of technology for wireless data transmission

Wireless data transmission is being studied in projects 2 and 4. Together, these two experiments cover data transmission in two stages from a plugged deposition tunnel to the ground surface. In the underground laboratory in Grimsel, Switzerland, transmission by high-frequency radio waves from a bentonite layer through a 4 m thick cement plug is being studied, and in the HADES laboratory in Belgium, transmission by low-frequency electromagnetic waves to the ground surface through a 225 m thick layer of clay with high electrical conductivity (0.1–0.02 S/m) is being tested. The sensors in the Grimsel experiment consist of integrated nodes with the dimensions 190 x ø75 mm. Each node has sensors for pressure and relative humidity, transmitter, antenna and a lithium battery for power supply. In the HADES experiment, the focus is on transmission capacity and design of the transmitter and receiver antennas. Energy consumption with the equipment used was 1 Ws/bit.

The results of the two projects show that data transmission from the repository to the ground surface is possible in principle, but the technology is far from operational. In project 2, sensors and transmitters are integrated in a node, but they have only been superficially embedded in the bentonite layer. One question is whether the signal strength in this solution is sufficient to transmit data from a 20 m long plugged deposition tunnel. In project 4, no connection was made to sensors. The available space in the underground laboratory did not permit an optimization of the transmitter antenna, but in a final repository, where enough space is planned from the start for the antenna, it should be possible to boost performance considerably, above all with regard to energy consumption. The results indicate that the electricity consumption of an optimized system in a repository in granite at a depth of 500 m will be less than 1 mWs/bit.

Power supply

Power supply of sensors and transmitters is discussed in reports 2 and 4, but without any deep analysis. The lithium battery in the Grimsel project has an estimated lifetime of 1–25 years depending on the application, but no measurements are presented that verify this estimate. The group around the HADES experiment says that the results cannot be used to analyze the possibilities of wireless transmission of energy to supply monitoring equipment in the repository. If monitoring is to be performed in sealed areas, high priority must be given to continued analysis and technology development for power supply to sensors and data transmission.

Summary assessment

In summary, it can be concluded that there is considerable interest outside Sweden in technology development for monitoring the state in the engineered barriers both during staged closure and in connection with post-closure institutional control. In two of the cases, France and the Netherlands, this interest is linked to requirements on the possibility of fuel retrieval, but in all cases there is a need to verify the safety assessment and build confidence in the process. Considerable technology development is being pursued, but more is required to achieve operational technology.

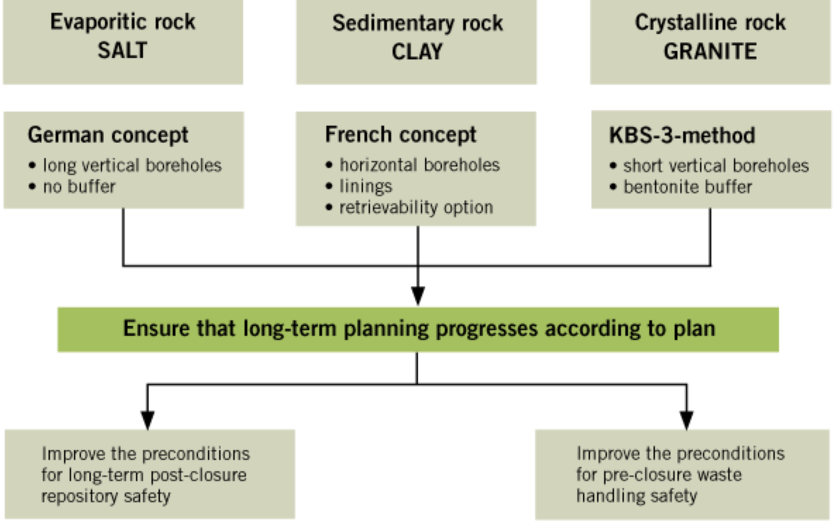
6.2.2 WP4 – Three case studies concerning nuclear waste disposal in different types of rock

The research programmes for developing technology for monitoring of repositories for spent nuclear fuel are based on international cooperation. The design of the final repository in different countries is determined by domestic legislation regarding nuclear waste management and the existing geological conditions. This usually means that different concepts are applied in different countries.

Figure 6.1 shows the different types of host rock and the corresponding disposal concepts. The overall primary and secondary objectives for the development of repository monitoring systems are also presented.

The work has been executed based on the safety assessment defined for the respective concept. The safety assessment is one of the main instruments for selecting which processes are of great importance for the evolution of the repository and thereby comprises a link to a monitoring programme. These processes can vary for different types of bedrock and concept.

Figure 6.1



The German method

The German method presented in the case study is based on disposal of high-level nuclear waste in a geological barrier of salt, and a concept for the demonstration of safety (Safety Assessment Concept) has recently been developed.[9] The key aspect is a systematic demonstration of the long-term confinement of the waste by demonstrating the integrity of all relevant engineered barriers as well as of the geological main barrier.

The geological integrity of the salt barrier at the Gorleben site is dependent on the barrier function of anhydrite ($CaSO_4$), and releases from an undamaged repository are judged to be out of the question. The threats for brine intrusion and the potential release of radionuclides are posed by shafts, drifts and openings resulting from waste emplacement. The goal is that once the repository is closed, the waste will be completely isolated. Demonstrating safe confinement has therefore become the main purpose. The engineered barriers in the German concept consist of shaft, drift and borehole seals as well as waste containers.

The main requirement on the geological main barrier concerns its tightness against fluids. There are two processes that could impair this function: excavation activities in the repository and the local heat output of the high-level waste. The thermomechanical effects must be determined in both cases, since they can lead to the formation of open, connected fissures which could permit the intrusion of brine into the emplacement area.

Model calculations are used to show that if transport pathways for brine can be avoided, the functionality and integrity of the main barrier can be ensured.

The most important processes that affect safety are the pressure and temperature evolution in the geological barrier. The maximum temperature in the repository has been determined to be 200°C.

The main function of the waste containers is safe confinement of the radioactive waste during transport above and below ground. Their function as a protective barrier is of a temporary nature, but these barrier properties must be maintained until the geotechnical

[9] Germany is currently studying several different alternatives for final disposal where disposal in salt formations is one alternative. See Chapter 2.

barriers (i.e. the backfill and borehole, shaft and drift seals) are in place and can take over. In each emplacement borehole, the containers will be stacked within a metal liner so that the waste can be retrieved if needed.

The most important post-closure processes are:

1. static mechanical impacts on the metal liner due to external pressure and thermally induced stress from the waste packages,
2. thermal impacts due to heat from the waste packages and from other nearby canisters,
3. corrosion of containers and liners due to radiolysis, oxidation by oxygen and, in applicable cases, by intruding water.

The parameters chosen to characterize these processes are temperature, pressure and water content in the vicinity of the liner, plus corrosion currents on the surface of the canister.

A monitoring system is based on the choice to measure those parameters that have the greatest impact on safety. Another important ingredient in the German concept is the use of a special monitoring field that can offer opportunities to measure relevant parameters without disturbing the actual repository. This also makes it possible to follow the evolution of an entire repository after closure.

According to MoDeRn, it is possible to monitor most of the relevant parameters using current technology. The biggest challenges are to ensure a long-term power supply, for around 100 years, and to transmit data wirelessly so that the barriers are not impaired.

The French method

The second case study describes the development of a monitoring programme for a repository in a clay-rich sedimentary rock (argillaceous rock). The reference system chosen for study is the French concept, which is designed to provide long-term passive post-closure safety, but also to permit retrieval of waste during the emplacement process. The monitoring option must be taken into account already during the design phase, and the monitoring methods must not reduce the repository’s long-term safety.

The French programme prescribes that the deep repository must be reversible for more than 100 years, and a new decision is required before the repository may be closed.

Monitoring is used to verify the predicted evolution of the repository and to provide a basis, together with previous studies and simulations, for stepwise decision-making regarding the further management of the waste, i.e. continue, interrupt, change or retrieve.

Transport of water in and through the repository is an important safety parameter and must be limited by choosing rock with very low permeability. The selected rock is located in eastern France, has no fractures and has a favourable geochemistry (reducing environment, low solubility of radionuclides and strong sorption properties), which are important properties for long-term safety. All factors – such as excavation, water saturation, desaturation, heating and chemical processes – must be well investigated and understood.

The transport of water through shafts and ramps must be restricted during deposition, along with the flow of water from the host rock to and in the vicinity of the waste packages. Transport of radionuclides outside the waste packages must be limited in time and space.

The high-level vitrified waste is placed in steel overpacks to prevent direct contact with water until the temperature has fallen to 50^{0}C, which can take up to 1,000 years. Backfilling and closure are done primarily with swelling clay that contains concrete plugs to provide mechanical stability.

The function of the engineered barriers – mainly waste packages, plugs and seals – must be verified. Disturbances of their function have above all thermal, mechanical or chemical causes and are subject to monitoring. Water saturation and swelling of seals affect water transport and will be monitored. Work is currently being pursued to find a good method for this.

Direct monitoring of corrosion of the liner is being considered, but this is problematic because it is a very slow process, and a possible alternative is to study the corrosion rate under comparable conditions (sacrificial structures) but without radioactive material. By combining knowledge of the thermal evolution with the results of corrosion studies, a basis is created for predicting the long-term durability of the liner.

Monitoring of chemical perturbations during the operating period will be done by sampling at a number of locations at different points in time. Monitoring of mechanical perturbations (e.g. deformation due to increased pressure and self-healing of backfill) during the operating period and to some extent after closure will be done at representative locations in the repository. Monitoring of thermal perturbations caused by heat output from the waste packages will be done in the immediate vicinity of the waste to determine its long-term effects.

The design of a monitoring system is based on previous knowledge concerning how the repository is expected to evolve in both the short and long term. It is necessary to position sensors where the chances of perturbations are the greatest and where they can function even under difficult conditions for tens of years. It is also necessary that monitoring be done on different time scales. Measurement points are distributed throughout the repository to start with, after which the number of measurement points is reduced as more knowledge is gained of repository evolution.

The planned monitoring methods will include both direct and indirect measurements. Methods are being developed to follow water saturation and oxygen consumption in boreholes, seals and backfill remotely, but also by retrieving samples for testing. The temperature evolution will be monitored by means of optical fibres and wirelessly.

The KBS-3 method

The case study for the KBS-3 method pertains to a final repository project in Olkiluoto, Finland. The list of authors includes Posiva, Finland, while SKB is among the reviewers.

In the same way as in the two previous case studies, safety functions are linked to the different barriers in order to arrive at processes that must be monitored and corresponding parameters that should be measured. The approach is broad. During the construction of the ONKALO underground laboratory, 59 physical, hydrogeological, geochemical and biological processes of importance for understanding the site and the performance of a repository on the site were identified. Posiva has performed an update with a focus on long-term safety and the engineered and geological barriers. The report identifies 36 FEPs (features, events and processes) of importance for the evolution of the engineered barriers and migration of e.g. radionuclides through these barriers. At this point the authors observe:

> Perhaps the most critical process affecting the performance of the engineered barriers, at least among those processes that are expected to occur during the operational period, is the water uptake into the buffer and backfill. It starts when unsaturated bentonite (and other clay) comes into contact with groundwater, and continues until the water-absorbing clays have saturated and hydraulic gradients have relaxed. [10]

The authors find that certain processes take place over such a long time that they cannot be observed within a reasonable time horizon. An example of such processes in the bentonite buffer and the backfill is mineralogical alteration. At the same time, the authors state that:

> water uptake and resulting swelling are essential processes that bring the barrier system from its initial state towards the intended target state during the years or decades during which monitoring is possible.[11]

After listing relevant parameters that can be measured, the case study ends with a proposal for monitoring of a demonstration repository designed in accordance with the Swedish/Finnish KBS-3V concept. The study is regarded as a complement to the French case study, where the focus lies on monitoring of the whole disposal cell, while in this case the focus lies on monitoring of the performance of the bentonite barriers.

The demonstration repository consists of an emplacement tunnel with dummy canisters without any radioactive content. The bentonite's water saturation is monitored by measuring swelling pressure, water content and relative humidity. The total length of the backfilled tunnel is 50–60 m and the distance between two "dummy" canisters is around 10 m. Data is transmitted wirelessly

[10] Jobmann, M. (editor), MoDeRn Partners (2013) WP4 "Case Studies Final Report", Deliverable 4.1, p. 79.
[11] MoDeRn, "Case Studies Final Report" Deliverable: D 4.1, p. 80.

by low-frequency radio waves (1–10 kHz), which have a longer range through moist material than the high-frequency signals used for example in the second field study in Grimsel in WP3. The radio signals from the disposal holes located farthest away go via relay stations to the monitoring station outside the plugged tunnel. Transmitters, relay transmitters and receivers are arranged so that the radio waves travel for the most part through the rock in the near-field, which has lower electrical conductivity than the moist bentonite. Sensors, transmitters and relay transmitters are supplied by a lithium battery and are expected to have a lifetime of 10 years.

In contrast to the previous two case studies, the Finnish case dismisses the possibility of monitoring conditions in a barrier in a real repository with waste packages. The authors note simply that: "(p)referably, no monitoring system should be installed into barriers designed to retain radionuclides."[12] A reflection is that the case study could serve as a basis for a mini-programme for monitoring of sealed areas during the operating period of a KBS-3 repository. A number of emplacement tunnels could serve as a demonstration repository with monitoring of the water saturation of the bentonite. The participants in WP4 are thinking along those lines themselves when they write in the chapter headed "Conclusions and lessons learned":

> The idea of establishing some form of "pilot facility" would enable not only increased process understanding during repository operation and to evaluate and update monitoring programmes prior to final closure but would also be a useful tool for stakeholder confidence building.[13]

6.3 Summary

The Council assumes that the EU project MoDeRn represents the state-of-the-art regarding monitoring of sealed parts of a final repository for long-lived and high-level nuclear waste. The examined reports were authored by organizations with high competence in the field in Belgium, Finland, France, Germany, the Netherlands, Spain, Switzerland and the UK. No experiments have yet been done with canisters or cells filled with radioactive waste. The

[12] MoDeRn, "Case Studies Final Report" Deliverable: D 4.1, p. 85.
[13] MoDeRn, "Case Studies Final Report" Deliverable: D4.1, p. 140.

ambitions in the national programmes vary, from the Finnish programme focused on a demonstration in a plugged emplacement tunnel with dummy canisters to the French or the Dutch programmes focused on the development of operational systems for the final repository.

The Council's conclusion is that there are important international actors who, in contrast to SKB, believe in both the importance and the possibility of developing systems for monitoring parameter values in sealed parts of the repository at a reasonable cost. These actors have already begun developing such systems, and they are generally in agreement with what the Council advocates.

Swedish National Council for Nuclear Waste's assessments and standpoints

The barriers in the KBS-3 method have been chosen based on their optimal properties, i.e. when rock, buffer and copper canister function best. At the same time, the debate regarding the strength of the engineered barriers has been lively and at times heated. The research results indicate that the performance of the bentonite buffer as a barrier to various attacks on the copper canister is of key importance.

A homogeneously water-saturated buffer in the deposition/ emplacement hole is an insurance for a long-term durable repository. Optimizing the preconditions for such a state is essential in creating a secure repository.

In its review of RD&D Programme 2010, the Council stated that SKB should develop: "a monitoring programme that makes it possible to verify changes that occur in the conditions in the buffer, deposition holes and deposition tunnels as the tunnels are sealed."[14] The Council's statement of opinion to the Land and Environment Court concerning supplements to SKB's application for a licence to build a final repository stress the need for a monitoring programme for sealed areas.[15] It is evident from both

[14] SOU 2011:50 *The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2010*, p. 92.

[15] *The Swedish National Council for Nuclear Waste's viewpoints regarding the need for supplementary information in applications for licences for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333-11).* (Reg. no. 43/2012), p. 42.

SKB's reply to the Land and Environment Court and SKB's oral presentation to the Council on 8 april 2013 that they have no intention of presenting such a monitoring programme. A monitoring programme before and during deposition is considered sufficient. In its second supplementary statement to the Land and Environment Court, the Council reiterates its demand that the application should be supplemented with a proposal for a monitoring programme to follow the evolution of conditions in deposition holes and tunnels after plugging and sealing.[16]

The need for a monitoring programme for sealed areas in the final repository was reiterated in the Council's review of SKB's RD&D Programme 2013. The RD&D programmes are supposed to present SKB's analysis and conclusions regarding the need for research and development with a focus on the upcoming three-year period. According to SKB's own plans, this is the last three-year period before the construction of the final repository will start. The need for monitoring programmes for sealed areas is not analyzed anywhere in the R&D programme.

[16] *Statement of opinion regarding the Swedish Nuclear Fuel and Waste Management Co's (SKB) response to the Swedish National Council for Nuclear Waste's requests for supplementary information in the application for a licence under the Environmental Code for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333-11). (*Reg. no. 19/2013), p. 38.

References

Swedish National Council for Nuclear Waste (2012), *Kärnavfallsrådets synpunkter på behov av kompletteringar av ansökan för tillstånd till anläggningar i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavfall (M 1333-11)* (Reg. no. 43/2012). ("The Swedish National Council for Nuclear Waste's viewpoints regarding the need for supplementary information in an application for a licence for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste", in Swedish. Available in English translation, see Appendix 3, SOU 2013:11 Nuclear Waste State-of-the-Art Report 2013 – Final repository application under review: supplementary information and alternative futures).

Swedish National Council for Nuclear Waste (2013), *Yttrande över Svensk kärnbränslehantering AB:s (SKB) svar på Kärnavfallsrådets yrkanden på kompletteringar av ansökan om tillstånd enligt miljöbalken i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavfall* ("Statement of opinion regarding the Swedish Nuclear Fuel and Waste Management Co's (SKB) response to the Swedish National Council for Nuclear Waste's requests for supplementary information in an application for a licence under the Environmental Code for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste", in Swedish) (M 1333-11). (Reg. no. 19/2013).

Swedish National Council for Nuclear Waste (2014), *New insights into the repository's engineered barriers; A report from the Swedish National Council for Nuclear Waste's scientific symposium on November 20–21, 2013*. Report 2014:1e. Stockholm: Fritzes.

Macdonald, D.D., Engelhardt, G.R., & Sharifi-Asl, S. (2014), *Issues in the Corrosion of Copper in a Swedish High Level Nuclear Waste Repository: Phase III. Role of Sulphide Ion in Anodic and Cathodic Processes*. SSM 2014:57 Technical Note. Swedish Radiation Safety Authority.

Land and Environment Court at Nacka District Court, M1333-11, case file appendix 282. Östhammar Municipality, Statement from the municipal executive board.

SOU 2011:50 *The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2010*. Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

SOU 2014:42 *The Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2013*. Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

Weiss, W., Larsson, C-M., McKenney, C., Minon, J-P. Mobbs, S., Schneider, T., Umeki, H., Hilden, W., Pescatore, C. & Vesterlind, M. (2013), *Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste ICRP.* Publication 122. Ann. ICRP 42(3).

MoDeRn (2010–2013), Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn), European Atomic Energy Community's 7th Framework Programme. See: www.modern-fp7.eu/publications/ (downloaded 2 February 2015).

- NDA, ANDRA, AITEMIN, NRG, EURIDICE, ETH ZURICH, (2010) WP3 ”Site Plans and Monitoring programmes report”, D 3.1.1.
- ETH Zurich and NDA, (2013) WP3 “Seismic Tomography at Grimsel Test Site”, Deliverable 3.2.1.
- AITEMIN (2013) WP3 ”Wireless sensor network demonstrator report”, Deliverable 3.3.1.
- EURIDICE (2013) WP3 “HADES demonstrator report”, Deliverable 3.4.1.
- T.J. Schröder, E. Rosca-Bocanvea, NRG (2013) WP3 “Wireless Data Transmission Demonstrator from the HADES to the surface”, Deliverable 3.4.2.
- ANDRA (2013) WP3 “Disposal cell monitoring system installation and testing demonstrator in Bure Underground Research Laboratory”, Deliverable 3.5.1.
- M. Jobmann (editor), MoDeRn Partners (2013) WP4 “Case Studies Final Report”, Deliverable 4.1.

7 Calculation of future costs for final disposal of nuclear waste and spent nuclear fuel

7.1 The licensees' obligations to finance future costs

The costs for decommissioning of existing nuclear power plants and management and final disposal of spent nuclear fuel are currently estimated at over SEK 100 billion. The estimate is very uncertain, and the final costs may well turn out to be 50 percent higher. The rule is that the costs must not burden future generations, but must be paid for from the revenues from electricity production. This requires a well-designed financing system with allocations to a fund and risk management. The financing system is described in last year's state-of-the-art report. This chapter focuses on calculations and handling of the costs and the uncertainties associated with the cost estimates.

According to the Nuclear Activities Act (the Act (1984:3) on Nuclear Activities), the holder of a licence for a nuclear activity is obligated to manage and dispose of spent nuclear fuel and nuclear waste. The reactor owners in particular are obligated to build a facility for final disposal of spent nuclear fuel.

The Financing Act (the Act (2006:647) on Financial Measures for the Management of Waste Products from Nuclear Activities) contains provisions to guarantee the financing of these obligations. According to the Financing Act, the licensees[1] pay a nuclear waste fee and are obligated to pledge guarantees for the costs that have

---

[1] By "licensee" is meant here the holder of a licence under the Nuclear Activities Act to own and operate a nuclear power reactor.

not yet been covered by paid-in fees. The fees are deposited in a special fund, the Nuclear Waste Fund. The guarantees are pledged by the parent company of the licensee in question.

The obligations have been discharged when the licensees' facilities have been decommissioned or cleared from regulatory control and all nuclear material and nuclear waste has been emplaced in repositories that have been closed and sealed which, in the case of spent nuclear fuel, will occur far in the future, perhaps around 2100. Long-term responsibility for final disposal will then be assumed by the state, which thereby bears the ultimate cost risk in the event the licensees are not able to discharge their obligations.[2]

In other words, the legislators make the licensees liable for payment. Accordingly, primary responsibility for estimating costs and uncertainties also rests with the licensees, who have delegated this responsibility to SKB. The state here assumes the role of reviewer via the Swedish Radiation Safety Authority (SSM). Normally, SKB carries out a cost estimate every three years, which is then reviewed by SSM. Based on SKB's cost estimate and SSM's review, the Government then determines the size of the fee to the Nuclear Waste Fund and of the guarantees that must be pledged for the supplementary and financing amounts. The supplementary amount hedges against uncertainties in the cost estimate for the fee, while the financing amount hedges against uncertainties in the licensees' future ability to pay.

The process, which is repeated every three years, utilizes five different barriers to protect the state, and ultimately future taxpayers, from having to pay for the decommissioning of existing reactors. Three of these barriers are owned and maintained by the state and two by SKB and its principals.

SSM's review of SKB's calculations constitutes an important administrative state barrier against the necessity for future taxpayers to pay for decommissioning and waste management. Another such state barrier (financial in this case) is the Nuclear Waste Fund and its management of paid-in fees. However, both of

[2] See Gov. Bill 1997/98:145, p. 381. See also SÖ 1999:60 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

these barriers are dependent on the third social barrier[3] , which consists of referral to stakeholders for comment[4], preparation in the Ministry of the Environment including joint preparation with other concerned departments – and then a decision by the Government on the size of the fee and the guarantee amounts.

The work with the three state barriers is based on the calculations and assessments done within SKB by their experts and reference persons. SKB's calculations and assessments constitute an expert barrier, which thus has a clear industrial identity. This means there is a partisan relationship Between SSM's administrative barrier and SKB's expert barrier. When the decommissioning and final disposal work has begun, there is potential for a second barrier within SKB. This barrier is a project barrier consisting of the cost control exercised by SKB. This cost control includes responsibility for learning processes within all sub-projects. These processes can, for example, be described by learning curves, for which credit should be taken in calculations and estimates of the future costs.

7.2 Factors that influence the estimate

7.2.1 Cost discrepancies in large investment projects

Several studies have shown that investments in large projects are associated with considerable risks of cost overruns. Even though some civil engineering projects have turned out to be less expensive than expected, cost overruns are normal. Cost overruns are generally slightly bigger for development projects than for civil engineering projects. The greater the element of pure research in the project is, the greater the cost overruns tend to be.[5]

Unusual and rarely executed projects are more subject to cost discrepancies than more run-of-the-mill projects. This is because there are few good precedents and little applicable experience for

[3] SOU 2007:38 *Nuclear Waste State-of-the-Art Report 2007 – responsibility of current generation, freedom of future generations*, p. 77.
[4] Licensees, their owner companies, government authorities and environmental organizations.
[5] SOU 2004:125 *Betalningsansvaret för kärnavfallet.* ("Payment liability for the nuclear waste", in Swedish), Financing Committee, Chap. 3.

these projects. Several studies also show a relationship between construction time and cost discrepancies.

The nuclear waste project is without doubt a big and long-term project. It also belongs to the category of unusual and rarely executed projects, and the project time is very long.

7.2.2 Few stakeholders assess the risks

Numerous stakeholders (risk-takers) are often involved in large and long-term civil engineering and industrial projects. Shareholders, lenders and other creditors, as well as guarantors and insurers, are examples of financial stakeholders in many projects. Their involvement often entails that they assume parts of the risk that accompany a project. If it should turn out that the project's costs are considerably higher and/or that its revenues are considerably lower, the risk-takers have to assume the financial consequences. Because they are taking a risk, they often make their own assessments of risks and make their own demands on the project. Projects with many risk-takers may thus be associated with multiple risk assessments.

The nuclear waste project has few financial stakeholders. There are no outside stakeholders that make their own assessments of the project's risks. The stakeholders that are involved in the nuclear waste project are the nuclear power industry and the state, mainly via the Swedish Radiation Safety Authority.

7.3 The three-year fee periods constitute the financing system's basic risk buffer

The financing system is built up around the fact that every third year, new cost calculations are made of the expected remaining financing amount in the financing system and new decisions are taken on the size of the nuclear waste fee and the guarantees. In other words, the financing system is built up around a rolling three-year mechanism.

This rolling means that when new cost calculations of remaining financing needs reveal unplanned outcomes that deviate from previous cost calculations, this has a direct impact on the reactor owners' payment liability. Provided that the expected financing need is estimated accurately and that appropriate decisions are made in keeping with this, this rolling mechanism gives the state a risk buffer that captures the system's different uncertainties. This is therefore a central part of the financing system and its function to serve as a risk management tool that takes into account the financial risk that accompanies the state's ultimate responsibility.

The long project time is an important aspect to consider for safe disposal of nuclear waste, especially in the light of the fact that the licensee's ability to bear unfavourable outcomes in the system is limited by the revenues from electricity production up to when the reactors are shut down. In this light, it can be claimed on good grounds that the rolling mechanism in itself is of uncertain value as a risk buffer in the system.[6]

The Financing Act's requirement that the licensees pledge guarantees as a complement to the nuclear waste fee and thereby induce other stakeholders with greater long-term financial strength to assume a secondary liability adds further weight to the value of the rolling mechanism in the financing system. This has meant that the licensees' owner companies have, via their guarantee commitments, formally assumed a certain portion of the licensees' financing liability.

In this way the uncertainties associated with calculations and fee decisions as well as the return on the paid-in fees will influence the decisions taken on new fees and guarantees.

7.4 The expert barrier – SKB's calculation system

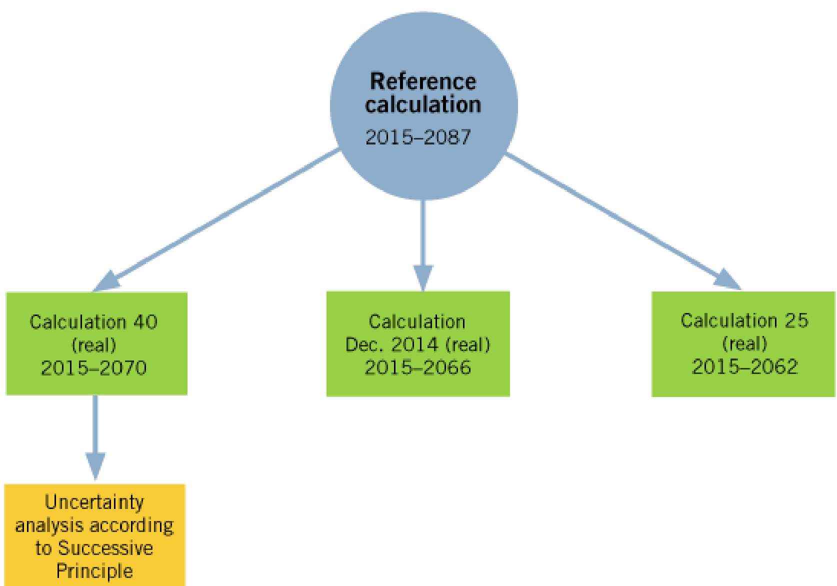
The Financing Act requires the licensees to carry out cost calculations. These calculations serve as a point of departure for the processes of determining fees, including supplementary and financing amounts. SKB carries out the calculations on behalf of the licensees, normally every three years. The most recent cost

[6] SSM, *Förändringar i lagen (2011:647) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet och förordningen (2008:715) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet ("Changes in the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities and the Ordinance (2008:715) on Financial Measures for the Management of Residual Products from Nuclear Activities", in Swedish).* (SSM2011-4690).

estimate, Plan 2013, was submitted to SSM in January 2014. After a statement of comment by SSM (the administrative barrier), the matter is submitted for a decision to the Government (the social barrier), as has been described in previous sections.

The quantity of waste produced depends on how long the nuclear power plants are operated for, and the operating life of the plants also determines when the last waste can be disposed of and waste management can be concluded. The legislation prescribes uniform planning horizons, which do not have to coincide with the licensees' own planning. The Financing Act assumes that all currently electricity-generating plants have a technical lifetime of 40 years, and if a plant has passed this age but is still producing electricity at the time of the calculation, it is assumed to continue doing so for another six years. Figure 7.1 shows how SKB's calculation system handles the relationship between the law's planning horizon and the licensees' own planning to calculate the basis for fees and for supplementary and financing amounts, and to allocate them between different plants.

Figure 7.1 SKB's calculation system



All calculations are based on a Reference Calculation that follow's the industry's own planning, where the operating time for O1, R1 and R2 has been assumed to be 50 years[7], while other plants have a planned operating time of 60 years. This means that the production of spent nuclear fuel amounts to 6,200 canisters or 12,000 tonnes of fuel. According to this calculation, waste management will be concluded in 2087 (see Fig. 7.1). The reference calculation is then scaled down to operating times that correspond to the provisions of the legislation, resulting in Calculation 40 (real). The word "real" shows that the calculation of the total cost for the system is based on assumptions concerning the real cost trend for external costs (such as labour, machinery and raw materials) during the period. The importance of these assumptions is discussed in the next section. Calculation 40 (real) is supplemented by an uncertainty analysis, and together with this analysis the calculation provides a basis both for the remaining basic cost, which is used to calculate the fee level, and for determining the supplementary amount. Calculation Dec. 2014 (real) calculates the remaining basic cost for the management of residual products from the operation of the reactors up until 31 December 2014. The financing amount is determined by the difference between this cost and the funds available in the Nuclear Waste Fund. Calculation 25 (real) is used to allocate the costs among the different reactors.

The continued discussion focuses on the left branch in Figure 7-1. The next section discusses a) the structure of the reference calculation and the assumptions regarding changes in external cost factors that are used to arrive at Calculation 40 (real), and b) SSM's review of external factors, based on SSM's responsibility for the administrative barrier. It could be said that SKB's calculation yields a basic cost that is based on fixed assumptions regarding what the system will look like and how the factors in the surrounding environment will evolve. Together, these assumptions form a basic scenario that serves as a point of departure for a deterministic calculation. The opposite is a probability calculation, which is based on the probability of finding a given value of key costs. Section 7.6 discusses SKB's method using this type of calculation to determine

[7] O1 is a Boiling Water Reactor (BWR) in Oskarshamn. R1 is a BWR in Ringhals. R2 is a Pressurized Water Reactor (PWR) in Ringhals.

the uncertainties in the basic scenario and from there the supplementary amount, and SSM's review and conclusions regarding the supplementary amount.

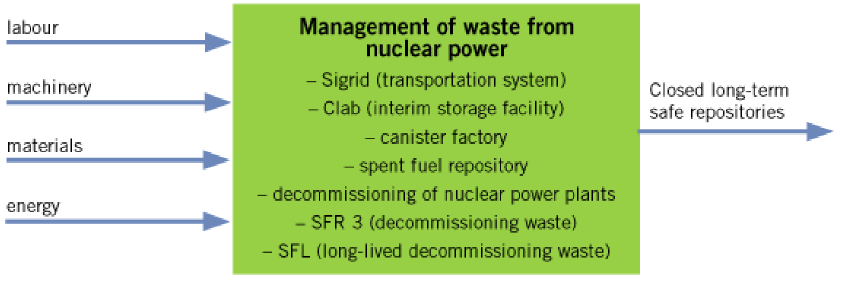
7.5 Reference calculation and external factors

7.5.1 SKB's calculation

The reference calculation is based on a picture of the waste management system, with existing or planned flows and facilities. The waste flows consist of spent nuclear fuel, waste from decommissioning of the nuclear power plants and waste from operation of nuclear power plants and waste facilities. The operational waste from the nuclear power plants is not covered by the Financing Act, but is paid for directly by the reactor owners, and the costs for this type of waste are therefore not included in Calculation 40 (real). Figure 7.2 shows the facilities that are to be fully or partially financed by the Nuclear Waste Fund. The existing facility in Forsmark for short-lived waste, SFR1, is not included since only operational waste is disposed of there.

Figure 7.2 An input-output model of the waste management system

The inputs to the system are, besides waste, labour, machinery, materials and energy. The system produces long-term safety by means of closed and sealed repositories. By "materials" is meant e.g. concrete, bentonite and copper.



Based on function descriptions for each facility, the need for the input factors labour, machinery, materials and energy is calculated. A base cost is calculated for each of the various construction and installation costs. According to SKB, this base cost consists of three parts:

1. Quantity-related costs. Quantity-related costs are based directly on the estimate of the need, i.e. the "quantity", of input factors expressed in physical units, for example man-months, m^3 or MWh. The costs of these items can be calculated from unit prices, for example for concrete casting, rock blasting and operating personnel. The unit prices are based on previous experience in the industry from nuclear facilities such as Clab and SFR1.
2. Non-quantity-related costs. In the case of future facilities, detailed data for more exact estimates of input factors are lacking in certain cases. SKB says that sufficiently accurate cost estimates can be obtained by means of experience-based percentage allowances.
3. Secondary costs. Costs for administration, design, procurement, inspection, and temporary buildings are included in secondary costs. These costs are estimated by means of experience-based percentage allowances.

An important factor for the calculation of Calculation 40 (real) from the Reference Calculation is assumptions about how real prices will develop during the period in question, which according to Figure 7.1 lasts from 2015 until 2070. SKB is introducing a number of conversion factors by which today's prices are multiplied to obtain the price at a given time in the future. The conversion factors are called external economic factors (EEFs) and consist of the costs of labour, materials, energy costs and machinery, as well as exchange rates. EEF 1–8 are described in the first column in Table 7.1. For each EEF, a trend line is given for the period 2015–2017. The trend line represents an extrapolation over 55 years from historical data.

The calculations are naturally associated with very great uncertainties. This applies both to the design of the future waste management system and the evolution of the system environment, which SKB handles by means of EEFs. To shed light on the uncertainty, let us make the thought experiment of going back 55 years into the past. That brings us to 1960, before the advent of mobile phones, personal computers and air travel for the masses. This makes it clear that even with normal technical progress and economic development, putting too much faith in extrapolations entails considerable risks for future taxpayers.

7.5.2 The administrative barrier – SSM's review of Calculation 40 (real)

In preparation for its review of Plan 2013, SSM contracted three different expert organizations to conduct special reviews. The National Institute of Economic Research (KI) has reviewed SKB's predictions for the development of EEFs, the Norwegian University of Science and Technology (NTNU) has reviewed SKB's uncertainty analysis, and the UK Nuclear Decommissioning Authority (NDA) has reviewed the decommissioning costs for the reactors in Ringhals, Oskarshamn and Forsmark.[8] SSM concludes that calculations of real price changes and the method for uncertainty analysis are critical for the cost trend, but that this does not apply to decommissioning costs.[9] In this section we discuss KI's analysis of SKB's estimates of real price changes, while the analysis of uncertainty is taken up in the next section.

Based on KI's analysis, SSM concludes that Calculation 40 (real) may be underestimated by up to SEK 10 billion or 12 percent, which is very significant for fee calculations. SSM therefore proposes a one-year fee period with decision only for 2015. SSM then wants to request new calculations from SKB based on KI's analysis in order to propose fees for 2016 and 2017.

Table 7.1 illustrates the differences between SKB's and KI's analyses of EEFs. The index for all EEFs has been normalized to

[8] Appendices to SSM (2014), *Yttrande avseende kärnavfallsavgifter samt finansierings- och kompletteringsbelopp för 2015–2017 enligt lagen (2006:647) om finansiella åtgärder för hantering av restprodukter från kärnteknisk verksamhet.* ("Statement regarding nuclear waste fees and financing and supplementary amounts for 2015 – 2017 under the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities", in Swedish. 13 October 2014. (SSM2013-6256).
[9] SSM's statement to the Government 13 October 2014. (SSM2013-6256), p. 3.

100 for 2007, and the table shows how this price index increases between 2011 and 2070. In all cases except for EEF 6, the real price of bentonite, SKB predicts a much lower price increase than KI. Both SKB and KI base their analyses on historical data for the period 1950–2010, except for energy prices, where the base period has been 1970–2010. The differences are due in part to the analysis of historical data and in part to the methodology for predicting the change in EEFs based on the historical analysis. A crucial factor is the forecasting model that was used.

Table 7.1 Projection of EEFs

		2011	2070
EEF 1 – real labour cost per unit produced, service sector	SKB	102.8	125.1
	KI	102.8	163.0
EEF 2 – real labour cost per unit produced, construction industry	SKB	115.7	136.0
	KI	115.7	201.0
EEF 3 – real machinery prices	SKB	101.0	72.7
	KI	97.8	92.7
EEF 4 – real prices of building materials	SKB	107.8	140.9
	KI	–	–
EEF 5 – real price of copper (USD/tonne)	SKB	114.0	70.2
	KI	114.1	225.3
EEF 6 – real price of bentonite (USD/tonne)	SKB	119.9	119.9
	KI	142.2	70.5
EEF 7 – real efficiency-adjusted energy prices	SKB	132.6	120.0
	KI	112.4	153.0
EEF 8 – Real SEK/USD exchange rate	SKB	95.0	107.1
	KI	97.2	96.5

Source: National Institute of Economic Research (KI), *Kommentarer till beräkningar av externa ekonomiska faktorer i SKB:s rapport Plan 2013 Underlag för kostnadsberäkninga* ("Comments on calculations of external economic factors in SKB's report Plan 2013 Basis for cost calculations", in Swedish) (Reg. no. 6.1-74-14). An appendix to SSM's statement of comment to the Government of 13 October 2014. (SSM2013-6256).

SKB uses a linear forecasting model, while KI advocates an exponential forecasting model. KI claims to have strong theoretical support in the economic literature for such an assumption. In the long run, a linear model leads to a trend where, in a sector with rising prices, the growth in productivity converges with the average rate of growth for production of the basket of goods and services included in the consumer price index, i.e. a form of economic "heat death". In a sector with falling prices, a linear model leads to negative prices.

A rough idea of the difference between the two forecasting models can be obtained using a numerical example. Assume that the historical analysis shows that the real rate of price increase has been constant at 2 percent per year. At the starting point year T, the index for EEFs is set at 100, and at T + 1 the index increases to 102 in both the linear and the exponential case. At T + 2 the index is 102 + 2 = 104 in the linear forecasting model, but the exponential model assumes a percentage price increase, i.e. the index is $102 \cdot 1.02 = 104.04$. There is a small difference for the first years, but at T + 20 the index in the linear model gives $100 + 2 \cdot 20 = 140$, while the index in the exponential model is $100 \cdot 1.02^{20} = 148$, i.e. 8 index units more. After 55 years the difference has grown to 297 – 210 = 87 index units.

KI's analysis brings up the question of how long productivity growth should be treated. Both SKB and KI solve the problem by forecasting the labour cost per unit produced on the basis of historical data. The learning curves that are described under the section on the project barrier offer a means for estimating long-term productivity and warrant further study. For example, the labour cost per unit can be divided into two factors: wages, i.e. labour cost per time unit, and productivity, i.e. number of time units per unit produced.

Real wage growth has been measured for different groups in society and cannot be influenced by SKB. The learning curves provide a means to estimate the productivity trend not as a function of time but rather as a function of accumulated production, which is under SKB's control. The section on the project barrier discusses the productivity trend for the canister line. Assume that an operationally independent production line is achieved by the 100th canister in 2032 and that production and deposition of this canister requires 1 time unit. With a 20 percent learning rate, this means that when the last canister is deposited in 2072 (in accordance with the reference calculation), this will require $1 \cdot (1 - 0.2)^{5.95} = 0.26$ time units.[10] If real payroll costs

[10] The number of man-hours per canister decreases by 20 percent with every doubling of the number of canisters produced. The learning curve follows a logarithmic logic so that an

increase by 2 percent per year, this means that the unit price for labour will increase by 221 percent between 2032 and 2072, but the total labour cost to produce and deposit one canister is only 0.26 ▪ 221 = 57 percent of the cost for the 100th canister, i.e. the labour costs have *decreased* by 43 percent! If we follow KI's indexing system with an index of 100 in 2007, the labour costs for the 100th canister correspond to an index = 164, while the labour costs for canister no. 6,200 correspond to an index = 93. However, this result is specific for canister production with many doublings. For e.g. the decommissioning of 12 nuclear power plants, similar estimates show that real wage increases and productivity growth balance each other.

7.6 Uncertainty analysis and supplementary amount

7.6.1 SKB's use of the Successive Principle

Uncertainty analysis tries in a structured manner to estimate the uncertainties in the cost calculations quantitatively. SKB uses a system called Successive Calculation or the Successive Principle, developed by Lichtenberg.[11]

The work is done in an Analysis Group and is coordinated by several Moderators, who should be well-acquainted with the methods of the Successive Principle. The members of the Analysis Group are presumed to be familiar with the principles of the waste system as well as the Reference Calculation and Calculation 40 (real).

The process begins with brainstorming where the participants in the Analysis Group propose features, events and processes (FEPs) that can influence the costs of waste management. FEPs are collected in overall structures, which are called general aspects in the method. In the next phase, these aspects are defined with respect to their importance for planning and what opportunities and risks they represent.

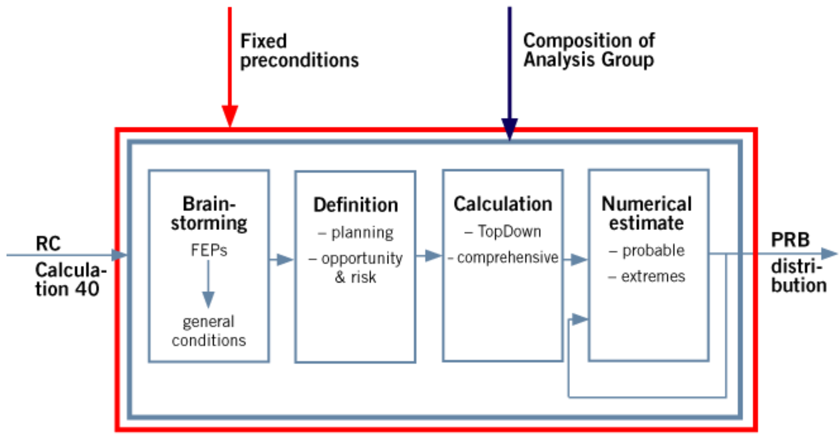
---

increase in the number of canisters produced and deposited from 100 to 6,200 is equal to 5.95 doublings.

[11] Lichtenberg, S. (2000), *Proactive management of uncertainty using the successive principle: a practical way to manage opportunities and risk.*

Figure 7.3 Process for the Successive Principle

RC = Reference Calculation; FEPs = Features, Events and Processes; PRB = Probability



The goal is to quantify the uncertainties. The moderators build up a calculation to be able to handle the Analysis Group's numerical estimates. Each member of the Analysis Group assesses the impact of each condition on the results of the deterministic calculations (Reference Calculation and Calculation 40 [real]) under the heading minimum/most likely/maximum. The figure "0" for "most likely" for a given aspect means that the member believes that the result of the deterministic calculation still gives the most probable cost outcome, i.e. the effect of the aspect is probably taken into account completely in the deterministic calculation. According to the methodology, the amount for "minimum" indicates that the probability is less than 1 percent that the cost will be lower than this amount compared with the most probable outcome, and the amount for "maximum" indicates that the probability is less than 1 percent that the costs will be higher than this amount. Based on the Analysis Group's numerical estimates, the calculation program computes a probability distribution for the cost of the project. The dominant aspects are discussed in the Analysis Group and new numerical estimates are calculated. The numerical estimates are recalculated until the Analysis Group agrees that the process reflects the importance of the different aspects for the uncertainty.

The end product of the process is a curve describing the probable distribution of the cost of the project.

In the documented procedure[12], the calculation program consists of standardized statistical tests. SKB uses a Monte Carlo model to weigh together the uncertainties from the different aspects, which reduces the transparency in a complex process. For example, it is not possible to see the contributions of the different uncertainties to the total standard deviation.[13]

7.6.2 The administrative barrier – review of the successive calculation

Figure 7.3 shows that the uncertainty analysis has two fixed frames: fixed preconditions and the composition of the Analysis Group. The importance of these frames is discussed in Licthenberg's and Borg's report to SSM about Plan 2010[14] and in NTNU's report to SSM about Plan 2013.[15]

A fixed precondition is an absolutely certain premise for the calculations. In accordance with Plan 2013, the fixed preconditions are decided "at a high level within SKB".[16] Examples of fixed preconditions are "No monitoring after closure", "The KBS-3 method is used" and "Retrieval of canisters shall be possible, but not included in the calculation". NTNU concludes that:

> Fixed preconditions are fixed only if someone provides credible assurances that they take full responsibility for ensuring that the preconditions will endure for the life of the project (translated from Norwegian).[17]

---

[12] Lichtenberg, S. (2000).
[13] Torp et al., (2014), "Vurdering av usikkerhetsanalyse: Sluttlagring for svensk kjernekraftavfall" ("Evaluation of safety assessment: Final disposal of Swedish nuclear power waste", in Norwegian).
[14] Lichtenberg, S. & Borg, L. (2011), *Granskning av SKB:s användning av den successiva kalkylmetoden – undersökning av SKB:s kostnadsberäkningar för Plan 2010.* ("Review of SKB's use of the successive calculation method – study of SKB's cost calculations for Plan 2010", in Swedish.) p. 3.
[15] Torp et al. (2014).
[16] SKB (2013), *Plan 2013 Costs from and including 2015 for the radioactive residual products from nuclear power*, p. 19.
[17] Torp et al. (2014), p. 20.

This means that someone outside the Nuclear Waste Fund must pay if they are forced to violate a fixed precondition during the project. What happens if a plugged deposition tunnel has to be opened to retrieve defective canisters? During construction of the Öresund Bridge, a nearly finished pylon had to be demolished due to faulty concrete casting. Retrieval is not unusual in large projects. NTNU concludes in its summing-up of fixed preconditons:

> We have the impression that there is a conflict of interest between SSM, which puts a strong emphasis on setting aside sufficient funds to reduce the state's risk, and SKB, which has the same overall goal but naturally wishes to keep the fee levied on production as low as possible (translated from Norwegian).[18]

The composition of the Analysis Group determines the perspective of the process. Lichtenberg & Borg and Torp, Klakegg & Austeng underscore the importance of a broad composition with competence from many different professions, not all strictly technological. Lichtenberg & Borg stress the need for one or more members to act as "devil's advocate". In Plan 2013, SKB claims that their Analysis Group "has a broad-based membership from areas linked to nuclear activities as well as from areas that are totally detached from such activities."[19] The NTNU reviewers say that SKB has succeeded in part, but note:

> However, the group is still very technology-oriented, male-dominated and has a high average age. There is also another factor that distinguishes this group from ordinary resource groups in uncertainty analyses: It seems to be of a fixed composition, rather than being assembled for a specific analysis. This enables the group to acquire experience and knowledge and thereby increase the potential for good judgements, but it also ties the group closely to the project, imposing natural limitations on perspective (translated from Norwegian).[20]

The NTNU reviewers recommend that the Analysis Group be broadened with at least 2–3 individuals who are not so closely tied to the process but who possess relevant competence within related sectors of society, and that an internal and an external moderator collaborate in the process.

---

[18] Torp et al. (2014), p. 20.
[19] *SKB Plan 13*, p. 16.
[20] Torp et al. (2014), p. 53.

The principal criticism levelled at both Plan 2010[21] and Plan 2013[22] relates to the width of the curve that describes probability for the project cost. This is a serious criticism, since the width of the curve determines the supplementary amount.

The width of the probability distribution is measured by the standard deviation.[23] According to Calculation 40 (real) in Plan 2013, the expected cost is more than SEK 100 billion, with a standard deviation of around SEK 10 billion, i.e. a relative standard deviation of 10 percent. The equivalent standard deviation for Plan 2010 was 15 percent. According to Lichtenberg & Borg and Torp, Klakegg & Austeng, the standard deviation for a project of the size and maturity of the nuclear waste project should be at least 20–30 percent. In other words, there is a considerable risk that the supplementary amount of SEK 11.1 billion proposed by SKB is far too small.

In their concluding chapter, the NTNU reviewers take up the question of where responsibility for the expert barrier should lie:

> SKB initially faces a difficult dilemma: Should they contribute to calculating a cost that results in a higher fee level for the nuclear power industry and thereby lower earnings, or should they contribute to calculating a cost that results in a low fee level and thereby good earnings for the owners? We are not saying that SKB's deliberately calculates costs in a tendentious manner, but merely wish to point out that it is difficult for them to maintain a neutral perspective on a project that directly affects their owners' cost and earnings. This aspect should receive great attention in SKB's further work. Swedish regulatory authorities may well ask themselves if it is right to put SKB in such a position (translated from Norwegian).[24]

[21] Lichtenberg, S. & L. (2011).
[22] Torp et al. (2014).
[23] For the symmetric normal distribution, mean value = expected value = most likely value. For this distribution, 2/3 of all cost outcomes fall within one standard deviation of the expected value, i.e. within the interval between (expected value – standard deviation) and (expected value + standard deviation). This is usually expressed by saying that "two thirds of all values lie within two standard deviations". It is worth noting that this means that 1/3 of all cost outcomes fall outside of two standard deviations.
[24] Torp et al. (2014), p. 72.

7.7 The project barrier and learning curves

The real cost for nuclear waste management and decommissioning is determined at the project level. It is in part a function of the nuclear power industry's and SKB's ability to assemble a site organization that is able to integrate safety issues, decommissioning of nuclear power plants, management of waste streams and construction, operation and closure of the waste system's facilities in an efficient, legitimate and authentic manner. The Council has in other contexts discussed the design of an organization for managing final disposal of spent nuclear fuel. From a cost perspective, one characteristic of the organization appears necessary: the cost constraints require *continuous learning* at all levels in the organization.

During the research and development phase of the waste system, SKB has proved to be a well-functioning learning organization with the ability to initiate, execute and learn from research and development projects. The transition to industrial activities involves new challenges as regards the application of RD&D results and SKB's own and others' experience from ongoing work with e.g. decommissioning, canister production and waste deposition. Internationally speaking, final disposal according to the KBS-3 method is a pioneering project, and vast experience is gradually being accumulated within the project from canister deposition and excavation of deposition tunnels. This experience should lead to continuous productivity improvement. Decommissioning of nuclear power plants is not a unique activity. The challenge here is to profit from the learning that is taking place at an international level. In both cases, *learning curves* are an established tool for planning, management and follow-up of the activity.[25]

The learning curves show how costs are reduced and technical aspects are improved as a function of accumulated production. Thus, the learning is not a function of time but is completely dependent on the activities in the organization. Measured in terms of specific costs, the nuclear power industry has been bad at profiting from its experience. The specific costs of building nuclear

[25] Jaber, M.Y. (editor) (2011), *Learning Curves – Theory, Models, and Applications.*

power plants have increased instead of decreasing, as in other energy categories.[26] One reason may be that the learning has been focused on increasing safety instead of reducing costs. Another reason may be that nuclear power plants are large entities that are built under the constant oversight of national regulatory authorities. This makes it difficult for the project team to achieve the “operational closure” that is required for learning.[27,28] But compared with building a nuclear power plant, canister production and deposition can be most appropriately described as a modular activity.

The purpose of this section is to show what gains can be achieved with an organization that is oriented towards learning. The focus is on specific repetitive activities, not on the cost of the whole project, but this technological learning is a cost-reducing process that can counteract the cost-driving factors identified in the uncertainty analysis. Technological learning is thereby an important barrier for protecting the national treasury and the taxpayers against escalating costs.

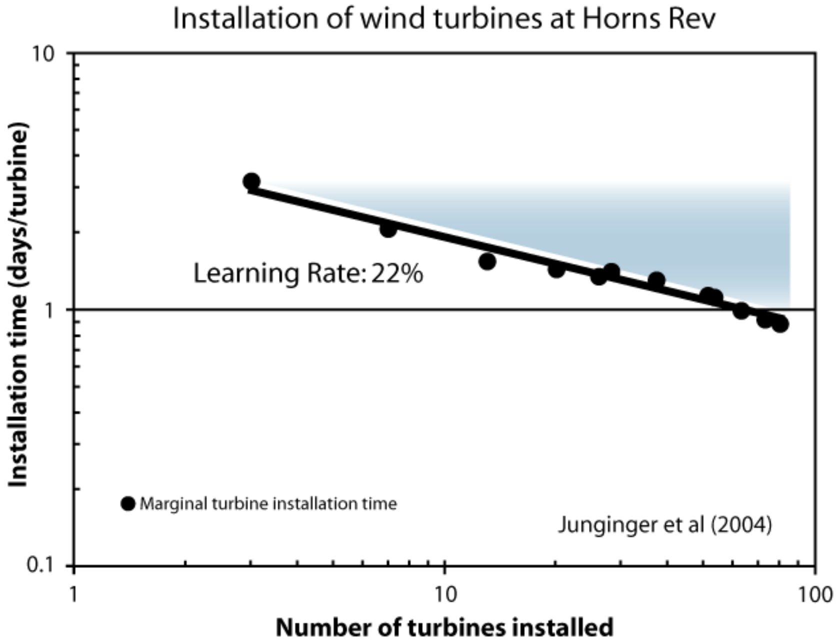
Figure 7.4 shows the learning curve for installing 80 wind turbines at a wind farm at Horns Rev outside Denmark. The third wind turbine took about three days to install, but the last turbine was installed in less than one day. The installation time for wind turbine no. N is given by the following equation:

(Installation time for turbine N) = (Installation time for third turbine) ▪ $(N/3)^{-E}$

E is a constant that gives the learning rate. The learning rate here is 22 percent, which means that the installation time decreases by 22 percent for each doubling of the number of installed turbines. The blue triangle shows the gain from technological learning. The total installation time for the wind farm is reduced by 56 percent due to technology learning.

[26] Junginger, M., van Sark, W. & Faaij, A. (2010), *Technological Learning In The Energy Sector: Lessons for Policy, Industry and Science.*
[27] Wene, C.-O. (2007), “Technology Learning Systems as Non-Trivial Machines”, *Kybernetes* 36(3/4), pp. 348–363.
[28] Wene, C.-O. (2008), “Energy Technology Learning through deployment in competitive markets”, *The Engineering Economist* 53(4), pp. 340–364.

Figure 7.4 Learning curve for installation of an offshore wind farm at Horns Rev in Denmark. Both axes are logarithmic



Source: Junginger et al., 2004.[29]

The extensive literature on learning curves and technological learning shows that virtually all competitive activities exhibit learning of the type shown in Figure 7.4. The mathematical relationship between resource consumption (installation time) and cumulative production (number of turbines installed) is the same regardless of sector, location and technology. Stability, learning rate and interpretation of different breaks in the curve are discussed, all are agreed that the effect exists. The effect is also utilized in e.g. the launching of new products, where the first specimen can be priced below the production cost in the knowledge that it will gradually decline if the product breaks into the market and production can be ramped up. This is also an argument for government subsidies for new technology.[30]

[29] Junginger, M., Faaij, A. & Turkenburg, W.C. (2004), "Cost Reduction Prospects for Offshore Wind Farms", *Wind Engineering* 28(1), pp. 97–118.
[30] IEA (2000), *Experience curves for energy technology policy.*

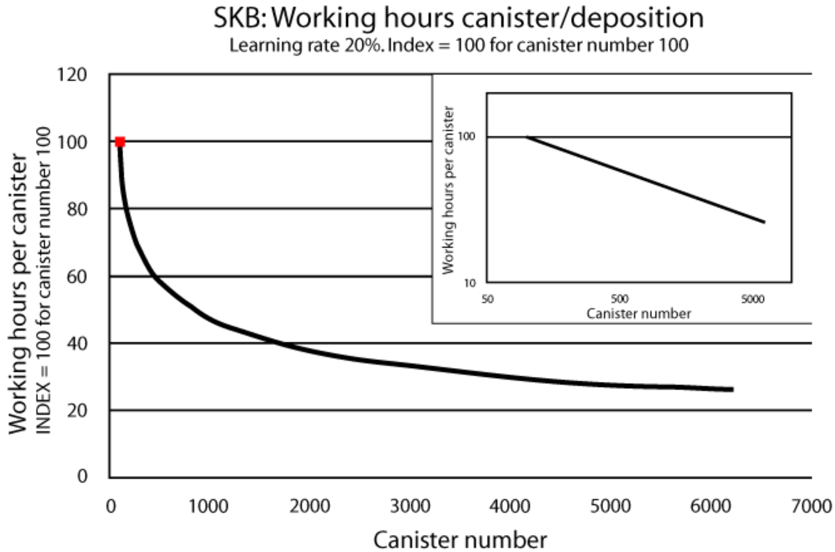
Figure 7.5 illustrates a hypothetical application of learning curves to production and deposition of 6,200 copper canisters. It can be argued that when the project team has achieved operational closure, the trip down the learning curve can begin and – provided that the team can retain its closure – continue until the last canister has been deposited. The learning rate is assumed to be 20 percent.[31] The conservative assumption is made in the figure that closure is not achieved until the 100th canister. Up until then, it is assumed that SKB will experiment with organization and technology while the regulatory authority looks for new procedures, which means that the project team does not have full control over its operations.

If the labour input for the 100th canister is set equal to 100 units, then the labour input for the last canister is 26 units. Technology learning has reduced the total labour input by more than 60 percent compared with a case where all canisters from 100 to 6,200 require the same labour input as the 100th canister.

[31] Wene, C.-O. (2011), "Energy Technology Learning – Key to Transform into a Low – Carbon Society" and Wene, C.-O. (2007), "Technology Learning Systems as Non-Trivial Machines", *Kybernetes* 36(3/4), pp. 348–363.

Figure 7.5 Example of a possible learning curve for the canister line

The big figure shows the learning curve in a linear plot. The inset shows the same learning curve in the same double-logarithmic plot as for the wind turbines in Figure 7.4.



7.8 The social barrier

The Government decided at the Government meeting on 18 December 2014 that the nuclear waste fee should be increased to an average of 4 öre/kWh of nuclear-generated electricity for the period 2015–2017, i.e. for all three years in the period. This increase is the same as that proposed by SSM. But as mentioned previously, the Authority's proposal was that the fee should only apply for 2015. SSM wanted better data from SKB as a basis for proposing fees for 2016–2017. SSM says that SKB's method for calculating the real price trend leads to underestimation of the costs by SEK 11 billion. SSM therefore believes that SKB's calculation of the expected costs must be redone.[32]

[32] See SSM's report *Förslag på kärnavfallsavgifter, finansierings- och kompletteringsbelopp för 2015.* ("Proposal for nuclear waste fees, financing and supplementary amounts for 2015", in Swedish.) (SSM2013-6255).

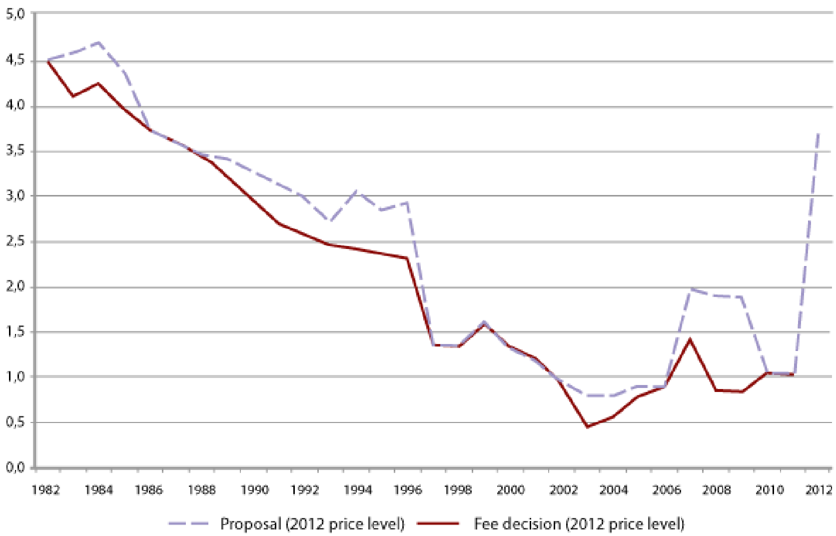
In the first chapter it was mentioned that SSM's review of SKB's calculations constitutes an important *administrative* state barrier against the possibility that future taxpayers will have to help pay the costs of decommissioning and waste management. Another such state barrier (financial in this case) is the Nuclear Waste Fund and its success in managing paid-in fees. However, both of these barriers are dependent on the third *social* barrier, which consists of referral for comment, preparation in the Ministry of the Environment and decision by the Government on the size of the fee and the guarantee amounts. The social barrier helps to prevent the spent nuclear fuel in the final repository from harming man and the environment.[33]

The Government's decision on the nuclear waste fee for the period 2015–2017 is an example of the social barrier where the Government makes a different judgement than the expert authority.

Over a long period of years the Government-determined fees have been below the fees proposed by the previous authorities – the National Board for Spent Nuclear Fuel and the Swedish Nuclear Power Inspectorate. Translated into 2012 prices, the fee has also been reduced since 1982. See Figure 7.6.

[33] See SOU 2007:38 *Nuclear Waste State-of-the-Art Report 2007*, p. 82.

Figure 7.6 Government-determined nuclear waste fee compared with expert authority's proposal



Source: SSM.

A fundamental principle for the management and disposal of nuclear waste and spent nuclear fuel is that the disposal costs must be covered by revenues from the energy production which has given rise to these wastes. This principle is reflected in the financing legislation. It is also found in the Nuclear Activities Act[34] and the Environmental Code.[35]

In its statement of opinion on SSM's proposal for fees and guarantees for the period 2012–2014, the Swedish National Council for Nuclear Waste said that it could be debated whether the Nuclear Waste Fund is currently underfunded.[36]

[34] Cf. Section 13 of the Nuclear Activities Act.
[35] Cf. Chap. 16 Sec. 3 of the Environmental Code.
[36] *Kärnavfallsrådets yttrande över Strålsäkerhetsmyndighetens förslag till kärnavfallsavgifter och säkerhetsbelopp för 2012–2014.* ("The Swedish National Council for Nuclear Waste's statement regarding the Swedish Radiation Safety Authority's proposal for nuclear waste fees and guarantee amounts for 2012–2014", in Swedish). (Reg. no. 42/2011).

References

IEA (2000), *Experience curves for energy technology policy.* International Energy Agency/Organisation for Economic Co-operation and Development: Paris.

Jaber, Mohamad Y. (editor) (2011), *Learning Curves – Theory, Models, and Applications.* CRC Press: Boca Raton.

Junginger, M., Faaij, A. & Turkenburg, W.C. (2004), "Cost Reduction Prospects for Offshore Wind Farms", *Wind Engineering* 28(1), pp. 97–118.

Junginger, M., van Sark, W., and Faaij, A. (2010), *Technological Learning In The Energy Sector: Lessons for Policy, Industry and Science.* Edward Elgar: Cheltenham, U.K.

National Institute of Economic Research (2014), "Kommentarer till beräkningar av externa ekonomiska faktorer i SKB:s rapport Plan 2013 Underlag för kostnadsberäkningar", ("Comments on calculations of external economic factors in SKB's report Plan 2013 Basis for cost calculations", in Swedish) (Reg. no. 6.1-74-14), Appendix to SSM's *Yttrande avseende kärnavfallsavgifter samt finansierings- och kompletteringsbelopp för 2015–2017 enligt lagen (2006:647) om finansiella åtgärder för hantering av restprodukter från kärnteknisk verksamhet* ("Statement regarding nuclear waste fees and financing and supplementary amounts for 2015–2017 under the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities", in Swedish). (Reg. no. SSM2013-6256).

Kärnavfallsrådet (2014), *Kärnavfallsrådets yttrande över Strålsäkerhetsmyndighetens förslag till kärnavfallsavgifter och säkerhetsbelopp för 2012–2014* ("The Swedish National Council for Nuclear Waste's statement regarding the Swedish Radiation Safety Authority's proposal for nuclear waste fees and guarantee amounts for 2012–2014", in Swedish). (Reg. no. 42/2011).

Lichtenberg, Steen (2000), *Proactive management of uncertainty using the successive principle: a practical way to manage opportunities and risk.* Polyteknisk Press: Lyngby.

Lichtenberg, S. & Borg, L. (2011), *Granskning av SKB:s användning av den successiva kalkylmetoden – undersökning av SKB:s kostnadsberäkningar för Plan 2010.* ("Review of SKB's use of the successive calculation method – study of SKB's cost calculations for Plan 2010", in Swedish). (SSM2011-153-28). Swedish Radiation Safety Authority.

SKB (2013), *Plan 2013 Costs from and including 2015 for the radioactive residual products from nuclear power.* Stockholm: Swedish Nuclear Fuel and Waste Management Co.

SOU 2007:38 *Nuclear Waste State-of-the-Art Report 2007 – responsibility of current generation, freedom of future generations.* Swedish National Council for Nuclear Waste. Stockholm: Fritzes.

SOU 2004:125 *Betalningsansvaret för kärnavfallet ("Payment liability for the nuclear waste", in Swedish)*. Financing Committee. Stockholm: Fritzes.

SSM (2014), *Yttrande avseende kärnavfallsavgifter samt finansierings- och kompletteringsbelopp för 2015–2017 enligt lagen (2006:647) om finansiella åtgärder för hantering av restprodukter från kärnteknisk verksamhet.* ("Statement regarding nuclear waste fees and financing and supplementary amounts for 2015 – 2017 under the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities", in Swedish). 13 October 2014. (SSM2013-6256). Swedish Radiation Safety Authority.

SSM (2014), *Förslag på kärnavfallsavgifter, finansierings- och kompletteringsbelopp för 2015.* ("Proposal for nuclear waste fees, financing and supplementary amounts for 2015", in Swedish). (SSM2013-6255). Swedish Radiation Safety Authority.

SSM (2013)*Förändringar i lagen (2013:647) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet och förordningen (2008:715) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet* ("Changes in the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities and the Ordinance (2008:715) on Financial Measures for the Management of Residual Products from Nuclear Activities", in Swedish). (SSM2011-4690). Swedish Radiation Safety Authority.

Torp, O., Klakegg, O.J. and Austeng, K. (2014), “Vurdering av usikkerhetsanalyse: Sluttlagring for svensk kjernekraftavfall”, (“Evaluation of safety assessment: Final disposal of Swedish nuclear power waste”, in Norwegian). Appendix to SSM:s *Statement regarding nuclear waste fees and financing and supplementary amounts for 2015–2017 under the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities”*, in Swedish). (SSM2013-6256).

Wene, Clas-Otto (2007), “Technology Learning Systems as Non-Trivial Machines”, *Kybernetes* 36(3/4), pp. 348–363.

Wene, Clas-Otto (2008), “Energy Technology Learning through deployment in competitive markets”, *The Engineering Economist* 53(4), pp. 340–364.

Wene, Clas-Otto (2011), “Energy Technology Learning – Key to Transform into a Low – Carbon Society”, *Climate Change – Research and Technology for Adaptation and Mitigation*, Juan Blanco and Houshang Kheradmand (Ed.), ISBN: 978-953-307-621-8, InTech. See: www.intechopen.com/articles/show/title/energy-technology-learning-key-to-transform-into-a-low-carbon-society (downloaded 28 January 2015).

Sweden’s international agreements (SÖ)

SÖ 1999:60 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Ministry for Foreign Affairs.

Government Bills (all in Swedish)

Regeringens proposition 1997/98:145 Svenska miljömål. Miljöpolitik för ett hållbart Sverige. (“Gov. Bill 1997/98:145 Swedish environmental objectives. Environmental policy for a sustainable Sweden”). Ministry of the Environment.

Swedish Code of Statutes

Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities. Ministry of the Environment.

Act (1984:3) on Nuclear Activities. Ministry of the Environment.

The Environmental Code (1998:808). Ministry of the Environment.

Ordinances

Ordinance (2008:715) on Financial Measures for the Management of Waste Products from Nuclear Activities. Ministry of the Environment.

Committee terms of reference 1992:72

Scientific committee charged with the task of investigating questions concerning nuclear waste and the decommissioning and dismantling of nuclear facilities etc.

Decision at Government meeting of 27 May 1992.

Conducted by the head of the Ministry of the Environment and Natural Resources, Minister Johansson.

My proposal

I propose that a special scientific committee be appointed charged with the task of investigating questions concerning nuclear waste and the decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities.

Background

In Gov. Bill 1991/92:99 regarding certain appropriation matters for the budget year 1992/93 and changes in the national organization in the nuclear waste field, the Government proposed that the National Board for Spent Nuclear Fuel be abolished as a separate agency and that its activities be transferred to the Swedish Nuclear Power Inspectorate. The Bill proposed that the scientific council -- KASAM -- tied to the National Board for Spent Nuclear Fuel be given a more independent position and be tied directly to the Ministry of the Environment and Natural Resources as a commission instead of being administratively tied to an authority.

The Government (1991/92:NU22, rskr. 226) has decided in favour of the Government's proposal for a changed national organization in the nuclear waste field.

Thus, a special scientific committee charged with the task of investigating questions concerning nuclear waste and the decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities should be appointed.

Task

The committee should

- every three years, starting in 1992, submit by not later than 1 June a special report describing its independent assessment of the state of the art in the nuclear waste field.

- not later than nine months after the point in time specified in Section 25 of the Ordinance (1984:14) on Nuclear Activities, submit a report describing its independent assessment of the programme for the comprehensive research and development work and other measures which the holder of a license to own or operate a nuclear reactor shall prepare or have prepared according to Section 12 of the Act (1984:3) of the Act on Nuclear Activities.

The committee should also offer advice in matters relating to nuclear waste to the Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority when requested to do so.

Whenever necessary and economically feasible, the committee should undertake foreign travel to study facilities and activity in the nuclear waste field and arrange seminars on general topics in nuclear waste management.

The committee should comply with the Government's instructions to state committees and special investigators as regards the thrust of its proposals (Dir. 1984:5) and the EU aspects of the investigations (Dir. 1988:43).

The committee should consist of a chairman and at most ten other members. It should also be allowed to engage outsiders for special assignment whenever necessary and economically feasible.

Chairman, members, experts, consultants, secretary and other assistants should be appointed for a defined term.

The committee's task shall be regarded as completed when the Government has made a decision on the license application for a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

Petition

With reference to the above, I petition that the Government authorize the head of the Ministry of the Environment and Natural Resources

to appoint a special scientific committee -- subject to the Committee Ordinance (1976:119) -- with not more than eleven members charged with the task of investigating questions concerning nuclear waste and the decommissioning and dismantling of nuclear facilities and of giving advice in these matters to the Government and certain public authorities,

to appoint chairman, members, experts, consultants, secretary and other assistants.

I further petition that the Government order that the costs be charged to appropriations under the fourteenth title "Commissions etc.".

Decision

The Government concurs with the rapporteur's suggestions and approves his petition.

Committee terms of reference 2009:31

Supplementary terms of reference for the Swedish National Council for Nuclear Waste (M 1992:A)

Decision at Government meeting of 8 April 2009

Summary of task

The Swedish National Council for Nuclear Waste was established by a decision at a Government meeting on 27 May 1992 (dir. 1992:72). The Swedish National Council for Nuclear Waste shall investigate and shed light on matters relating to nuclear waste and decommissioning and dismantling of nuclear facilities etc. and give advice to the Government in these matters. Aside from the Government, important target groups for the Swedish National Council for Nuclear Waste are also concerned public authorities, the nuclear power industry, municipalities, interested organizations, politicians and the mass media.

The Swedish National Council for Nuclear Waste shall possess broad scientific qualifications in natural science, technology, the social sciences and the humanities.

The task of the Council shall be regarded as completed when the Government has decided on a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

These terms of reference replace the terms of reference from 27 May 1992.

Task

The Swedish National Council for Nuclear Waste shall assess the Swedish Nuclear Fuel and Waste Management Co's research, development and demonstration programmes (RD&D programmes), applications and other reports of relevance for the final disposal of nuclear waste. The Council shall – not later than nine months after the Swedish Nuclear Fuel and Waste Management Co has submitted its RD&D programme in compliance with Section 12 of the Act (1984:3) on Nuclear Activities – submit its independent assessment of the research and development activities and the other measures described in the programme. The Council shall also follow the work being done on decommissioning and dismantling of nuclear facilities.

In the month of February every year, starting in 2010, the Council shall submit a report on its independent assessment of the state of the art in the nuclear waste field.

The Council shall investigate and shed light on important issues in the nuclear waste field, for example by holding hearings and seminars, so that it can make well-founded recommendations to the Government.

The Council shall also keep track of other countries' programmes for management and disposal of nuclear waste and spent nuclear fuel. The Council should also follow and, where necessary, participate in the work of international organizations on the nuclear waste issue.

These terms of reference replace the terms of reference from 27 May 1992 (dir. 1992:72).

Organization

The Swedish National Council for Nuclear Waste shall consist of a chairman and not more than ten other members (one of whom also acts as deputy chairman). The members shall have broad scientific qualifications in fields related to the nuclear waste issue. It can engage outsiders for special assignments whenever necessary and economically feasible. Chairman, members, experts, consultants, secretary and other assistants shall be appointed for a defined term.

Timetable

The task of the Council shall be regarded as completed when the Government has decided on a final repository for spent nuclear fuel and high-level nuclear waste in Sweden.

(Ministry of the Environment)

The mission of the Swedish National Council for Nuclear Waste is to advise the Swedish Government in matters concerning nuclear waste and the decommissioning of nuclear facilities. The Council is an independent scientific committee whose members possess expertise in technology, science, ethics and the social sciences.

In February each year, the Swedish National Council for Nuclear Waste publishes a State-of-the-Art Report with the Council's independent assessment of the current state of the art in the nuclear waste field. The purpose is to shed light on a selection of issues which the Council considers important.

This year's report—SOU 2015:11, entitled *Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety*—covers both the natural sciences, ethics and the social sciences. The relationship between the different chapters is illustrated by the cover illustration. The cost calculation is a precondition for the final disposal project and thereby sets constraints on the other parts. The topic of safeguards impinges on subjects such as supervision and monitoring of conditions in the final repository, which also includes the question of monitoring programmes. Safeguards are also of interest in conjunction with record-keeping and preservation of information and knowledge, since they are based on a thorough accounting of the number and content of the nuclear fuel assemblies as well as of the design of the final repository. Furthermore, information preservation can be seen as an aspect of safeguards in a very long time perspective. InSOTEC, a research project dealing with the relationship between technical and social challenges, along with the issue of information preservation, also tie in with the social science aspect of the final repository project.

The report can be downloaded at www.karnavfallsradet.se/en and can also be ordered by emailing to karnavfallsradet@gov.se.

Fritzes
ett Wolters Kluwer-företag

106 47 Stockholm Tel 08-598 191 90 Fax 08-598 191 91 order.fritzes@nj.se www.fritzes.se

ISBN 978-91-38-24288-9 ISSN 0375-250X