Nuclear Waste State-of-the-Art Report 2017

Nuclear waste – an ever-changing issue

Report from the Swedish National Council for Nuclear Waste, Stockholm 2017

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Swedish National Council for Nuclear Waste

SWEDISH GOVERNMENT INQUIRIES

SOU 2017:8

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Translation of SOU 2017:8

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The Swedish National Council for Nuclear Waste
(M 1992:A)

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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 fuel, 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 seventeenth in this series) SOU 2017:8 entitled *Nuclear Waste State-of-the-Art Report 2017. Nuclear waste – an ever-changing issue.*

This report is endorsed by all members and experts in the Swedish National Council for Nuclear Waste. 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, 2014, 2015 and 2016 are also available.

Stockholm, 24 February 2017

Carl Reinhold Bråkenhielm	Tuija Hilding-Rydevik
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1.1 Introduction

This chapter contains brief descriptions of the different chapters in the report, a recounting of the work of the Swedish National Council for Nuclear Waste (the Council) during 2016, an overview of events in the nuclear waste field in 2016 in Sweden, and an international review covering a few relevant countries and fields.

1.2 Summaries of chapters in State-of-the-Art Report 2017

1.2.1 How the requirements on a final repository for spent nuclear fuel have evolved in Swedish legislation

In this chapter we describe how Swedish legislation stipulating the best way to manage the waste from nuclear power has evolved over the years. It took nearly 30 years of nuclear power development before the requirements on management of nuclear waste and disposal of nuclear fuel were reflected in the legislation. The Swedish Riksdag passed the Radiation Protection Act dealing with the risks accompanying the use of X-rays and radioactive substances in medical care in particular in 1941, but the problems associated with nuclear energy and its waste products did not exist at that time.

General requirements on the management and disposal of spent nuclear fuel were first established by the Nuclear Activities Act, which entered into force on 1 February 1984 and is still in effect today.

1.2.2 Future scenarios for the final repository project

The project for management and disposal of all nuclear waste and spent nuclear fuel brings up numerous questions about the future. The project will continue until the end of this century. What societal changes could affect the execution of the project? What world events could cause delays and comprise significant barriers in the process? What can we do to mitigate the consequences? Can we already start preparing today? The main purpose of the chapter is, based on the results of ongoing future studies, to draw up several different scenarios for the future and illustrate the possible consequences for the final repository project if one or more of these scenarios is realized.

1.2.3 Future political challenges – financing and retrievability

In this chapter we describe and discuss the political debate in the Riksdag conducted over the years concerning two issues related to the spent nuclear fuel: financing of a final repository and the possibility of retrieving the spent nuclear fuel after it has been deposited in a final repository. We focus on which issues have been addressed by the Riksdag via motions and interpellations. The purpose is to show what types of issues have historically been debated in the Riksdag over the years, which may indicate what issues will be discussed in the Riksdag in the future in the continued final repository process.

1.2.4 A new generation of nuclear reactors?

It has been a long-term goal of the nuclear power industry to replace present-day technology using enriched uranium as nuclear fuel with technology where fissile nuclear fuel is generated during the energy production process, so-called generation IV systems (Gen IV systems). Possible advantages of Gen IV systems are that the energy content of the nuclear fuel, originally uranium and plutonium, is utilized much better and that the waste that is generated does not pose radiation protection problems for as long times as the spent nuclear fuel from today's nuclear power plants. Naturally there are also conceivable disadvantages relating to risks, but the focus in this chapter is on technical challenges. Several major countries, or groups of countries, have research programmes to develop Gen IV systems, but this work is proceeding slowly due to significant technical difficulties and high development costs.

1.2.5 Organization for a century of challenges

This chapter deals with the need for studies of the organization that will build and operate a final repository for spent nuclear fuel. The organization faces two extreme time perspectives. The repository will be built and operated during a period of about 100 years and the integrity of the sealed repository has to be guaranteed for at least 100,000 years. The purpose of the chapter is to highlight several questions which should be addressed by organization studies.

The focus is on conflict risks and interaction between activities representing the two time perspectives, i.e. between units responsible for construction and operation of the repository and units responsible for the long-term safety assessment. The questions relate to continuity, identity, the place of the safety assessment in the organization chart, resistance to structural changes and adaptation to global changes. This chapter was written by Clas-Otto Wene, former member of the Swedish National Council for Nuclear Waste.

1.3 The work of the Swedish National Council for Nuclear Waste in 2016

The Swedish National Council for Nuclear Waste has a new Vice Chairman, Tuija Hilding-Rydevik, who has been a member of the Council since 2002. Carl Reinhold Bråkenhielm, who has been Chairperson of the Swedish National Council for Nuclear Waste since 2013, has had his appointment extended until 30 June 2019.

During 2016, the Council has worked in accordance with Directive 2009:31 and aired nuclear waste issues via publications, meetings and seminars.

State-of-the-Art Report 2016

In its annual state-of-the-art report, the Swedish National Council for Nuclear Waste gives an account of the previous year's work and its independent assessment of the current situation in the nuclear waste field. Last year's state-of-the-art report SOU 2016:16 *Nuclear Waste State-of-the-Art Report 2016. Risks, uncertainties and future challenges* was handed over to climate and environment minister Åsa Romson in February.

State-of-the-Art Report 2016 was presented to the Council's target groups at an open seminar in Stockholm on 15 March, after which newsletters on the relevant topics were published (all newsletters are in Swedish): *Låga stråldoser från närodlad mat vid läckage* ("Low radiation doses from locally produced food in the event of leakage"), *Kärnkraftsbolag utan tillgångar när reaktorerna är avvecklade* ("Nuclear power companies without assets when the reactors have been decommissioned"), *Mätprogram i passiva förvar* ("Monitoring programmes in passive repositories"), *Positivt mervärdesavtal med etiska utmaningar ("Positive added-value agreement with ethical challenges"), Om jordbävningar i Sverige* ("About earthquakes in Sweden") and *Risker för kompetensbrist på slutförvarsområdet* ("Risks of skills shortages in the final repository field").[1]

The Council's work on the current State-of-the-Art Report 2017 began in the spring of 2016.

Assess the activities of the Swedish Nuclear Fuel and Waste Management Co (SKB)

In accordance with the directive, the Swedish National Council for Nuclear Waste shall assess SKB's applications and research programmes. The Council submitted its viewpoints on relevant matters in a statement to the Land and Environment Court at the end of May.[2] In its statement, the Council draws the Court's attention to questions which have still not received satisfactory answers and which the Council considers crucial for being able to judge whether

[1] You will find the newsletters (in Swedish) under "publikationer" at: www.karnavfallsradet.se
[2] *Yttrande över Svensk kärnbränslehantering AB:s ansökan om tillstånd enligt miljöbalken i ett sammahängande system för slutförvaring av använt kärnbränsle och kärnavfall.* (Dnr Komm2016/00858/M1992:A).

SKB's application complies with relevant legislation and whether the KBS-3 method can be judged to be acceptable.

SKB submitted its research programme *RD&D Programme 2016* in the autumn, and the Council has begun the work of reviewing it. The Council's review statement must be submitted to the Government by no later than June 2017.

Meetings and seminars

The Council has held 6 Council meetings and a number of meetings with its target groups, including the Swedish NGO Office for Nuclear Waste Review (MKG), the Swedish Radiation Safety Authority (SSM) and the Ministry of Environment and Energy.

In June 2016, the Council held a meeting with the municipalities of Östhammar and Oskarshamn concerning information and knowledge preservation (following up an initial meeting in November 2015). The topic is an urgent one, and during the year the Council published an external report on its website: *Long-term Records, Memory and Knowledge Preservation – Recent thinking and progress in the field of geological disposal of radioactive waste, and further avenues of research* written by Claudio Pescatore.[3]

The Council arranged an international seminar on ethical issues on 13 June 2016: *Ethical Perspectives on the Nuclear Fuel Cycle* read more in Newsletter 2016:8 *Kärnbränslecykeln i etisk belysning* ("Ethical perspectives on the nuclear fuel cycle," in Swedish).

In order to reach the target group of politicians, the Swedish National Council for Nuclear Waste arranged a seminar in July during Almedal Week dealing with *Kärnavfallets framtid – ett sekel av utmaningar* ("The future of nuclear waste – a century of challenges"). Read more in Newsletter 2010:9 Är Sverige redo att besluta om ett slutförvar? ("Is Sweden ready to decide on a final repository?" in Swedish).

[3] Read under publikationer/externa publikationer at www.karnavfallsradet.se.

International work

The Council's mission includes following developments in how other countries manage nuclear waste and spent nuclear fuel. The purpose is two-fold: to monitor international developments in the field that can contribute to knowledge-building in Sweden, and to contribute to the work being pursued in different international organizations and projects.

In October 2016, the Council made a study trip to Switzerland. On a visit at The Paul Scherrer Institute, the Council met representatives of the Laboratory for Waste Management.

A site selection process is underway in Switzerland under the leadership of the Swiss Federal Office of Energy (SFOE), which falls under the Federal Department of the Environment, Transport, Energy and Communications (DETEC). In the course of an afternoon, the Council discussed the consultation processes in Sweden and Switzerland with various actors in Switzerland. Besides SFOE, there were representatives from:

- ENSI, the Swiss Federal Nuclear Safety Inspectorate (the regulatory authority).
- Nagra, the National Cooperative for the Disposal of Radioactive Waste (responsible for planning, building and operating geological repositories).
- Representatives of the relevant regions in the site selection process: Regional Conference Jura Ost, Regional Conference Zürich Nordost, Regional Conference Nördlich Lägern and Canton Aargau.[4]

The Council also visited Zwilag, an interim storage facility for nuclear waste. There the Council studied dry storage of spent nuclear fuel and reprocessed waste.[5]

[4] Read more about what's new in the site selection process in Switzerland below.
[5] Read more about the interim storage facility at: http://www.zwilag.ch/en (downloaded 31 Jan. 2017).

Conferences and meetings

During the spring, the Council had a meeting with the Environmental Rights Center Bellona, a Russian organization that works to promote public participation and engagement in decision-making regarding radioactive waste management.[6]

Council members and the Council secretariat have participated in various international conferences and working groups during the year, some of which are mentioned below.

The Forum on Stakeholder Confidence was established by OECD's Nuclear Energy Agency to foster stakeholder confidence in nuclear waste management.

ABG (Advisory Bodies to Governments) held a meeting in Paris. ABG is a collaboration between the Swedish National Council for Nuclear Waste and advisory bodies in the USA, the UK, Switzerland, France and Germany.

Council representatives were also in Paris at the International Conference on Geological Repositories: Continued Engagement and Safe Implementation, in Moscow at the 11th International Public Dialogue Forum "Nuclear Energy, Environment, Safety-2016"[7] and at the Swedish Radiation Safety Authority's international conference in cooperation with the OECD/NEA in Stockholm on the costs of decommissioning.[8]

1.4 The nuclear waste field in Sweden in 2016

2016 has been an eventful year in the nuclear waste field, particularly when it comes to SKB's work. SKB has ongoing licensing processes and has submitted a research programme to SSM for review. It is the Government that decides whether or not to approve the applications and the research programme. A general description of the process follows below.

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[6] http://bellona.org/ (downloaded 31 Jan. 2017).
[7] Read more about Russia below.
[8] http://www.oecd-nea.org/rwm/workshops/findecom/presentations/ (downloaded 31 Jan. 2017).

1.4.1 SKB's activities in 2016

The licensing process for the final repository for spent nuclear fuel

Supplementary information phase 2011–2016

SKB submitted its applications on final disposal of spent nuclear fuel to the Land and Environment Court at Nacka District Court (the Land and Environment Court) and SSM back in 2011. In the ensuing years, the processing of the applications concerned whether they were complete enough to be considered.

Announcement and issue-specific review phase 2016–

On 29 January 2016, the applications were officially announced by the Land and Environment Court and SSM, which meant that the issue-specific review phase could begin.

The reviewing bodies submitted statements on specific issues to the Land and Environment Court and SSM before the summer. SKB responded to these statements during the autumn.

SSM submitted its statement as a reviewing body to the Land and Environment Court in June 2016. SSM concludes that SKB is capable (based on this step in the licensing process) of fulfilling the radiation safety requirements for the final repository under the Environmental Code.[9]

Espoo Convention

The Swedish EPA coordinates the consultation process under the Espoo Convention that gives neighbouring countries an opportunity to offer viewpoints on the environmental impact assessment in the application under the Environmental Code for a final repository for spent nuclear fuel. Consultations with the countries around the Baltic Sea were held when SKB prepared the environmental impact

[9] SSM. 2016. *Yttrande över ansökan från Svensk Kärnbränslehantering AB om tillstånd enligt miljöbalken för ett system för hantering och slutförvaring av använt kärnbränsle.* (Dnr SSM2016-546).

statement before the application was submitted in 2011. After the announcement in 2016, it was possible for SKB to continue to hold consultations with those countries that so wished, and Denmark, Finland, Germany, Lithuania, Latvia and the Czech Republic submitted statements in the spring. In October 2016, SKB sent the statements to the Land and Environment Court and responded to the viewpoints.[10]

The Land and Environment Court's two consultations during the autumn of 2016

In October, SKB submitted its Supplement V with its responses to the statements on specific issues submitted to the Land and Environment Court in the spring of 2016.[11] The reviewing bodies had the opportunity to submit statements to the Court regarding SKB's responses by not later than 14 February 2017.

During the autumn, SKB submitted an application to the Land and Environment Court regarding harbour activities in Forsmark (adjacent to the final repository for spent nuclear fuel). This means that the Land and Environment Court is considering four licensing cases simultaneously:

- the case concerning a final repository system for spent nuclear fuel (M1333-11)
- the case concerning expanded harbour activities (M6009-16)
- the case concerning exemption from the Habitats Directive (M4617-13) and
- the case concerning SFR II (M7062-14) (read more below).

[10] Read more in Land and Environment Court at Nacka District Court, dept. 4. M 1333-11, case file appendix 427.
[11] Read more in Land and Environment Court at Nacka District Court, dept. 4. M 1333-11, case file appendix 425.

Since the Land and Environment Court believes that the reviewing bodies should have an opportunity to submit statements on the need for coordination of the cases, they do not expect a main hearing to be held before the autumn of 2017.[12]

The licensing process for a final repository short-lived low- and intermediate-level waste (SFR II)

SKB submitted applications for licences for an extension of SFR (here called SFR II) to the Land and Environment Court and SSM at the end of 2014. The new repository will have room for all the short-lived low- and intermediate-level nuclear waste arising during the operation and decommissioning of our existing reactors. It will also be an interim storage facility for long-lived low- and intermediate-level waste until such time as a final repository for long-lived radioactive waste (SFL) is put into operation, which according to SKB will not be before 2045. Since the licensing process for the extension is delayed, the waste from 7 reactors (Barsebäck 2, Oskarshamn 2, Ringhals 2 and the Ågesta reactor) will have to be interim-stored.

The Council and Östhammar Municipality are two of the reviewing bodies that have previously submitted statements with the viewpoint that the application under the Environmental Code should be treated as a new construction project with a new activity rather than just an extension of an existing activity. The difference is important since it affects the licensing process: new construction requires the Government's permissibility assessment. The Government decided on 4 May 2016 that the application for SFR II is of such great scope that it will be considered under Chap. 17 Sec. 3 of the Environmental Code.[13]

[12] Read more in Land and Environment Court at Nacka District Court, dept. 4. M 1333-11, case file appendix 444.
[13] Land and Environment Court at Nacka District Court, dept. 3. M7062-14, case file appendix 47.

Supplementary information phase 2014–

The Land and Environment Court has ordered SKB to respond to the viewpoints of the reviewing bodies on the need for supplementary information regarding SFR II. SKB will respond by no later than 15 May 2017. SKB must also submit supplementary information regarding SFR II to SSM in the application under the Nuclear Activities Act by 15 May 2017. In other words, the licensing process for SFR II is still in the supplementary information phase.

The Land and Environment Court's consultation procedure concerning the possibility of coordinating four cases (see above) includes SFR II, which could be one reason why the timetable has been further delayed.

RD&D programme 2016 – SKB's research programme

SKB publishes its research programme every three years, and the latest one was published on 30 September 2016. SSM is reviewing the programme, and after circulation for comments they will submit their statement to the Government by no later than 31 March 2017. The Council will submit its review statement to the Government at the end of June 2017. It is the Government that approves the programme and can then also stipulate conditions on the activity.

Plan 2016 – SKB's cost calculations

Every three years SKB submits a calculation of the costs for the Swedish nuclear waste programme to SSM, and the latest one was submitted at the beginning of January 2017. SSM will review the report and submit its review statement to the Government, which will make a decision during 2017 on the fees the nuclear power industry has to pay to the Nuclear Waste Fund during the period 2018–2020.[14]

[14] SKB. 2016. *Plan 2016. Costs from and including 2018 for the radioactive residual products from nuclear power. Basis for fees and guarantees during the period 2018–2020.*

1.4.2 Organization- and competence-related issues

The Swedish National Council for Nuclear Waste has previously noted, and does so in this report as well, that problems can arise with an industrial organization that has to create a final repository for spent nuclear fuel, particularly in view of the long project period (up to a century). In November, SSM published the supervision report *Verksamhetsbevakning säkerhetsledarskap SKB*[15] ("Activity oversight safety leadership SKB," in Swedish), which points out deficiencies in SKB's organization.

The Council has also called attention to the problem that nuclear waste issues take a century to solve, while interest in them might gradually decline. This makes preservation of the necessary skills and competence an important challenge. The importance of this problem is shown by the fact that the Government recently instructed SSM to inquire further into the issue in *Uppdrag om långsiktig kompetensförsörjning* ("Assignment regarding long-term competence management").[16]

1.4.3 New financing for environmental organizations

As of 26 January 2017, one year after the announcement of the application regarding the repository for spent nuclear fuel, environmental organizations are no longer able to obtain financing from the Nuclear Waste Fund. Instead they have now been given the opportunity to obtain financing by the Swedish EPA's appropriation direction 2017, where it says:

> At most SEK 2,500,000 shall be used for grants to environmental NGOs for efforts in connection with siting of facilities for management and disposal of spent nuclear fuel.[17]

[15] SSM. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* ("Activity oversight safety leadership SKB," in Swedish) (SSM 2016-3279-2).
[16] Government decision of 22 Dec. 2016 M2016/03064/Ke.
[17] Swedish EPA's appropriation direction 2017. Government decision I:12 M2016/02982/S (partially) M2016/02923/S M2016/02948/Mm etc.

1.5 Global perspective

The Swedish National Council for Nuclear Waste's mission includes global environmental analysis. During 2016 the Council made a study visit to Switzerland and was represented at a conference in Moscow. The section below contains presentations of the situation in the nuclear waste field in these countries as well as in Finland, which has come far in its process of creating a final repository for spent nuclear fuel.

Some international issues that are also described are cost calculations for decommissioning and dismantling of reactors, the search for a site to test deep boreholes in the USA, and Canada's research on new canister designs.

1.5.1 Update on the site selection process in Switzerland

There are five reactors in operation in Switzerland. The plan is not to replace them with new reactors, but to continue operating them as long as the reactor owners can show the regulatory authority, ENSI, that they are safe. This, however, does not apply to the Mühleberg reactor, which is scheduled to be closed in 2019, after which it will be decommissioned and dismantled.

Site selection process

In Switzerland[18] the plan is to build two deep geological repositories where all types of radioactive waste will be disposed of. A process is underway to select locations for the repositories that will be built on two different sites or the same site (but will then have separate storage spaces). The Swiss Federal Office of Energy (SFOE), which is subordinate to DETEC, is responsible for creating and coordinating the site selection process in accordance with The Sectoral Plan for Deep Geological Repositories. It is taking place in three stages:

[18] Read more about Switzerland in the Swedish National Council for Nuclear Waste's state-of-the-art reports: SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey*, pp. 93 ff; SOU 2015:11 *Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety*, pp. 36 ff.

Stage 1: Selection of geological siting areas for further study: 2008–2011

6 sites were approved in 2011 by the Federal Council for further study in Stage 2.

Stage 2: Selection of at least two sites 2012–

The Federal Council will decide whether 3 of the 6 sites will proceed to Stage 3.

Stage 3: Selection of the site

According to the current timetable, the Federal Council will make a decision on the site in 2029 at the earliest.

Three sites being considered in Stage 2

Stage 2 is currently underway and Nagra – which is responsible for creating, building and operating the repositories – has since 2012 investigated the 6 potential sites that were selected in Stage 1 in order to narrow down the selection for Stage 3. In early 2015, Nagra submitted proposals to ENSI (the regulatory authority) for the two sites which Nagra considered to be most promising for further investigation in Stage 3. In December 2016, ENSI announced that the two sites selected by Nagra should be supplemented with one additional site:

- Zürich Nordost (Nagra's proposal)
- Jura Ost (Nagra's proposal)
- Nördlich Lägern (ENSI's additional proposal)

ENSI will submit a more detailed statement to the Federal Council (the national government in Switzerland) concerning Nagra's work with Stage 2. An open consultation will also be held. The Federal Council will then decide whether all three sites should be further investigated in Stage 3, which is planned to take place in around 2018.[19]

[19] https://energeiaplus.com/2016/12/14/noerdlich-laegern-soll-weiter-untersucht-werden/#more-5418; http://www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=de&msg-id=64954; http://www.nagra.ch/en/news/newsdetailen/response-to-ensi-analysis-of-the-siting-proposals-for-stage-3-of-the-sectoral-plan-process.htm (downloaded 31 Jan. 2017).

Measurements on sites in Stage 2 and preparations for Stage 3

In Stage 2, Nagra carried out 3D seismic measurements during 2016 in Zürich Nordost and Jura Ost. Since ENSI has required that Nördlich Lägern be further investigated, measurements are being conducted there as well between Oct. 2016 and Feb. 2017.

In preparation for Stage 3, Nagra submitted applications in September 2016 for a licence to drill 16 boreholes for further investigation of the geology on the two sites in Stage 3. Nagra has announced that they will also submit applications for boreholes for Nördlich Lägern in the spring of 2017. The boreholes require a licence from DETEC. The work with the boreholes is planned to start during 2019, provided that the Federal Council has decided that Stage 2 is finished and Stage 3 can begin.

Nagra's 2016 Waste Management Programme and 2016 Research Programme

On behalf of the waste producers, Nagra submitted its waste management programme to SFOE in December 2016.[20] The programme describes the basic procedures to be followed for planning, constructing and operating a deep geological repository up till the time of its closure. It is an update of the first programme, which was published in 2008.

The 2016 Waste Management Programme provides the framework for the long-term planning of deep geological repositories and explains what decisions have to be made, when they have to be made, and what information they are based on. It also contains details on the origin, types and volumes of radioactive waste and its allocation to the two repositories. The design and layout of the repositories is also presented. The programme contains an implementation plan, information on financing and details on the capacity of interim storage. It also presents Nagra's concept for communication and information.

Nagra has also updated its plans for research, development and demonstration (RD&D). The programme, which is updated every

[20] http://www.nagra.ch/en/news/mediareleasedetail/guidelines-for-basic-waste-management-procedures.htm (downloaded 31 Jan. 2017).

five years, is reviewed by SFOE, ENSI and the Nuclear Safety Commission (NSC). After a period of open consultation (around the middle of 2018), the Federal Council is expected to decide on the Programme at the beginning of 2019.

High-level nuclear waste

High-level nuclear waste (HLW) arises after reprocessing of spent nuclear fuel. Up until 2005, Switzerland sent its spent nuclear fuel to France and the UK for reprocessing. In accordance with the 2005 Nuclear Energy Act, this was to be discontinued for at least 10 years, and the nuclear power companies have chosen not to begin again. During 2015 and 2016, HLW has been shipped back from the UK. It is being stored in the Zwilag interim storage facility pending final disposal together with the spent nuclear fuel.

1.5.2 Plans for final repository for spent nuclear fuel in Russia

Russia is considered one of the four countries in the world today (along with India, China and South Korea) that is investing most heavily in developing and building nuclear power. For decades Russia has been heavily committed to defensive nuclear weapons, and has also had a large civilian nuclear power programme since the 1960s. Historically, Russia has focused on developing fast reactors to be able to use reprocessed nuclear fuel and thereby close the fuel cycle. As the development of fast reactors has stagnated, however, the focus has shifted to interim storage of spent nuclear fuel.[21] Against this background, it is highly satisfying that the existing programme for managing different types of nuclear waste and spent nuclear fuel has made significant progress in recent years, at least on paper.

The first stage in a Russian federal programme for nuclear and radiation safety was adopted in 2008. In November 2015, the Russian

[21] Högselius, P. 2010. 2010. "The Decay of Communism: Managing Spent Nuclear Fuel in the Soviet Union, 1937–1991" i *Risk, Hazards & Crisis in Public Policy* 1:4). See: http://onlinelibrary.wiley.com/doi/10.1002/rhc3.2010.1.issue-4/issuetoc (downloaded 20 Jan. 2017).

Government adopted Rosatom's proposal for a second stage in the programme that is envisioned to last from 2016 until 2030. This second stage is divided into three 5-year phases that include the establishment of a final repository for spent nuclear fuel and the decommissioning of 82 nuclear facilities. Within the framework of the second stage, 73 percent of the costs will go to decommissioning of commercial reactors as well as four facilities that have previously been involved in the Russian defence programme. Nearly 20 percent of the costs will go to creating the infrastructure required for management and final disposal of spent nuclear fuel and radioactive waste. About 70 percent of the SEK 85 billion budget for the second stage of the programme will be covered by the Russian state, and most of the rest by Rosatom.

The state-owned National Operator for Radioactive Waste Management (NO RAO), which was formed in March 2012, is responsible for management of all nuclear waste in Russia, including spent nuclear fuel. About 32 million cubic metres of radioactive waste is to be disposed of up until 2035 within the framework of NO RAO's program at a cost of about SEK 45 billion. Owners of the radioactive waste are to provide 80 percent of the money, while the remaining 20 percent is to come from the federal budget.[22]

Low- and intermediate-level nuclear waste

Russia's first repository for low- and intermediate-level waste opened in December 2016 near Novouralsk, about fifty km north of Yekaterinburg in the Sverdlovsk region. It is a near-surface repository built on a former temporary repository and holds 48,000 cubic metres of nuclear waste that can be stored for 300 years. In this stage the repository was opened for 15,000 cubic metres of waste from a nuclear fuel production plant, the Urals Electrochemical Combine. The facility is the first in number of different storage facilities for low- and intermediate-level waste that are planned to be built in different parts of Russia over the next few years up until

[22] http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-fuel-cycle.aspx (downloaded 5 Jan. 2017).

2018. A facility for 100,000 cubic metres is planned to open near Ozersk, about 150 km south of Yekaterinburg, where the ill-fated Mayak facility for manufacture of weapons-grade plutonium is located. The world's third-worst nuclear power accident occurred here in 1957; only the accidents at Chernobyl and Fukushima have had more far-reaching consequences. A third facility of 200,000 cubic metres is planned at Seversk near Tomsk about 1,000 kilometres east of Yekaterinburg. A fourth facility of 50,000 cubic metres is also planned at Sosnovy Bor, on the southern shore of the Gulf of Finland.[23]

The Russian programme for spent nuclear fuel

The framework of the second stage of the Russian federal programme for nuclear and radiation safety includes establishing a final repository for spent nuclear fuel and other high-level waste. Some thirty or so potential disposal sites for spent nuclear fuel have been investigated in 18 regions in Russia. In 2003, for example, Krasnokamensk, about 7,000 km east of Moscow, was suggested as a suitable site for a spent fuel repository.

In 2008, one site was put forward as being particularly suitable for a final repository for spent nuclear fuel in Russia: the Nizhnekansky Granite Massif at Zheleznogorsk in Krasnoyarsk Territory in Siberia. Nizhnekansky had long been considered as a candidate for a Russian final repository for spent nuclear fuel, mainly because a granite massif is judged by geologists as favourable for hosting a final repository.[24] But in recent years Nizhnekansky has been increasingly put forth as a favourable site.[25]

Public hearings on the Nizhnekansky Granite Massif were held in July 2012 and in November 2013. NO RAO was authorized to establish an underground hard rock laboratory in Nizhnekansky to investigate the suitability of the rock for disposal of solid HLW as

[23] http://bellona.org/news/nuclear-issues/2016-12-russias-first-nuclear-waste-repository-starts-operation (downloaded 5 Jan. 2017).
[24] Baksht et al. 1998. "On the question of predicting the safety of the Northern 'Polygon'…".
[25] https://www.iaea.org/OurWork/ST/NE/NEFW/CEG/documents/ws022009/4-5.%20Programs%20for%20Deep%20Geological%20Repositories%20and%20Underground%20Labs/4.7%20Creation%20of%20DGR%20in%20Krasnoyarsk%20Region%20(presentation)%20Engl.pdf (downloaded 5 Jan. 2017).

well as solid intermediate-level long-lived waste. The underground laboratory is planned to be built at a depth of between 450 and 525 metres in three vertical 500-metre-deep shafts connected by horizontal tunnels totalling about 5,000 metres in length with additional side tunnels and shafts. The goal of the laboratory is to study the properties of the rock and judge its suitability for hosting a final repository for high- and intermediate-level nuclear waste. Research will also be conducted on different types of engineered barriers and on different technical solutions for transport and handling of nuclear waste in the final repository. It is hoped that a decision can be made on a final repository in Nizhnekansky by 2025 if conditions prove favourable.[26] If all goes according to plan, the repository will be completed in 2047 and then contain 4,500 cubic metres of high-level waste in 7,500 canisters, plus 155,000 cubic metres of high- and intermediate-level waste. But a great deal remains to be done before the laboratory is completed and can begin operation.

1.5.3 Finland's final repository for spent nuclear fuel – the first in the world to start construction

The Finnish decision process around the construction of a final repository consists of three decisions made by the Finnish Government: a decision in principle, a decision on a construction licence and a decision on an operating licence.[27]

The first decision in the licensing process was taken in 2001, when the Finnish Government made a decision in principle to approve the construction of a final repository for spent nuclear fuel in Olkiluoto in the municipality of Eurajoki in Finland.

At the end of 2015, the Government took *the second decision* and gave Posiva a construction licence to build an encapsulation plant and a final repository for spent nuclear fuel, but it was subject to certain requirements. The Radiation and Nuclear Safety Authority (STUK) is the authority that oversees radiation and nuclear safety

[26] http://bellona.org/news/nuclear-issues/2016-12-russias-first-nuclear-waste-repository-starts-operation (downloaded 5 Jan. 2017).
[27] Read more in the Swedish National Council for Nuclear Waste's state-of-the-art reports: SOU 2012:7 pp. 81 ff.; SOU 2015:11, p. 24; SOU 2016:16 *Nuclear Waste State-of-the-Art Report 2016. Risks, uncertainties and future challenges*, p. 24.

in Finland. STUK has reviewed how Posiva describes its organization and construction preparedness, for example when it comes to plans for human resources, project management, quality management, safety culture, planning, rock construction, oversight of the consequences of the construction activities, and safeguards.

Based on its review, STUK decided in November 2016 that Posiva can start the first excavation works in the construction of the final repository. Posiva and the contractor, YIT Rakkenus Oy, have signed a contract to begin excavating the first tunnels in December 2016. This project phase is expected to take about 2.5 years. STUK will oversee Posiva during the construction phase as well and will review the plans for the upcoming excavation works.[28]

Posiva's application for a final repository for spent nuclear fuel is largely based on the Swedish KBS-3 method, and they are cooperating closely with SKB in their research.

1.5.4 International cost calculations for decommissioning

Ensuring that sufficient funds (financing) are available for decommissioning and dismantling of reactors is a problem outside of Sweden as well[29]. SSM and OECD/NEA arranged the seminar *International Conference on Financing of Decommissioning*[30] in Stockholm in the autumn of 2016. The following text is based on the publication *Financing the Decommissioning of Nuclear Facilities*.[31]

[28] http://www.posiva.fi/en/media/press_releases/first_excavation_works_for_posivas_final_disposal_facility_to_begin_-_yit_as_contractor.3300.news#.WJA7jf4zVhg;
http://www.stuk.fi/web/sv/-/stuks-beslut-posiva-kan-borja-bygga-slutforvaringsanlaggning (downloaded 31 Dec. 2017).

[29] When it comes to the financing legislation in Sweden, decommissioning and dismantling are included in what the Nuclear Waste Fund is supposed to pay for. The Swedish National Council for Nuclear Waste has described the financing system in previous state-of-the-art reports in the following chapters: SOU 2014:11 "Financing of the residual products of nuclear power"; SOU 2015:11 "Calculation of future costs for final disposal of nuclear waste and spent nuclear fuel"; SOU 2016:16 "Obligations and responsibilities in connection with decommissioning and dismantling of nuclear power reactors".

[30] http://www.oecd-nea.org/rwm/workshops/findecom/presentations/ (downloaded 31 Jan. 2017).

[31] NEA /OECD. 2016. *Financing the Decommissioning of Nuclear Facilities*. NEA No. 7326.

Reactors in the world

More and more reactors in the world are approaching the decommissioning phase. In July 2016, 157 civilian reactors in 19 countries had ceased operation, including 33 in the United States, 30 in the United Kingdom, 28 in Germany, 12 in France, 16 in Japan, 6 in Canada and 5 in Russia. These are mostly commercial reactors, but also prototypes and experimental reactors. The reactors have either been shut down at the end of their life, or prematurely closed for financial or political reasons.

A total of about 440 nuclear reactors are in operation around the world. Nearly 250 reactors are more than 30 years old and some 75 reactors are over 40 years old. Many reactors will have to be decommissioned in the years to come, and some 60 nuclear reactors are currently under construction, mainly in Asia and in non-NEA member countries.

Scarcity of data on decommissioning costs

It is difficult to calculate decommissioning costs, since only a few nuclear power plants have been decommissioned in the world today. There are many reactors that have been shut down, but their decommissioning has been postponed. Only a limited quantity of data is available from the projects that have been completed, and the costs have not always been systematically analyzed. Comparisons are complicated by the fact that only a few projects have been carried out recently, and they involve different types of reactors. This means that the financing of decommissioning still relies more on cost estimates than on data actual decommissioning costs.

Decommissioning of both commercial and research reactors is expected to increase considerably over the coming years. It is important to carry out realistic cost calculations as soon as possible in order to ensure that future decommissioning costs are covered.

Responsibility for future generations and for environmental protection

The process of decommissioning nuclear facilities spans over long periods of time. Our generation has to make decisions with consequences for future generations. In order to be sustainable, these decisions should be based on ethical considerations, an awareness that a wide range of uncertainties must be taken into consideration, such as changes on the financial market, changes in public energy policy, and changes in the legal framework and requirements on decommissioning. We must be aware of the uncertainties when cost calculations are updated, and they should be updated regularly.

Sufficient financing is required to enable reactors to be decommissioned and dismantled, which is necessary in order to protect human health and the environment for both this and future generations. Responsibility for ensuring that sufficient financing is available rests with the creator of the waste in accordance with the "polluter pays principle". Financial rules on how the costs of decommissioning are to be covered are thus important both to avoid burdening future generations and to guarantee adequate protection of the environment.

Comparisons between countries

Legal and/or regulatory frameworks have been put into place in most NEA member countries for the financing of decommissioning. Most countries have created decommissioning funds. However, they differ in the way that the fund assets are accumulated, how oversight is exercised, and who is responsible for this. What the funds are to be used for also differs. Sometimes decommissioning, dismantling and management of radioactive waste are all covered, and sometimes separate funds are created to cover these different costs. There is no international standard or "best practices" to ensure the availability of assets in the decommissioning funds, since they are set up by countries with different legal and regulatory systems.

In 2012, the NEA published the International Structure for Decommissioning Costing (ISDC) to provide an improved basis for preparing comprehensive and comparable decommissioning cost estimates internationally.

1.5.5 Deep Boreholes – searching for a site for testing of boreholes in the USA

In June 2016, the US Department of Energy (US DOE) gave up its first attempt to find a site for the testing of deep boreholes after the local populations at the proposed sites turned down the project.

In December, the DOE announced that they would make a new attempt by selecting four companies that will try to find sites for test drilling. One of these companies will then be contracted to execute the project. The companies will try to gain greater social acceptance for the project by engaging the local community to a greater extent.[32]

1.5.6 Canister development in Canada

The Nuclear Waste Management Organization (NWMO) is responsible for designing and implementing the program for long-term nuclear waste management in Canada. A proposed concept for permanent storage of spent nuclear fuel involves use of a deep geological repository (DGR), within which multiple engineered barriers isolate the used fuel from the environment. Beginning in 2011, the NWMO initiated a design change for their DGR system. In addition to significant changes to emplacement and clay buffer methods, a primary change was the adoption of a copper-coated used fuel container (UFC). The previous reference UFC consisted of a two-part, steel-copper cylindrical vessel, consisting of an inner carbon steel 100 mm thick structural and containment component, and an outer 25 mm thick wrought copper corrosion barrier. The new UFC design (denoted the 'Mark 2') instead utilizes a 3 mm integral copper coating on a fully welded cylindrical carbon steel container with hemispherical heads. Electrodeposition and cold spray coating technologies are evaluated. In addition to advantages in its structural integrity under pressure and some manufacturing considerations, the Mark 2 is also substantially shorter and lighter than its predecessor, which offers improved flexibility in handling and reduced cost.

[32] Read more: https://www.energy.gov/under-secretary-science-and-energy/articles/studying-feasibility-deep-boreholes;
http://dakotafreepress.com/2016/12/07/haakon-county-plans-more-meetings-on-borehole-daugaard-still-supports/ (downloaded 31 Jan. 2017).

Historically, copper containers designed with an external, self-standing (durable) copper shell and an internal (structural) cast iron insert have been developed (in Sweden/Finland). This design typically provides a relatively thick corrosion barrier (50 mm of copper) but may be relatively expensive from the manufacturing and resource usage perspective. Recently, a single shell design envisaging the use of a coating system onto a carbon steel substrate has been developed in Canada, with support from Switzerland, providing the opportunity to reduce manufacturing complexity and resource-usage costs, the latter by employing a relatively thin layer of copper (3 mm in the current Canadian design). This design also eliminates the potential of creep failure during the deformation of the external copper shell onto the cast iron insert. However, given its lower copper thickness, this design increases the potential impact of any localised corrosion (and possibly environmentally-assisted cracking) and, depending on the thickness of the steel structural member, of radiation-induced corrosion due to the higher radiation fields expected outside waste containers.

To support this DGR concept and the new UFC design, the NWMO in Canada has initiated a comprehensive proof test plan (PTP). The PTP outlines a program to verify that the design concept meets design requirements and to develop a formal body of knowledge that can be used to illustrate this proof to the regulator, NWMO Board of Directors, and the Canadian public. One important goal of the PTP is to demonstrate confidence that the Mark 2 UFC will safely contain nuclear waste for a minimum of 100,000 years. To build this necessary confidence, the NWMO has initiated a series of corrosion research programs that complement the many years of research that have been previously performed on copper corrosion for its use in DGRs. The goal of this research is to demonstrate confidence in the corrosion resistance of the Mark 2 UFC.

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2 How the requirements on a final repository for spent nuclear fuel have evolved in Swedish legislation

2.1 Introduction

The laws of a country reflect that country's values and policies. In order to correctly understand and interpret current law, it is essential to be knowledgeable about and try to understand the context of a given statute. This is particularly true in the field of nuclear activities, and especially when it comes to issues related to the final disposal of spent nuclear fuel.

As a rule, lawmakers try to balance the social benefit of a measure or an activity with the risks to people and the environment that might be caused by the measure or the activity. In order to mitigate the risks, rules are introduced for licences associated with conditions and regulations concerning safety precautions and liability.

In this chapter we will show how the legislation governing management of the waste from nuclear power has evolved. But the premises have varied through the years. For example, the Swedish strategy during the 1960s and 1970s was that the spent nuclear fuel should be reprocessed. Since 1982, the Swedish strategy has been direct disposal of the fuel without reprocessing. But there is no prohibition on reprocessing in Swedish legislation.

However, it took nearly 30 years of nuclear power development before the requirements on management of nuclear waste and disposal of nuclear fuel were reflected in the legislation. The Swedish Riksdag passed the Radiation Protection Act dealing with the special risks etc. accompanying the use of X-rays and radioactive substances in medical care in particular in 1941, but the problems associated with nuclear energy and its waste products did not exist at that time.

The general requirements on the management and disposal of spent nuclear fuel and final repositories that are in effect today were first established by the Nuclear Activities Act, which entered into force on 1 February 1984 and is still in effect today.

Certain fundamental principles have been of central importance in the political discussion since the mid-1970s. These include the principle that those who generate the waste shall bear all responsibility and all costs associated with waste management. The reactor owners must not be allowed to shift this responsibility onto the state or anyone else.[1]

2.2 The early development of nuclear energy in Sweden

Sweden was one of the countries that made an early commitment to the development of nuclear energy. On 23 November 1945, the Government appointed a committee tasked to promote research in nuclear physics and nuclear chemistry. The terms of reference for the committee stated that: "… the main goal of the research is to find suitable methods for harnessing atomic power for peaceful purposes."[2]

At the Government's initiative, AB Atomenergi was formed in November 1947 – a kind of joint venture between the state, the institutes of technology and the industry. The company's purpose was to conduct research and development on the peaceful uses of nuclear power. The Swedish Defence Research Institute (FOA) was responsible for the military use of development of nuclear energy.

Sweden's first nuclear reactor, which was planned by AB Atomenergi, was built at a depth of 25 metres in the bedrock at Drottning Kristinas Väg 47–51 next to the Royal Institute of Technology in Stockholm. The reactor, designated R1, went critical on 13 July 1954 at 18:59 hrs.[3] From an original capacity of "… just a

[1] See Gov. Bill 1997/98:145, p. 381.
[2] Larsson, K.-E. 1987. *Kärnkraftens historia i Sverige*, p. 126.
[3] Larsson, K.-E. 1987. *Kärnkraftens historia i Sverige*, p. 134 f.

few watts," the capacity of the reactor was gradually increased, finally reaching 1,000 kW (1 MW).[4]

The reactor was used for research and teaching as well as for the production of radionuclides for e.g. medical uses. The nuclear fuel consisted of natural (not enriched) French uranium. Heavy water imported from Norway was used as a moderator.

As far as the Swedish National Council for Nuclear Waste has been able to determine, questions concerning the management and eventual final disposal of the radioactive waste were not addressed at all in the development work. In order to solve the more acute problems, it happened on a couple of occasions in the 1950s and 1960s that radioactive waste was dumped in the Baltic Sea, the Gothenburg archipelago and the Atlantic.[5] There is still nuclear waste at the nuclear facilities in Studsvik from the period in question that has not yet been finally disposed of.

2.3 The first laws in the field of nuclear technology and radiation protection

2.3.1 The 1941 radiation protection act

The 1941 radiation protection act was a general protection act that covered all activities involving radiation. The 1941 radiation protection act[6] introduced, for the first time in Sweden, a statute that took into account the special risk conditions that accompany the use of X-rays and radioactive substances, in particular for medical purposes. The law gained importance in the field of nuclear technology due to the fact that the licence to operate the R1 nuclear reactor was issued by the Royal Medical Board in accordance with the 1941 radiation protection act, after consultation with the Insti-

[4] Fjæstad, M. 2001. *Sveriges första kärnreaktor – Från teknisk prototyp till vetenskapligt instrument* ("Sweden's first nuclear reactor – From technical prototype to scientific instrument," in Swedish) SKI report 01:1. p. 84 f.
[5] Larsson, A. och Karlsson, G. 1996. *Hantering av radioaktivt avfall i Sverige före år 1980 samt radium och radiumavfall fram till år 1996.* ("Management of radioactive waste in Sweden before 1980 and radium and radium waste up until 1996," in Swedish.) SKI report 96:78, SSI report 96-18.
[6] Act (1941:334) on Supervision of Radiological Work etc.

tute of Radiophysics. To a great extent, however, radiation protection matters are mainly an occupational health problem.[7]

2.3.2 The 1956 Atomic Energy Act

Up until 1956, the 1941 radiation protection act was the law that regulated activities in the nuclear energy field. The Atomic Energy Act (1956:306), which entered into force on 1 June 1956, introduced requirements on licences to erect, own or operate "atomic reactors" and to have dealings of any kind with "atomic fuel"[8]. With the support of this law, licences were approved for the 12 nuclear power reactors that had been in commercial operation since 1975 and had generated the spent nuclear fuel that is planned to be disposed of in the planned final repository for spent nuclear fuel at Forsmark in Östhammar Municipality. The law also introduced certain rules concerning supervision of these activities. The licences were subject to a number of conditions concerning construction and operation of the reactors. The licence decisions do not contain any conditions regarding management of the spent nuclear fuel.[9]

By means of an amendment to the Atomic Energy Act in 1 July 1978, a requirement was introduced for a licence to erect, own and operate a facility for processing, storage or disposal of spent nuclear fuel or radioactive waste arising during the operation of nuclear power reactors. Waste issues had not previously been dealt with in the Atomic Energy Act.

2.3.3 The 1958 Radiation Protection Act

The Radiation Protection Act of 1958[10] introduced requirements on licences and supervision for virtually all radiation sources that generate ionizing radiation. This included radiation from radioactive substances, X-rays and radiation with similar biological effects. The law did not contain any provisions on how radioactive waste was to be managed and disposed of. However, via conditions and regu-

[7] Gov. Bill 1987/88:88, p. 15.
[8] Gov. Bill 1956:178, 3LU 1956:23, rskr. 1956:345.
[9] Gov. Bill 1976/77:53, p. 17.
[10] Radiation Protection Act (1958:110).

lations, the Swedish Radiation Protection Authority[11] could, with the support of the 1958 Radiation Protection Act, indirectly stipulate requirements on waste management from a radiation protection viewpoint.

2.3.4 The Stipulations Act

It was not until 1977, with the passage of the Stipulations Act[12] that matters related to final disposal of spent nuclear fuel were dealt with by the legislation. The provisions of the Stipulations Act were largely based on the findings of the AKA Committee.[13] However, the law did not apply to all nuclear power reactors that had been licensed under the Atomic Energy Act, but only those that had not yet been put into operation when the law entered into force. Outside of this area of application were reactors that had already been put into operation and thus been loaded with nuclear fuel. This included the Oskarshamn 1 and 2, Ringhals 1 and 2 and Barsebäck 1 reactors.[14]

Under the Stipulations Act, a reactor could not be loaded with nuclear fuel without a special licence from the Government. To get such a licence, the reactor owner had to produce a legally binding agreement for reprocessing of spent nuclear fuel and show how and where a final disposal of the high-level waste from reprocessing could take place. The agreement had to contain provisions on how adaptation to technical progress in the reprocessing field could be ensured.[15]

If the spent fuel was not to be reprocessed, the reactor owner had to show how and where a safe final disposal of the spent nuclear fuel could take place. The reactor owner had to furnish detailed and extensive information for the assessment of safety. It wasn't enough to present general plans and sketches. The reactor owner had to specify concretely in what form the waste or the spent nuclear fuel was intended to be disposed of, how the disposal site would be

[11] The Swedish Radiation Protection Authority was established in 1965.
[12] Act Concerning Special Permission to Load a Nuclear with Nuclear Fuel etc.
[13] Government Committee (I 1972:08) on radioactive waste.
[14] Gov. Bill 1976/77:53, p. 23.
[15] Gov. Bill 1976/77:53, p. 23.

arranged, how fuel shipments would take place, and whatever else was needed to judge whether the proposed final disposal could be considered completely safe and feasible. The risk that the waste or the spent nuclear fuel could contaminate the biosphere via natural processes, accidents or acts of war was also to be taken into account. But a prepared disposal site did not have to be available when the licence application was considered.[16]

2.3.5 The Act (1981:669) on the Financing of Future Expenses for Spent Nuclear Fuel etc.

In the spring of 1981, the Riksdag considered a Government Bill regarding guidelines for a national energy policy extending up to around 1990.[17] In accordance with the Bill, the Riksdag passed a new law: the Act (1981:669) on the Financing of Future Expenses for Spent Nuclear Fuel etc. (the Financing Act), which entered into force on 1 July 1981.

The act defines the obligations of the reactor owners. The holder of a licence to own and operate a nuclear reactor shall be responsible for ensuring that spent nuclear fuel and radioactive waste are managed and disposed of in a safe manner, that the reactor plant can be decommissioned and dismantled in a safe manner, that the research and development activities needed to fulfil these obligations are conducted, and that funds are available to pay the actual costs of waste management. The reactor owners must also draw up a joint plan for the research and development activities.[18]

In its statement of comment on the draft law, the Council on Legislation pointed out that the obligations of the reactor owner should include:

> ... not only to implement and pay for the actual measures required, but also to be liable up to the remainder of the company's total assets for costs which the state might incur for such measures in the event the

[16] Gov. Bill 1976/77:53, p. 24.
[17] 1981 energy policy bill, Gov. Bill 1980/80:90, NU 1980/80:60.
[18] Cf. Secs. 1–3 of the Act (2006:647) on Financial Measures for the Management of Waste Products from Nuclear Activities and Gov. Bill 1980/80:90, appendix 1, p. 614 ff.

reactor owner fails to discharge his obligations and the state is therefore compelled to implement the measures.[19]

The act lays down the principles that still apply today regarding the reactor owners' obligations for nuclear waste and spent nuclear fuel. The provisions are also largely commensurate with those now embodied in the Nuclear Activities Act[20] and the Financing Act.[21]

2.4 The Act (1984:3) on Nuclear Activities (Nuclear Activities Act)

The Nuclear Activities Act established the current framework for general requirements on the management and final disposal of spent nuclear fuel and final repositories. The law entered into force on 1 February 1984 and is still in effect.

The terms "nuclear material" and "nuclear waste"

As its name implies, the Nuclear Activities Act applies to nuclear activities. The term is defined in the introduction to the Act. Besides operation of nuclear power reactors or other nuclear facilities, the term also includes: "acquisition, possession, transfer, handling, treatment, transport of or other dealings with nuclear material or nuclear waste".[22]

The act also uses the terms "nuclear material" and "nuclear waste". Nuclear material: "uranium, plutonium or other material that is used, or can be used, for production of nuclear energy," or in summary "nuclear fuel". Spent nuclear fuel is "nuclear material" provided it has not been placed in a repository. If the spent nuclear fuel has been placed in a repository, it is defined as "nuclear waste".[23]

Thus, according to the definition, spent nuclear fuel ceases to be nuclear material when it has been placed in a repository, after which it is then to be regarded as nuclear waste. Note that the final

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[19] Gov. Bill 1980/81:90, app. 1, p. 637.
[20] Cf. Secs. 10, 11 and 12 of the Act (1984:3) on Nuclear Activities.
[21] Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities.
[22] Cf. Section 1 of the Nuclear Activities Act.
[23] Cf. Section 2 of the Nuclear Activities Act.

repository does not have to be closed in any respect. The reason for this difference in importance is that spent nuclear fuel that has not yet been placed in a final repository can be reprocessed. The plutonium and uranium that is obtained from reprocessing can be used once again as fuel in a nuclear power reactor, for example it can be transformed into MOX fuel.

2.5 The implications of a licence for nuclear activities

As a rule, nuclear activities may not be pursued without a licence[24] or approval.

It is punishable by law to conduct nuclear activities without a licence or approval. The licence applies only to the licensee and no-one else. It is thus prohibited for the parent company or other companies in the same group of companies to conduct the nuclear activity covered by the licence.

The Government, or in certain cases the Swedish Radiation Safety Authority (SSM), considers applications for licences and approval. The licence applies only to the nuclear activity specified in the licence. These rules are fundamental to the Nuclear Activities Act.

2.5.1 The licensee's obligations

A licence under the Nuclear Activities Act carries a number of obligations. The obligations include not only upholding safety and radiation protection, but also ensuring that nuclear waste and nuclear material that is not reused can be managed and disposed of in a safe manner.

The obligations also include ensuring that the nuclear facility in which the activity has been conducted is decommissioned and dismantled in a safe manner when it has been permanently shut down. This entails complete dismantling and removal of the facility and other devices included in the nuclear activity which are radio-

[24] For activities that are of small scope or scientific activities at universities and similar institutions, there are provisions regarding exemptions from the licence obligation in Secs. 4–15 a in the Ordinance on Nuclear Activities (1984:14).

actively contaminated.[25] The licensees' obligations have been fulfilled when the facilities have been dismantled or released for unrestricted use and all nuclear material and nuclear waste has been emplaced in a final repository that has been closed.[26]

The Nuclear Activities Act uses the phrase "sealed permanently" to define the point after which the licensee's responsibility has ceased to exist. An important legal principle is that the licensees for the nuclear facilities are severally and individually responsible for the nuclear waste generated in their respective activities. The reactor owners' obligation to dispose of the spent nuclear fuel is a serious obligation that must be fulfilled. It is in the vital interests of society that those who are responsible for nuclear waste management must not be allowed to opt out of it.

The provisions of the Nuclear Activities Act entail that obligations under the law will exist for many decades after the last nuclear power reactor has been permanently shut down and electricity production has ceased. According to the operating plans for the nuclear power plants presented by the power industry, the last nuclear power reactors may be shut down between 2040 and 2045.[27] It is not unreasonable to assume that it may be 2100 before final closure of the repository occurs. It is also in view of this that a special financing system has been devised for this purpose.

Clearly, a licence to operate a nuclear power reactor is a very long-term commitment. The Nuclear Activities Act emphasizes this by stating that the obligations incumbent upon a licensee shall continue to exist even if the licence is revoked, the licence expires or a nuclear power reactor is permanently shut down until the licensee has fulfilled the obligations.[28]

In Sec. 14, second paragraph of the Nuclear Activities Act, the lawmaker has, however, provided that the licensee can in certain cases be released from the obligations. The following factors are considered in deciding whether such an exemption can be granted:

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[25] Cf. Sec. 10 first paragraph of the Nuclear Activities Act.
[26] Cf. Sec. 10 first paragraph point 3. See. also Gov. Bill 2009/10:172, p. 55 f.
[27] SKB. 2016. *RD&D Programme 2016. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste.*
[28] Cf. Sec. 14 first paragraph of the Nuclear Activities Act.

> ... the obligations incumbent upon the licensee can be fulfilled by another. In such a situation, it should also be determined whether the requirements on safety and safe waste management and decommissioning of the facility in question can be considered to be satisfied and that funds are available for this.[29]

In this case an exemption can be granted by the Government.[30]

2.5.2 Requirements on an adequate organization and sufficient resources

The objective in the nuclear activities legislation is to eliminate, as far as is humanly possible, the risks of a radiological accident and thereby ultimately the risk of losses of life or property. The requirements on safety and radiation protection are far-reaching. The Nuclear Activities Act can be said to have been designed to give the licensee nearly strict responsibility for the operation of a nuclear facility, responsibility which cannot be transferred to someone else. Great weight is therefore attached to the licensee's demonstrated capability to fulfil the obligations that accompany nuclear activities.[31]

The Nuclear Activities Act clarifies the licensee's obligations by requiring an organization that is designed and staffed in such a way as to ensure safe and reliable operation of the activity.[32] The term "operation" also includes all activities associated with decommissioning and dismantling of nuclear facilities. The requirement that the licensee have an adequate organization also applies to any contractors hired by the licensee.

The licensee is also obliged to have sufficient financial resources to implement the measures required by the Nuclear Activities Act or by conditions or regulations issued pursuant to the Act, as well as protective measures in the event of operational disruptions or accidents at the facility.[33] The licensee must be able to demonstrate credibly that the financial capacity required to meet the requirements in a sustainable manner exists either directly, e.g. in the form

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[29] See Gov. Bill 1983/84:60, p. 94.
[30] Cf. Sec. 17 of the Ordinance (1984:14) on Nuclear Activities.
[31] See Gov. bill 2009/10:172, pp. 43, 44 and 57.
[32] Cf. Sec. 13 first paragraph of the Nuclear Activities Act.
[33] Cf. Sec. 13 first paragraph of the Nuclear Activities Act.

of sufficient share capital, or in the form of financial guarantees by the parent company of the group to which the licensee may belong.[34]

Those licensees that comply with the requirements of the Financing Act can also be said to comply with the requirements of the Nuclear Activities Act on financial resources as regards the general obligations that follow from Secs. 10–14 of the Nuclear Activities Act.

2.5.3 Research and development activities

In addition to being obliged to take all measures needed to ensure that nuclear waste and nuclear material arising in the activity that is not reused can be managed and disposed of safely[35] , the holder of a licence to own or operate a nuclear power reactor (the reactor owner) is responsible for ensuring that the comprehensive research and development work needed to fulfil the obligations is conducted. The research shall cover the entire process chain for management and disposal of the waste, including different types of interim storage facilities and other facilities required before prior to disposal.

Unlike the general requirements under the Nuclear Activities Act, the obligation to conduct research and development applies only to reactor owners.[36]

2.5.4 RD&D programme

A reactor owner shall, in consultation with other reactor owners, prepare, or have prepared, a programme for the comprehensive research and development activities and other measures needed to fulfil their obligations under the law. SKB has been tasked by the reactor owners to prepare the research programme.

The research programme, referred to as the RD&D programme[37], shall describe the research and development that needs to be conducted to find a final solution to the problems surrounding safe management and final disposal in accordance with the method that is found to be best with regard to safety and radiation protection.

[34] See Gov. Bill 2009/10:172, pp. 44 and 57.
[35] Cf. Section 10 of the Nuclear Activities Act.
[36] Cf. Section 11 of the Nuclear Activities Act.
[37] RD&D stands for Research, Development and Demonstration.

In the words of the Nuclear Activities Act and in accordance with the travaux préparatoires, the research programme shall be comprehensive. According to the travaux préparatoires, the requirement on a comprehensive programme and a continuous presentation of the research results ensures openness and transparency with regard to the problems that remain to be solved. It is pointed out in the travaux préparatoires that great importance should be attached to follow-up and evaluation of the research work on safe final disposal.

The requirement on a comprehensive programme also includes an account and a follow-up of alternative management and disposal methods that emerge during the ongoing research in the waste field as a result of both own and foreign research. The purpose of this provision is to prevent premature commitment to a given management or disposal method before sufficient knowledge has been acquired for a full understanding and assessment of the safety and radiation protection problems involved. According to the travaux préparatoires, if a new and better method emerges in the course of the research work, this method should be chosen instead.

The first research and development programme was submitted to the Government in 1986 pursuant to Sec. 12 of the Nuclear Activities Act. Since then the programme has been reviewed and evaluated every three years by the Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority, and nowadays by SSM. The Government then considers the question of whether conditions need to be stipulated for the continued research.

The programme is submitted to the Government for review and evaluation. Prior to being submitted, it is also reviewed by SSM, which issues a statement of comment after having solicited opinions from a large number of public authorities and outside experts.

As a consequence of the review, the Government can issue conditions for the continued research and development activities. The conditions could, for example, stipulate that certain supplementary R&D must be done. In the travaux préparatoires, the Government points out that it is the reactor owners who are independently responsible for the research and development activities. Conditions should not be used for detailed control of the activities.[38]

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[38] Gov. Bill 1983/84:60, pp. 41, 92 and 93.

In accordance with its instruction, the Swedish National Council for Nuclear Waste has commented on the reactor owners' research programme. Some of the Council's observations have been that little effort has been made to study alternative management and disposal methods to the KBS-3 method.

2.5.5 Regulations issued pursuant to the Nuclear Activities Act

SSM has been authorized by the Government to issue more detailed regulations for the application of the Nuclear Activities Act.[39] The following regulations – which are described briefly below – apply regarding final disposal of nuclear material and nuclear waste and regarding protection of human health and the environment in connection with final disposal of spent nuclear fuel and nuclear waste.

The regulations are formulated in general terms and do not specify what methods are to be used for final disposal.

The Swedish Radiation Safety Authority's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste (SSMFS 2008:21)

Safety after the closure of a repository shall be maintained through a system of passive barriers. The barrier system shall be able to withstand such features, events and processes that can affect the post-closure performance of the barriers. The barrier system shall comprise several barriers so that, as far as possible, the necessary safety is maintained despite a single deficiency in a barrier.

The barriers in a repository can be engineered (man-made) or natural. Examples of engineered barriers include containers for nuclear material and nuclear waste, concrete structures and backfill materials consisting of clay, sand or concrete. Parts of the repository or materials in the repository can also be considered as barriers without necessarily comprising an obstacle to physical transport. This could for example be the case for materials that contribute to providing a chemical environment counteracting the transport of

[39] Cf. Sec. 20 a of the Ordinance (1984:14) on Nuclear Activities.

radioactive substances. An example of this is a chemical environment that results in low solubility and a high sorption of radioactive substances.

The function of each barrier shall be to, in one or several ways, contribute to containing, preventing or retarding the dispersion of radioactive substances, either directly, or indirectly by protecting other barriers in the barrier system. "Barrier function" is a term used to designate the different ways that barriers function and the capability of a barrier to protect and preserve the function of other barriers. In this way, a single barrier can have several barrier functions and several barriers can have the same, or similar, barrier functions.

The barriers or barrier functions that are needed and how these needs are met should be clearly described in the safety analysis report for the repository. The safety analysis report shall show how the safety of the repository is arranged to protect human health and the environment against radiological accidents and to prevent unauthorized dealings with nuclear material and nuclear waste.

The repository's safety shall be based on a safety assessment. Such a safety assessment shall show how different types of deficiencies in barriers and barrier performance cannot on their own lead to unacceptable risks due to dispersion of radioactive substances from the repository. The safety of the repository after closure is analyzed quantitatively, primarily by estimating the possible dispersion of radioactive substances and how they are distributed in time for a relevant selection of future possible sequences of events (scenarios). The purpose of the safety analysis is to show that the risks from these scenarios are acceptable in relation to the requirements on the protection of human health and the environment. The safety assessment should also aim to provide a basic understanding of the performance of the repository in different time periods and to identify requirements on the performance and design of different repository components.

According to the regulations, a safety assessment shall cover as long a period of time as barrier functions are required, but at least ten thousand years. In the case of a repository for spent nuclear fuel, the safety assessment may have to include scenarios which take into account major expected climate changes, primarily in the form of future glaciations. For example, the next complete glacial cycle, which is currently estimated to be on the order of 100,000 years, should be taken into account.

The Swedish Radiation Safety Authority's regulations on protection of human health and the environment in connection with final management of spent nuclear fuel and nuclear waste (SSMFS 2008:37)

According to the regulations, an assessment of the protective capability of a repository for final disposal of spent nuclear fuel shall be presented for two time periods:

– the first thousand years following closure of a repository

– the period after the first thousand years following closure of a repository

The description shall include a case which is based on the assumption that the biospheric conditions which exist at the time when an application for a licence to construct the repository is submitted will not change. Uncertainties in the assumptions made shall be described and taken into account in the assessment of the protective capability.

For the first thousand years following closure, the assessment of the repository's protective capability shall be based on quantitative analyses of the effects on human health and the environment. For the period after the first thousand years following repository closure, the assessment of the repository's protective capability shall be based on various possible sequences for the evolution of the repository's properties, its environment and the biosphere.

For a repository for spent nuclear fuel or other long-lived nuclear waste, the risk analysis should cover at least approximately 100,000 years or the period for a glacial cycle to shed light on reasonably predictable external stresses on the repository.[40] The risk analysis should thereafter be extended in time for as long as it provides important information about the possibility of improving

[40] According to the travaux préparatoires, a risk analysis is an analysis aimed at clarifying the protective capability of a repository and its consequences with regard to environmental impact and risk for human beings.

the protective capability of the repository, but no longer than for a time span of up to one million years.

2.6 SKB's mission to fulfil the reactor owners' obligations

Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Co, SKB) – which is owned by Vattenfall AB, OKG Aktiebolag, Forsmarks Kraftgrupp AB and Sydkraft Nuclear Power AB – has been tasked by its owners with the mission of fulfilling the obligations of the licensees of the nuclear power reactors when it comes to disposing of the radioactive waste and the spent nuclear fuel from the reactors. Since the start of the company in 1972, SKB has had an extensive undertaking as a contractor to the licensees when it comes to transportation, interim storage and final disposal of spent nuclear fuel and nuclear waste.

SKB's mission is based on two consortium agreements concluded between the licensees and approved by the Government after authorization by the Riksdag. They are the 1972 consortium agreement, and a new consortium agreement which succeeded the 1972 agreement on 1 July 1981. The agreement will remain in force up to 2020, with an option to extend by 10 years.

SKB's mission includes both preparation of the research and development programme (RD&D programme) in accordance with Sec. 12 of the Nuclear Activities Act, and execution of the research activities in accordance with the programme. Further, SKB is responsible for the cost calculations etc. for the execution of the final repository programme which the licensee is obliged to prepare according to the Financing Act.[41]

According to its mission, SKB is responsible for furnishing a final repository for spent nuclear fuel and nuclear waste for the reactor owners. But SKB does not assume formal ownership under the Nuclear Activities Act of the nuclear waste that is deposited in the repository. Ownership, and the responsibility that accompanies it, remains with each licensee even after the waste has been deposited

[41] Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities.

in the final repository. After this, it is not practically possible for the licensee to exercise its ownership responsibility.

2.7 The state's ultimate responsibility for final disposal of spent nuclear fuel and other radioactive waste

2.7.1 Division of responsibility between the state and the reactor owners

As is evident in section 2.5.1, the reactor owners, as well as other licensees of nuclear activities, are obliged under the Nuclear Activities Act to ensure that nuclear material, spent nuclear fuel and nuclear waste that has arisen in the activity and will not be reused is safely managed and disposed of. This obligation entails a long-term commitment on the part of the reactor owners. The reactor owners' obligations have not been fulfilled until a final repository has been closed and sealed permanently.

According to the Nuclear Activities Act, the reactor owners are also responsible for the costs of the management and final disposal of the spent nuclear fuel and the nuclear waste. According to the Financing Act, the reactor owners are obliged to pay a fee (nuclear waste fee) to finance the future costs of final disposal of spent nuclear fuel and long-lived nuclear waste generated by the operation of the nuclear power reactors as well as decommissioning and dismantling of the nuclear power reactors and other nuclear facilities.

A government agency, the Nuclear Waste Fund, shall manage the paid-in nuclear waste fees in a fund. The Nuclear Waste Fund's annual accounts shall be prepared in such a manner that they show how large a proportion of the Fund's assets accrues to each reactor owner. In addition to paying fees to the fund that will cover the reactor owner's costs, each reactor owner shall provide guarantees up to a given amount. The assets managed by the Nuclear Waste Fund shall cover both current and future waste management costs. The principle for the financing of the disposal of nuclear waste is that the nuclear power industry – not the taxpayers – should be liable for the costs.

The Riksdag has on a number of occasions established that the state has overall responsibility for spent nuclear fuel and nuclear waste.[42] The long-term responsibility for a final repository should, according to the Riksdag's statements, rest with the state. One reason is that some form of responsibility for and supervision of safety at the final repository will probably be needed for a considerable time after closure of the repository. One idea is that a government agency could assume responsibility for the closed final repository. The Government has stated that it is only natural that the state should bear ultimate responsibility for ensuring that the repository functions satisfactorily even in the very long term.[43] However, ultimate responsibility is not regulated in the Nuclear Activities Act or in any other legislation. A government committee of inquiry has proposed that a legal rule be introduced that assigns ultimate responsibility for the spent nuclear fuel to the state.[44] The committee's proposal has not resulted in any legislation.

The principle that ultimate responsibility rests with the state is also regulated internationally partly by the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Nuclear Waste Convention) and partly by the EU's Waste Framework Directive.

2.7.2 The state's ultimate responsibility for safety – International obligations under the Nuclear Waste Convention

By ratifying the *1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*[45], the Swedish state has undertaken to ensure that prime responsibility for safety in the management of spent nuclear fuel or radioactive waste rests with the licensee of the facility that generated the waste. According to the Convention, the state shall take suitable measures to ensure that each such licensee assumes its responsibility. If there is no such licence holder or other responsible party, the

[42] See e.g. Gov. Bill 1980/80:90, appendix 1, p. 319; Gov. Bill 1983/84:60, p. 38; Gov. Bill 1997/98:145, p. 81; Gov. Bill 2005/06:183 and Parliamentary Committee on Industry and Trade reports 1988/89:NU31 and 1989/90:NU24.
[43] See Gov. Bill 1997/98:145, p. 381.
[44] Radiation Safety Committee. 2011. SOU 2011:18 *Strålsäkerhet – gällande rätt i ny form. ("Radiation safety – harmonizing the law," in Swedish.)*
[45] See: SÖ 1999:60.

responsibility rests with the state.[46] In other words, the state's responsibility has two components:

1. The state has an overall responsibility to ensure that final disposal is implemented.
2. The state has an ultimate responsibility for final disposal in the sense that the state itself is forced to assume the role of both purchaser and financer if the nuclear power industry is not able to perform the task or for another reason refrains from doing so.

The state's ultimate responsibility does not entail any limitation of the nuclear power industry's responsibility under the Nuclear Activities Act.

2.7.3 According to the EU's Nuclear Waste Directive, radioactive waste shall be disposed of in the Member State in which it was generated

On 19 July 2011, the European Council decided to establish a Community framework for the responsible and safe management of spent fuel and radioactive waste – the Nuclear Waste Directive – which entered into force on 22 August 2011.[47]

The Directive formulates a number of general principles that shall apply to the management of spent nuclear fuel and radioactive waste, including that all Member States are obligated to avoid placing any undue burden on future generations and therefore that the Member States must ensure that adequate financing is available for the management of spent fuel and radioactive waste.

In accordance with Article 4.4 of the Nuclear Waste Directive, the main principle is that radioactive waste shall be disposed of in the Member State in which it was generated. As an exception from this main principle, radioactive waste can be disposed of in another country if the Member State has entered into an agreement with the other country – a Member State or a third country – to use a

[46] Cf. Article 21 of the Nuclear Waste Convention.
[47] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (EUT L 199, 2.8.2011, p. 48, Celex 32011L0070).

facility there for final disposal. According to Article 4.4, such an agreement must meet certain requirements regarding parties, content and the time when it shall have been entered into. Prior to a shipment to a third country, the exporting Member State shall also inform the European Commission of the content of such an agreement and take reasonable measures to be assured regarding a number of conditions in the country of destination, for example that a disposal facility is in operation and is authorized to receive the radioactive waste to be shipped.

The Nuclear Waste Directive was implemented in Swedish legislation by means of an amendment to the Nuclear Activities Act.[48] The changes in the law, which entered into force on 1 May 2014, entail that it is prohibited without a licence to dispose of nuclear waste or nuclear material not intended for reuse in another country if the waste or material comes from a Swedish facility or other nuclear activity in Sweden. Prior to this it was already prohibited to dispose of or interim-store nuclear waste or nuclear material not intended for reuse in Sweden if the waste or other material comes from a nuclear facility or other nuclear activity in another country.[49]

The requirement on authorization is a prerequisite for the implementation of Article 4.4 of the Nuclear Waste Directive, which requires that what is defined in the directive as radioactive waste (and in Sweden is called nuclear waste, nuclear material not intended for reuse or other radioactive waste) shall be disposed of in the Member State in which it was generated, unless an agreement meeting certain conditions has been entered into with another country to use a disposal facility there. The requirement on authorization ensures that the requirement on an agreement can be asserted by the licensing body. Nuclear materials for which there is an intended use are not covered by Article 4.4 of the Directive.

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[48] Gov. Bill 2013/14:69.
[49] Cf. Secs. 5a, 5b third paragraph, 5d and 5e of the Nuclear Activities Act.

2.8 Further legislation in the nuclear waste field

2.8.1 Nuclear activities are established in three laws and require two licences

The currently applicable rules for safety and radiation protection in connection with the management and final disposal of spent nuclear fuel and nuclear waste are established in three laws. These are:

- The Act (1984:3) on Nuclear Activities (Nuclear Activities Act)
- The Environmental Code (1998:808), and
- The Radiation Protection Act (1988:220).

The provisions of these three laws are supplemented by ordinances and government regulations containing more detailed provisions.

Pursuing a nuclear activity requires a licence under the Nuclear Activities Act. Since nuclear activities are usually environmentally hazardous activities, a licence under the Environmental Code is also required. Thus, two different licences are required under two laws to pursue a nuclear activity.

2.8.2 Provisions within the framework of the EU and The Euratom Treaty

The rules are also governed by provisions promulgated within the framework of the EU. The Nuclear Activities Act will, for example, be augmented during the year with provisions implementing Euratom's revised Nuclear Safety Directive.[50] Previously the European Council's Nuclear Waste Directive was implemented in the Nuclear Activities Act and the Radiation Protection Act.[51]

[50] Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations.
[51] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.

Sweden will also get a new radiation protection act during the year as a result of a new radiation safety directive, which also takes up with issues not previously regulated by law.[52]

2.8.3 The need for regulatory simplification and streamlining

The need for regulatory simplification and streamlining when it comes to nuclear activities and other activities involving radiation has been apparent for some time.[53]

In view of the fact that the Environmental Code, the Nuclear Activities Act and the Radiation Protection Act are to be applied in parallel, licence conditions issued by the environmental court in a licensing matter pursuant to the Environmental Code may include measures already required by regulations issued pursuant to the Nuclear Activities Act and the Radiation Protection Act. It is not only the question of the duplicate or overlapping licensing processes involved with two separate licences with similar legal effect that has been seen as a problem. Other issues stemming from a lack of harmonization in the legislation have also been raised.

A government committee of inquiry, the Radiation Safety Inquiry, stated in its report[54] that radiation protection and nuclear safety matters cannot always be kept separate and need to be considered in a single context. The need to harmonize safety and radiation protection interests is evident in almost all stages of the nuclear fuel cycle and makes itself felt both when studying and processing the data on which the design of a facility is based and when considering what measures need to be taken when the facility goes online. In practice, too, certain supervisory measures under the three sets of provisions have overlapped to some extent. In the light of this, the Committee proposed that the provisions under the Nuclear

[52] Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.
[53] See: The Organization Committee for Radiation Safety's (M2007:05) communication to the Government of 31 March 2008 (reg. no. M2008/1430/Mk) and the Swedish Radiation Safety Authority's report "Översyn av lagstiftningen på strålsäkerhetsområdet" ("Survey of legislation in the radiation safety field," in Swedish) to the Government on 4 November 2008 (reg. no. M2008/4084/Mk).
[54] Radiation Safety Committee. SOU 2011:18.

Activities Act and the Radiation Protection Act should be combined and integrated into the Environmental Code.

Another reason for this according to the Committee was that formally speaking, the rules in the Environmental Code already cover activities involving both ionizing and non-ionizing radiation. Another advantage is that certain rules in the Environmental Code, such as the general rules of consideration, are already being applied and are taken into account when cases are dealt with under the Nuclear Activities Act. The supervision chapter in the Code is complete and in principle does not need to be changed if substantive provisions under the Nuclear Activities Act and the Radiation Protection Act are introduced into it. The same applies to the provisions on sanctions in the Environmental Code.

Some of the Committee's proposals have been introduced into the Environmental Code and the Nuclear Activities Act. But a substantive harmonization of the legal rules in the field of nuclear safety and radiation protection in one law has not (yet) been realized.

2.8.4 Further evolution of the legislation

Legislation in the nuclear waste field will continue to evolve. The long time span (about 100 years) involved in the construction of a final repository for spent nuclear fuel and the technical progress that could conceivably take place during this time span will naturally influence the legislation and lawmaking efforts.

In retrospect we see that the link between the military and civilian development of nuclear energy that took place in the 1950s and early 1960s influenced the legislation in the nuclear energy field. The political need to bring a potentially hazardous activity under the control of the Government was urgent, in view of Sweden's ambitions at this time to develop nuclear weapons.

Looking ahead, nuclear-related legislative efforts will increasingly be dominated by the need to implement various EU instruments. Experience to date shows that Government bills in such matters have a tendency to be of a different character than the proposed legislation we have previously been accustomed to in Sweden. They can often be more technically focused on the substantive issues, since the political commitment has already been made in the European Council.

Appendix

The 1941 radiation protection act	The 1941 radiation protection act was a general protection act that covered all activities involving radiation.
The Atomic Energy Act of 1956 (The Act (1956:306) on the Right to Generate Atomic Energy etc.)	The act introduced requirements on licences to erect, own or operate "atomic reactors" and to have dealings of any kind with "atomic fuel". The licence decisions do not contain any conditions regarding management of the spent nuclear fuel. It was not until 1 July 1978 that requirements on licences for facilities for spent nuclear fuel and nuclear waste were introduced into the act.
The 1958 Radiation Protection Act	Requirements on licences for and supervision of virtually all radiation sources that generate ionizing radiation were introduced. The law did not contain any provisions on how radioactive waste was to be managed and disposed of.
The 1977 Stipulations Act (The Act (1997:140) Concerning Special Permission to Load a Nuclear with Nuclear Fuel etc.)	It was not until the enactment of the Stipulations Act that rules governing final disposal of spent nuclear fuel were adopted in the legislation.
The 1981 Financing Act (The Act (1981:669) on the Financing of Future Expenses for Spent Nuclear Fuel etc.)	The act defines the obligations of the reactor owners when it comes to management and final disposal of spent nuclear fuel and nuclear waste.
The Act (1984:3) on Nuclear Activities (the Nuclear Activities Act) from 1984	It was by the passage of the Nuclear Activities Act that the current framework for general requirements governing management and final disposal of spent nuclear fuel and final repositories was established. The law entered into force on 1 February 1984 and is still in effect.
The Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities	The act entered into force in its entirety on 1 January 2008, when the Act (1992:1537) on the Financing of Future Expenses for Spent Nuclear Fuel etc. ceased to apply. The purpose of the law is to secure the financing of the general obligations that follow from the Nuclear Activities Act. The law thereby supplements the obligations regarding management and final disposal of spent nuclear fuel that are incumbent upon the reactor owners under the Nuclear Activities Act.

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Legal EU documents

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Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.

Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (EUT L 199, 2.8.2011, p. 48, Celex 32011L0070).

International conventions

The 1999 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Nuclear Waste Convention).

Laws and other statutes

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

The Ordinance (1984:14) on Nuclear Activities.

The Act (1984:3) on Nuclear Activities.

The Act (1981:669) on the Financing of Future Expenses for Spent Nuclear Fuel etc.

The Act (1977:140) on Special Permission to Load a Nuclear Reactor with Nuclear Fuel etc.

The Radiation Protection Act (1958:110).

The Act (1956:306) on the Right to Generate Atomic Energy etc.

The Act (1941:334) on Supervision of Radiological Work etc.

Government bills and parliamentary committee reports

Gov. Bill 2013/14:69, Säker och ansvarsfull hantering av radioaktivt avfall – genomförande av kärnavfallsdirektivet (“Safe and responsible management of radioactive waste – implementation of the Nuclear Waste Directive”).

Gov. Bill 2009/10:172, Kärnkraften – förutsättningar för generationsskifte ("Nuclear power – premises for a generation change").

Gov. Bill 2005/06:183, Finansieringen av kärnavfallets slutförvaring ("Financing of the final disposal of nuclear waste").

Gov. Bill 1997/98:145, Svenska miljömål. Miljöpolitik för ett hållbart Sverige. ("Swedish environmental objectives. Environmental policy for a sustainable Sweden").

Gov. Bill 1987/88:88, om ny strålskyddslag, m.m. ("on a new Radiation Protection Act, etc.").

Gov. Bill 1983/84:60, med förslag till ny lagstiftning på kärnenergiområdet ("with proposals for new legislation in the nuclear energy field").

Gov. Bill 1980/ 81:90, bilaga 1, om riktlinjer för energipolitiken ("appendix 1, on guidelines for national energy policy").

Gov. Bill 1976/77:53, med förslag till lag om särskilt tillstånd att tillföra kärnreaktor kärnbränsle, m.m. ("with draft law concerning special permission to load a nuclear with nuclear fuel etc.").

Gov. Bill 1956:178, 3LU 1956:23, rskr 1956:345.

Parliamentary Committee on Industry and Trade's report 1989:90: NU24, Bankstödet m.m. ("NU24, Bank support etc.").

Parliamentary Committee on Industry and Trade's report 1988/89: NU31, ändringar i ellagen. ("NU31, changes in the Electricity Act").

Parliamentary Committee on Industry and Trade's report 1980/81:90 NU, över proposition 1980/81:90 om riktlinjer för energipolitiken jämte motioner ("on Gov. Bill 1980/80:90 on guidelines for national energy policy and motions").

3 Future scenarios for the final repository project

3.1 Introduction

All planning and all decision-making for the future entail making conscious or unconscious assumptions about what the future will be. It is easy to project from the current situation and make simple extrapolations of reality. However, history has shown that the future is not simply a linear extrapolation of the present. History is full of surprises and unexpected sequences of events linked to both natural events and human actions. Faced with making a decision on a final repository for spent nuclear fuel (here called the final repository, the final repository project) that must be safe for 100,000 years, it is important that we investigate phenomena, trends, risks and surprises that could influence the execution and safety of the final repository. The aim of this chapter is to shed light on and describe in brief some of the methods and approaches that can be used to study the future, and to highlight some of the future issues that need to be considered as a basis for decisions on the final repository. *More specifically, the purpose of this chapter is to draw attention to different future societal changes and human actions that could result in (1) a serious delay in waste deposition, backfilling and/or closure of the final repository, or (2) abandonment of the final repository without completion of deposition, backfilling or closure.* The focus here is thereby on the next 100 years, when the repository will be built and closed.

Section 3.2 provides some background with examples of the future issues that have thus far been studied in relation to the final repository by, among others, the Swedish Nuclear Fuel and Waste Management Co (SKB). Section 3.3 describes some examples of methods for future studies with a focus on trend extrapolation and scenarios, while section 3.4 gives a more detailed description of a method that is frequently used in social planning: backcasting. Both of these method sections discuss the relevance of these methods for the two issues on which the chapter is focused. Section 3.5 discusses the question of what circumstances could contribute to preventing the execution of a planned and commenced final repository project, the consequences of these circumstances, how they can be mitigated and the responsibility of different actors in this respect. In conclusion, section 3.6 presents some general comments on the importance of concrete measures within the framework of the Government's recently adopted *national security strategy*.[1]

Following is some background as to why the above issues are worthy of attention.

3.2 Background – completed studies

In RD&D programme 2013, under the heading "Flexibility in the face of changed premises," SKB writes:

> SKB's planning is based on the assumptions that apply today for the current nuclear power programme … Planning of the nuclear waste programme is based on the strategic assumptions that are judged to be most realistic today. The current time horizon is about 70 years, so SKB has to assume that changes will occur in the planning premises and that the current assumptions for the planning may be re-evaluated.[2]

In this RD&D programme, SKB studied four such changes, namely changes regarding (1) operating times of the nuclear power reactors, (2) commissioning of the extended SFR, (3) commissioning of the Spent Fuel Repository and Clink, and (4) new nuclear power reactors.

SKB's application documents for the final repository for spent nuclear fuel include more detailed and systematic studies of what external global changes could influence the design or safety of the final repository. These include for example the report *Handling of*

[1] *Nationell säkerhetsstrategi.* ("National security strategy"). Swedish Government, Prime Minister's Office 2017.

[2] SKB. 2013. *RD&D Programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, p. 63.* See also The Swedish National Council for Nuclear Waste. 2014. 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*, p. 25 f.

future human actions in the safety assessment SR-Site.[3] The purpose of this report is stated as follows:

> The purpose of this report is to provide an account of general considerations concerning FHA (Future Human Actions), the methodology applied in SR-Site to assess FHA, the aspects of FHA needed to be considered in the evaluation of their impact on a deep geological repository and to select and analyse representative scenarios for illustrative consequence analysis. The main focus of this report is a time period when institutional control has ceased to be effective, thereby permitting inadvertent intrusion. However, a brief discussion of the earlier period when the repository has been closed, sealed and continuously kept under institutional control is also provided.[4]

It should be noted that this report does not intend to examine conditions during deposition prior to closure of the repository. Among SKB's application documents there is a section in SR-Drift ("SR-Operation") concerning such events which includes a list of "Non-anticipated/improbable events (mishaps)".[5] Such events are also dealt with in an older SKB report, *Scenarier baserade på mänskliga handlingar. Tre arbetsmöten om metod- och säkerhetsanalysfrågor* ("Scenarios based on human actions. Three meetings on method and safety issues," in Swedish) from 1998.[6]

In SR-Site, SKB emphasizes the importance of correct execution of deposition, backfilling and closure of the final repository. SKB writes the following in SR-Site:

> According to the assessment of a stylized FHA scenario, if the repository is abandoned without backfilling and closure of all parts, the backfill in the deposition tunnel may be lost and the safety functions for containment may be compromised for the deposition holes located near the mouth of the deposition tunnels. Without backfill in parts of the system, no canister failure is expected to occur during the first period with temperate conditions. During the ensuing glaciation period, which is expected to last up to 66,000 years after the present, corrosion failure may occur and the estimated annual effective dose from radio-

[3] SKB. 2010. "Handling of future human actions in the safety assessment SR-Site". SKB TR-10-53.
[4] SKB. TR-10-53, p. 5.
[5] SKB. 2010. "Säkerhetsredovisning för drift av slutförvarsanläggning för använt kärnbränsle (SR-Drift) kapitel 3 – Krav och konstruktionsförutsättningar" ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 3 – Requirements and design premises," in Swedish) p. 9.
[6] Morén, L, Ritchey, T. and Stenström, M. 1998. *Scenarier baserade på mänskliga handlingar. Tre arbetsmöten om metod- och säkerhetsanalysfrågor.* ("Scenarios based on human actions. Three meetings on method and safety issues," in Swedish). SKB R-98-54.

> nuclides in the leaky canisters may exceed the regulatory risk limits. In view of the great uncertainties and conservative assumptions made in the assessment, the result can be regarded as a simplified illustration of possible consequences. The result points towards the necessity of correctly backfilling and closing the repository /translated from the Swedish/.[7]

The concluding sentence underlines the urgency of preventing the abandonment of a half-finished repository, or at least mitigating the consequences of such an eventuality (we will return to this). The description and assessment of the risks is an example of what is meant by “futures studies”. The next section describes some approaches to studying the future and how they can shed light on future issues of importance for the final repository.

3.3 Studying the future – trend extrapolation and scenarios

In the field of **futures studies**, different approaches and methods are used to investigate the future. A distinction is made between trend extrapolation and scenario technique. A *trend extrapolation* is based on seeing what trends we can see in the current situation and conditions and then extrapolating them to say something about the immediate future. In relation to the final repository issue, one might for example try to answer the question of whether there are any present-day circumstances that could result in a serious delay of the execution of the final repository project. This would be a broad investigation involving many years of research in the social sciences and can therefore not be pursued in this context.

Another method for futures studies is to construct stylized *scenarios* and then investigate their consequences for the execution of the final repository project. Such a study would also require extensive research work involving more time and resources than are currently available to the Council. In this chapter we will content ourselves with a few relevant examples of the technique and its importance for the nuclear waste issue. One form of such futures studies has been carried out by SKB and is presented in the main

[7] SKB. 2011. “Redovisning av säkerhet efter förslutning av slutförvaret för använt kärnbränsle. Huvudrapport från projekt SR-Site Del I” (“Post-closure safety of the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project Part I,” in Swedish), p. 41.

report from the SR-Site project[8] and in greater detail in the appended FEP report.[9]

FEP stands for "features, events and processes". The FEP method comprises three steps: step 1 comprises identification of all the events that could affect the final repository's long-term safety, step 2 comprises a thorough description of the desired initial state of the repository after closure, and step 3 is a study of how external conditions, i.e. "climate-related issues,", "large-scale geological processes and effects," and "future human actions" could affect the final repository.

Another form of future studies has been developed by the Swedish Civil Contingencies Agency (MSB). In the first step, different future scenarios with a given time horizon are developed; in the second step, the consequences for a given societal sector are explored; and in the third step, ways to manage the consequences are investigated. MSB uses a scenario technique that in some respects resembles SKB's FEP method. MSB's technique entails: "a systematic description of a possible future situation and of a possible course of development from the current state to the described situation".[10] Four fundamental concepts are *scenarios, analysis area, dimensions* and *variables*.

A *scenario* can be defined as: "a simplified picture of the whole and of the relationships between different societal sectors, often with contributions from many areas of knowledge."[11]

Another fundamental concept is *analysis area*. Examples are politics, communications, economics, technology, climate or values. Politics and political phenomena are, for example, an important part of all five scenarios.

For example, within the analysis area of politics we can distinguish different *dimensions*, such as national politics, European politics and global politics, which are interrelated in a more or less complicated fashion.

[8] SKB. 2011. "Redovisning av säkerhet efter förslutning av slutförvaret för använt kärnbränsle. Huvudrapport från projekt SR-Site Del III" ("Post-closure safety of the final repository for spent nuclear fuel at Forsmark. Main report of the SR-Site project Part III," in Swedish), p. 76.
[9] SKB. 2011. "FEP report for the safety assessment SR-Site." SKB TR-10-45.
[10] Definition of framtidsforskning (translated to English) in National Encyklopedin (NE).
[11] Definition of scenario (translated to English) in NE.

Finally, it is possible to distinguish different *variables* within an area. MSB, for example, distinguishes seven different variables within the dimension of national politics (responsibility for civil contingencies, control of vital public services, ability to prioritize resources in a crisis, decision-making/type of political decisions, corruption, criminality and public control on an individual level versus integrity).

An example is the MSB study *Samhället år 2032*[12] ("Society in 2032"), where five scenarios are analyzed, which we will return to further on in this chapter. In the light of these scenarios, MSB discusses: a) the consequences of these scenarios and b) the different measures which MSB should prepare to deal with these consequences. MSB has developed this scenario method with a view to the agency's remit and resources.

In a similar manner, the same method could be developed for the final repository and the next 100 years in order to:

1. get an idea of various societal changes and phenomena that could have good or more serious consequences for the execution of the final repository project,
2. get an idea of what these consequences area and how they can be managed (prevented, mitigated etc.),
3. review which actors and regulatory authorities should have responsibility for managing these consequences, and
4. review what resources and preparations may be required for effective management.

Several of the analysis areas in MSB's study *Samhället år 2032* could also be relevant in a future study of the final repository project, namely politics, military defence, communications (including transportation and trade relations), economics, technology, climate as well as values and value development. Different dimensions with associated variables are examined in these areas, for example in politics (global, national and local politics) and military defence (global conflicts and national threats), but also more close-at-hand in the area of transport, for example obstacles to transportation of

[12] MSB. 2012. *Samhället år 2032. Fem utmanande framtidsscenarier för samhällsskydd och beredskap.* ("Society in 2032. Five challenging future scenarios for societal security," in Swedish).

spent nuclear fuel from the encapsulation plant in Oskarshamn to the final repository in Forsmark. In the area of technology, there is a possibility of significant breakthroughs in the management of spent nuclear fuel. The climate dimension primarily examines variables having to do with global climate change, but also local phenomena such as storms and floods. The dimension "value changes" deals with global, national and local value changes (for example, reduced acceptance for the final repository project in the municipalities).

3.4 Finding ways and obstacles to the future – backcasting

Backcasting is a special method in the area of futures studies. Backcasting can be contrasted with forecasting, which entails trying to predict the future based on analysis of current trends, as described in the preceding section. Backcasting instead starts with a defined future situation and asks what will promote or counteract arriving at this situation. A distinction can be made between positive and negative backcasting. *Positive backcasting* entails first envisioning a desired situation in the future and then asking what would promote the realization of this goal. Josefin Wangel describes this in her 2012 dissertation as follows:

> Backcasting is a method for futures studies that is used to explore how a given target can be met. Instead of identifying a current situation and looking forward, backcasting takes its point of departure in the future and looks backward in order to investigate what changes may be needed to achieve this target /translated from the Swedish/.[13]

Negative backcasting instead entails describing a future situation which for various reasons is not desirable and then asking what can be done to avoid this situation. Current studies of climate change may be of this type. Based on probable climate states 60–70 years in the future, an attempt is made to describe how these states can be avoided and – in a second step – what different actors can contribute by their actions to avoiding these states.

[13] Wangel, J. 2012. *Making Futures: On Targets, Measures and Governance in Backcasting and Planning for Sustainability.* Royal Institute of Technology.

In a similar manner, different states could be described within this century which, in relation to the final repository project, can be considered undesirable for different reasons. These include:(a) a serious delay of deposition, backfilling or closure of a final repository and (b) abandonment of a final repository without completion of deposition, backfilling or closure.[14] Based on these undesirable future states for the final repository, the following three questions could be formulated.

1. What circumstances could lead to (a) a serious delay of deposition, backfilling or closure, or (b) abandonment of the repository without completion of all deposition, backfilling of all galleries and shafts and/or closure of the entire repository – and what are the consequences?
2. What preventive measures could be adopted to reduce the likelihood that (a) or (b) will occur, or – if (a) and (b) occur – mitigate the consequences?
3. Which persons or institutions are responsible for these matters and can and should adopt these preventive measures?

Calculating the probability that something will occur that leads to a delay of deposition, backfilling or closure, or the interruption of the ongoing execution of the final repository project, is naturally very difficult to do, even with low standards of accuracy. An initial summary of different circumstances that could hinder the final repository project is provided below, without any accurate assessment of the probability that these events will actually occur. It should be emphasized that the following survey is merely a preliminary outline of something that could be developed into a more comprehensive research programme.

[14] It may be difficult to distinguish between (a) and (b), but (b) entails, in contrast to (a), that the activity at the final repository has ceased completely.

3.5 Circumstances that could prevent the completion of a commenced final repository project – and the consequences

There are many different kinds of circumstances that could seriously delay or hinder a commenced final repository project – or lead to its abandonment. *In the first place* we can roughly distinguish between global, national and local circumstances. They may be, but are not necessarily, related. Examples of phenomena of a global nature include e.g. a full-scale nuclear war or a global pandemic. Such phenomena would indirectly affect the final repository project in a way to which we will return shortly. At best we have resources to somewhat mitigate the negative consequences for Sweden and for the final repository project, even though it is difficult to make completely reliable assessments.

Global disasters differ from more national and local phenomena or societal changes. Examples are a serious accident (fire, flood) in the unfinished repository, or a national financial crisis or societal system collapse due to corruption and increased organized crime. Here there are perhaps greater opportunities to mitigate the consequences or in any case adopt timely preventive measures.

In the second place we can distinguish between phenomena or circumstances that are caused by natural events and those that are caused by human actions (inadvertently or intentionally). The first category of natural events includes e.g. an asteroid impact on the unfinished repository or somewhere close by. The probability is of course low, but not non-existent. This is something we will return to, along with other similar but less improbable phenomena such as a supervolcano eruption and a natural pandemic. Human errors could have global consequences and indirectly delay or halt the final repository project. But careless mistakes may also be made on the actual worksite, and poor decisions may be made in the management of the project. Deliberate sabotage or acts of terrorism are familiar scenarios that are dealt with in the classified parts of SKB's application.

There is one category of global phenomena that could affect the project, but are not necessarily negative. This category is technical advances when it comes to alternative methods for managing spent nuclear fuel, such as partitioning and transmutation. It also includes commercial success for Gen IV, i.e. the fourth generation of nuclear reactors. These changes could lead to a re-evaluation of the entire final repository project.[15]

There are thus many phenomena or societal changes – primarily of a global nature, both natural ones and ones that are the result of human actions – that could cause delay or abandonment of an ongoing final repository project during the present century. Nor do they necessarily need to be related to circumstances that are directly related to the project. Examples are global disasters, financial crises, outbreaks of violence or unforeseen degradations of the earth's climate. In the book *Here be dragons* (2016), Olle Häggström – professor of mathematical statistics at Chalmers University in Gothenburg – discusses a number of such phenomena which could even threaten the survival of humanity. An example is eruptions of so-called supervolcanoes, which long ago caused a deterioration of the Earth's climate and triggered a biological mass extinction. Häggström goes through 13 such dystopias and asks how great the risk is that some of these scenarios will be realized before 2100. Nick Bostrom and Anders Sandberg at *The Future of Humanity Institute* in Oxford asked a number of experts to assess the probability that one of these events will happen. The answer was that the average probability that one of these events will happen is 19 percent.[16]

There is a natural objection to the relevance of such observations in relation to the final repository project. It is this: That even a massive leakage from a half-finished and perhaps collapsed repository pales in comparison with the consequences of an eruption from a supervolcano or, for example, a full-scale nuclear war. But that naturally depends on the scale of such a disaster. In a newspaper interview, Nick Bostrom says that even after a full-scale nuclear war, remnants of humanity could remain. The chances of survival of these remnants of humanity could at least to some extent be affected negatively by a leaking final repository. Human civilization could perhaps recover, but the radiation from the spent nuclear fuel remains hazardous for 100,000 years. The question of how the repository construction project would be affected by a global

[15] See the chapter "A new generation of nuclear reactors?" in this report.
[16] Häggström, O. 2016. *Here Be Dragons. Science, Technology and the Future of Humanity*, p. 201.

nuclear war can therefore not be completely disregarded. Even less how this project would be affected by violent conflicts in the near region.

Figure 3.1 Overview of circumstances and phenomena with consequences for final disposal and interim storage

	Global circumstances	*National circumstances*	*Local circumstances*
Natural phenomena	*A.* *Supervolcano eruption,* *Natural pandemic*	*B.* *See C.*	*C.* *Asteroid impact,* *Storms, floods,* *Earthquake*
Human actions (inadvertent or intentional)	D. Full-scale nuclear war, Global warming, Technical progress for alt. disposal method, Human-initiated pandemic	E. National financial crisis, Social collapse, Acts of terror	F. Crises in the near region, Fire, Floods due to the human factor, Detonation

3.5.1 Local circumstances

Local circumstances that could cause delays of the final repository project (and at worst abandonment of the repository) are dealt with in some previously cited SKB reports. In SR-Drift, a distinction is made between disturbances (less anticipated deviations from normal operation) and more serious “non-anticipated/improbable events (mishaps)”. The report gives the following examples:

1. fire of major scope
2. handling mishaps such as dropped canister, collision during transport
3. missiles or other external processes that cause severe external damage or stress on the canister
4. major flooding
5. the canister gets stuck in the KBT (canister transport cask) or in the deposition machine’s radiation shielding tube during transfer or deposition

6. earthquake
7. extreme weather conditions
8. events that lead to major damage to buffer and/or host rock with impact on deposition holes containing deposited canisters. The event requires that affected canisters be returned to a preceding handling step. The integrity of the canisters is not affected by the event
9. detonation in vicinity of canister (handling of explosive)
10. events related to criticality safety.[17]

The consequences of such events are not further dealt with in SR-Drift, nor how these consequences could be prevented or mitigated.

3.5.2 National/global circumstances

The question of how different national/global crises or disasters might prevent the completion of a commenced final repository project involves social science issues and processes that are very hard to assess. Studies based on different future scenarios and with the goal of assessing the consequences for the pre-closure repository are lacking. Scenario selection and social science studies are key issues which cannot be addressed in this chapter.

In the absence of a more comprehensive future study of the final repository issue, we refer to MSB's previously cited study *Samhället år 2032* ("Society in 2032," in Swedish) to conduct a thought experiment. MSB's study looks at five different scenarios, which are briefly described as follows:

- Scenario 1 – A growing population and deteriorating public health,
- Scenario 2 – Weak economy, high unemployment and social unrest,
- Scenario 3 – Accelerating climate change and rising oil prices,

[17] SKB. 2010. "Säkerhetsredovisning för drift av slutförvarsanläggning för använt kärnbränsle (SR-Drift) kapitel 3 – Krav och konstruktionsförutsättningar" ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 3 – Requirements and design premises," in Swedish) p. 26.

- Scenario 4 – The threat of terrorism in a world of conflict, and
- Scenario 5 – Antibiotic-resistant bacteria spread across the world.[18]

Scenarios 1, 2 and 4 can more accurately be described as social situations of type C, E or F (depending on whether they are a part of global phenomena or not) in Figure 3.1. Scenarios 3 and 5 are more of a global nature, i.e. of type C or F (depending on whether or not they are considered to be the result of human actions – inadvertent or intentional).

Regardless of the precise categorization of these scenarios, one can ask the question of whether the scenarios could affect an ongoing final repository project, and if so how. Scenario 1 is summarized as follows in MSB's study:

> The global rate of population growth has outstripped UN projections. By 2032 the world population is 8.5 billion and the population of Sweden is 11 million. Sweden has a relatively high employment rate, and Swedish companies are acquitting themselves well in new technological fields such as nanotechnology. The world can be said to have undergone an energy revolution, and the share of renewable energy has increased rapidly due to technological and scientific breakthroughs. The population density in our big cities is high, while rural areas are being depopulated. Public health issues such as severe obesity, high blood pressure and diabetes are posing major challenges to society.[19]

If this scenario comes true in the 2030s, it will not have any decisive effect on an ongoing final repository project – at least not a negative one. Sweden is predicted to have undergone an energy revolution, and 90 percent of electricity production will be based on renewable energy sources. If this is an overestimate and if new nuclear energy technology contributes significantly to electricity production, it may be in the form of fourth generation nuclear power (Gen IV). In that case, spent nuclear fuel could be considered as an energy source. If that were to happen, the execution of the final repository project (in part or in its entirety) might be reconsidered. Storage times for spent nuclear fuel in the interim storage facility Clab could also be longer than originally planned.

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[18] MSB. 2012. *Samhället år 2032 ("Society in 2032").*
[19] MSB. 2012. *Samhället år 2032 ("Society in 2032")* p. 9.

If we assume that scenario 1 comes true and new forms of nuclear energy are developed, alternative uses of the Nuclear Waste Fund's assets would probably come up for discussion. A question to be considered is whether it would be meaningful to carry out a study of such a re-allocation of the Nuclear Waste Fund's resources already today. In any case, the reason for and against such a study need to be discussed.

We will return to the question of the consequences of extended storage at the interim storage facility Clab.

Scenario 2 describes a societal state of weak economy, high unemployment and social unrest. This is summarized as follows:

> Revolutionary advances in the field of information and communications are changing the world, but most countries in Europe are struggling to keep up with the pace of progress in the strong Asian economies. In recent years, Sweden has been struggling with a faltering economy and high unemployment, and in 2032 the population of Sweden declined for the first time in modern history. The country's welfare system and infrastructure are plagued by inadequacies. Public trust in politics and society is being eroded and social unrest is on the rise.[20]

In contrast to scenario 1, scenario 2 could have more or less far-reaching consequences for a commenced and ongoing final repository project. This scenario entails social and economic stresses with repercussions for the project. Some of these are a consequence of the reduced ability of national and local authorities to regulate and supervise the activities of corporations, for example in the energy sector. Moreover, the scenario entails increased corruption, which could adversely impact the final repository project in Forsmark. Furthermore, a shortage of skilled labour, including engineers, is predicted in this scenario. Supplies of goods, raw materials and products are expected to be good, but vulnerable. Widespread sabotage and hacking of IT systems will put great strain on social systems. (A brief power cut at Sturup Airport on 30 November 2016 had quite far-reaching consequences). Infrastructure systems are assumed to be particularly vulnerable in rural areas, such as Forsmark. In this scenario, public distrust of information is growing, and MSB predicts that interactive social media will account for a greater share of communications and information between people. Confidence

[20] MSB. 2012. *Samhället år 2032* ("Society in 2032"), p. 17.

in private experts and public bodies is declining. It is difficult to distinguish public relations from news – "rogue news sources could have a great impact".[21]

All of this could have negative consequences for an ongoing final repository project. The risk for what SKB calls more serious "non-anticipated/improbable events (mishaps)" will increase and may lead to shorter or longer interruptions in the deposition of canisters in the repository. The risk of deficiencies in the execution of the final repository project will increase, with the result that different safety systems and protective barriers may not perform as planned. Public confidence in the project could be greatly eroded.

The preventive measures that could be planned now in the event that scenario 2 should come true in part or in whole are limited. Aside from possible delays and their consequences, the importance of a robust safety culture within the final repository organization (as so often pointed out by the Swedish National Council for Nuclear Waste) is glaringly apparent in this situation. SSM also concurs with this assessment and has emphasized the importance of the licensee's organization in its statement of comment to the Land and Environment Court:

> The safety and radiation protection requirements in the Nuclear Activities Act and the Radiation Protection Act entail that a licensee must have a deep and broad knowledge of the activity. Further, the Nuclear Activities Act and SSMFS 2008:1 stipulate requirements on the licensee's organization. The nuclear activity shall be conducted with the support of a management system that is designed so that the requirements on safety and radiation protection are met. The licensee shall ensure that personnel and contractors have the competence and suitability in other respects that is needed.[22]

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[21] MSB. 2012. *Samhället år 2032* ("Society in 2032"), p. 23.
[22] SSM. 2016. *SSM's statement of comment to the Land and Environment Court 2016. Yttrande över ansökan från Svensk Kärnbränslehantering AB om tillstånd enligt miljöbalken för ett system för hantering och slutförvaring av använt kärnbränsle* ("Review of application from the Swedish Nuclear Fuel and Waste Management Co for a licence under the Environmental Code for a system for management and disposal of spent nuclear waste," in Swedish). (SSM 2016-546), p. 10. Cf. Review Report "Systemövergripande frågor" ("System-wide issues," in Swedish), p. 13 and p. 17. See also SSM. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* ("Activity oversight safety leadership SKB," in Swedish).

It should also be added that it is important in a situation with a general shortage of technical competence that the regulatory authority preserve its competence. Preventive measures to ensure that such competence is preserved in the light of the present scenario could include conducting long-term studies and preparing an emergency organization in the event of a competence shortage.

Scenario 3 is summarized under the heading “accelerating climate change and rising oil prices” and is described as follows:

> Sweden’s economy has been stable in recent years with increasing growth, but in 2032 the world is facing accelerating climate change and rising oil prices that threaten continued positive economic growth. Adaptation of infrastructure and buildings to the changing climate has proceeded relatively slowly, and increased precipitation, high water levels and higher temperatures have recently caused a number of disturbances.[23]

In this scenario, the negative consequences of climate change play a decisive role.

> Heat waves, prolonged droughts, torrential rains, floods, earthslips, landslides and extensive forest fires are more common phenomena and are causing major problems and damage to buildings and infrastructure around the world. - - - Roads and conduit-based systems for electricity supply and drinking water distribution have been hit hard by the various types of damage and disruption.[24]

Such processes can also affect the final repository project. Flooding of the repository during ongoing deposition is a particularly serious threat. This is mentioned in SKB’s application documents, but a survey of preventive measures is lacking, and the need for and nature of a rescue organization has been inadequately studied. Long-term safety after deposition (post-closure safety) has been thoroughly investigated, as opposed to the more short-term problem of safety during deposition up until closure around the end of this century (pre-closure safety).

The scenario does not take into account higher sea water levels, but if the scenario is postponed a few decades, this could have consequences for the final repository project.

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[23] MSB. 2012. *Samhället år 2032* (“Society in 2032”), p. 25.
[24] MSB. 2012. *Samhället år 2032* (“Society in 2032”), pp. 26, 29.

It is assumed in the scenario that obsolete nuclear power plants must be replaced with new ones. This brings up the question of how spent nuclear fuel from these new facilities can be utilized.

Scenario 4 is characterized by the threat of terrorism in a world of conflict. This is summarized as follows:

> In 2032, the world is characterised by unrest and poor economic growth. The past decade has seen armed conflicts in many parts of the world, and even though Europe and its neighbours have been spared from war, the security situation has often been strained. Terrorism is a growing threat within Europe as well. As a reaction to this development, nation-states in many parts of the world are strengthening their position. In Sweden, numerous enterprises that had previously been privatised have returned to the public sector.[25]

In this scenario, critical social functions have been placed under state control or been heavily regulated and supervised by the state. Far-reaching anti-terror legislation has been enacted. This brings to the fore questions regarding nuclear safeguards and physical protection, which are thoroughly dealt with in SR-Drift.[26] The issue of safeguards is discussed in the Swedish National Council for Nuclear Waste's State-of-the-Art Report 2015.[27] There it is stated that 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. 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

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[25] MSB. 2012. *Samhället år 2032* ("Society in 2032"), p. 33.

[26] SKB. 2010. "Kontroll av kärnämne inom KBS-3-systemet" ("Nuclear material safeguards in the KBS-3 system," in Swedish). (SR-Drift, chap. 4).

[27] Swedish National Council for Nuclear Waste. 2015. SOU 2015:11 *Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety*, pp. 49–72.

main target of physical protection, but also facilities for disposal of radioactive material.

Safeguards and physical protection are issues that are particularly relevant in scenario 4. They will not be further dealt with in this chapter. Essential aspects are discussed in the classified parts of SKB's application.

Scenario 5 deals with a social situation that is seemingly less relevant in this context, namely that antibiotic-resistant bacteria spread across the world. This scenario is linked with significant scientific breakthroughs and technical innovations. At the same time, the situation is darkened by an emerging threat of global proportions. This is summarized as follows:

> In 2032, antibiotic-resistant bacteria represent a huge global problem, and the lack of effective antibiotics has had far-reaching consequences for societies all over the world. In particular, the inability of healthcare to use established methods of treatment is perceived as a problem, but antibiotic resistance is also causing major problems for food producers in the form of diseases in animals and plants.[28]

The consequences of antibiotic-resistant bacteria spreading across the globe do not in themselves have to pose any problems for an ongoing final repository project. But the consequences are hard-to-assess and could make it difficult to staff the project with sufficiently skilled personnel. It could be even worse if another related horror scenario is realized, namely that bacteria or virus cause a global pandemic. This could happen by mistake if dangerous pathogens escape from a laboratory. But it could also be brought about intentionally to create global mass destruction. This might seem to be taken from a horror film, but Sir Martin Rees quotes the following from a report published by the US National Academy of Sciences:

> Just a few individuals with specialized skills and access to a laboratory could inexpensively and easily produce a panoply of lethal biological weapons that might seriously threaten the US population. Moreover, they could manufacture such biological agents with commercially available equipment – that is, equipment that could also be used to make chemical, pharmaceuticals, foods, or beer – and therefore remain inconspicuous. The deciphering of the human genome sequence and the

[28] MSB. 2012. *Samhället år 2032* ("Society in 2032"), p. 41.

> complete elucidation of numerous pathogen genomes ... allow science to be misused to create new agents of mass destruction.[29]

Hopefully, the consequences do not have to lead to the demise of mankind, but this is judged by initiated futurologists (such as Anders Sandberg) to be a not entirely improbable scenario. And even if such an act of terror would not cause the demise of mankind, it could pose serious challenges to humanity. The threat of a half-finished final repository pales in comparison to such challenges. But it doesn't make mankind's future less vulnerable.

To this list of global threats must also be added a global nuclear war, or less drastic conflicts that could harvest millions of victims and hamstring the world's economy and global trade for decades or even centuries. If a final repository project cannot be completed for such a reason and the repository is left half-finished with a large quantity of spent nuclear fuel remaining in the interim storage facility Clab, the durability and inviolability of the interim storage facility once again becomes a crucial issue. This question has also been dealt with in connection with other future scenarios. What can we do today to secure the interim storage facility in the event one of these scenarios should come true?

3.5.3 The no action alternative – extended interim storage in Clab

If any of the events or processes summarized in Figure 3.1 above should be realized, what is usually known as the "no action alternative" becomes an option to consider. This may entail leaving the spent nuclear fuel in the interim storage facility for a longer time than planned – or at worst indefinitely. What are the consequences of this? What safety risks would a delay in transferring all or part of the spent nuclear fuel in Clab to the final repository entail? And what would be the consequences of leaving it in place indefinitely?

SKB has examined these consequences in special reports.[30] The results are summarized in a report from 2000, *Vad händer om det*

[29] Häggström, O. 2016. *Here Be Dragons*, p. 197.
[30] See Söderman, E. 1997. *Kontrollerad långtidslagring i CLAB ("Supervised long-term storage in CLAB," in Swedish).* SKB R-98-17.

inte byggs något djupförvar? Nollalternativet – förlängd mellanlagring i CLAB ("What happens if a deep repository is not built? The no action alternative – extended interim storage in CLAB," in Swedish).[31] Chapter 1 provides a background, and Chapter 2 deals with the question of whether interim storage in Clab can be regarded as a no action alternative, i.e. as a description of "the consequences if the activity or measure is not implemented" (from the Environmental Code). The report answers the question in the negative, referring to KASAMS's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 1998. Long-term storage cannot be regarded as a final solution:

> … since it presumes that future societies through many generations of decision-makers will feel an equally great responsibility for the nuclear waste as our generation does. Regardless of their own societal crises and political priorities, they will have to continuously provide the financial resources and the regulatory and supervisory structure needed so that a supervised storage will be at least as safe as the final disposal our generation can carry out. This is an unreasonable presumption.[32]

Chapter 3 of SKB R-00-31 provides a brief description of Clab, and Chapter 4 provides a summary of R-98-17 and the prospects for extending the operating time to 100–200 years. The survey shows that according to SKB, spent nuclear fuel could be interim-stored in the facility for up to 1,000 years.

Of central importance in this context is the accident analysis that is done in Chapter 5 of SKB's report. The consequences of fire, handling accidents, long-term loss of cooling and topping-up of the pools, plus external forces and earthquakes, were analyzed in separate reports. The consequences of a stone block falling down into a pool were thereby also analyzed.[33] "The accidents resulting from these initial events do not in any case lead to consequences that pose a significant danger to the public."[34] Two other events are also dealt with, namely total loss of water in the pools and exten-

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[31] SKB. 2000. *Vad händer om det inte byggs något djupförvar? Nollalternativet – förlängd mellanlagring i CLAB ("What happens if a deep repository is not built? The no action alternative – extended interim storage in CLAB," in Swedish).* SKB R-00-31.
[32] KASAM. 1999. SOU 1999:67 *Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 1999, Treatment and Final Disposal of Nuclear Waste.* p. 23 (in Swedish); SKB. 2000. R-00-31, p. 11.
[33] SKB. 2000. R-00-31, p. 27 and special reports cited there.
[34] SKB. 2000. R-00-31, p. 27.

sive fuel damage due to falling stone blocks, which could occur if testing and maintenance are neglected. Such events could occur if the facility suddenly had to be abandoned due to war or environmental disaster. According to the reports, loss of water in the pools does not have to lead to any crucial safety problems, especially if it occurs after 100 years, since the decay heat has then declined considerably. This naturally assumes that personnel can return to the facility and restore the cooling system. Nor would occasional falling stone blocks necessarily cause any serious problems, although it could lead to some increase in radiation.

In the same SKB report, sudden abandonment of Clab was analyzed in three different scenarios: one where abandonment occurs around 2010 (with maximum decay heat), another in 2150 and a third in 2250. Due to the diminished decay heat, early abandonment of Clab would in the first scenario, i.e. 2010, result in all cooling water boiling off in between 0.3 and 2 years. If Clab is abandoned in 2085, this would take between 1 and 6 years. If Clab is abandoned later than 2250, the fuel will probably not be exposed. SKB summarizes:

> However, if the personnel are forced to abandon Clab in the future, this may have serious consequences. The radiation doses to persons in the environment would not be acceptable, and the facility itself would be contaminated to such an extent that it would be very difficult at a later date to resume control and move the fuel to a safer place. Since it is difficult to predict how society will evolve in a long-term perspective, the possibility that Clab will eventually have to be abandoned cannot be ruled out. This risk is impossible to quantify, but it cannot be disregarded in the perspective of thousands of years which we must use when it comes to nuclear waste.[35]

In the cited report, SKB does not speculate further as to how the consequences of the events described in different scenarios could be handled or what kind of emergency organization would be required for this.

[35] SKB. 2000. R-00-31, p. 37.

3.6 Conclusion

The future of the safety of the final repository project, after closure and the end of institutional controls and in the 100,000-year perspective, is dependent on both natural and societal events. In a 100,000-year perspective, we know by looking to the past that very great changes and events have occurred – from the evolution of mankind as a species, large volcanic eruptions and ice ages to more present-day technological advances accompanied by changes in lifestyle. It is therefore natural to try to study possible changes in the future, even though we have to accept that all predictions are associated with a great deal of uncertainty. Looking back just 100 years, major events have taken place: two world wars, countless acts of terrorism, climate change, volcanic eruptions, earthquakes, tsunamis, financial collapses, several nuclear power plant accidents; in addition, industrialization of the production of goods has taken place along with huge technical advances, an explosion of the global population and great lifestyle changes entailing that a growing portion of the Earth's population lives in cities, and that obesity rather than starvation has become a global problem. This means that even such a "short" time perspective as 100 years in the future may involve changes and events that affect that which is the focus of this chapter, *i.e. various societal changes and future human actions that could result in (1) a serious delay in waste deposition, backfilling and/or closure of the final repository the final repository, or (2) abandonment of the final repository without completion of deposition, backfilling or closure.*

Future issues in relation to the final repository project have received relatively little attention. The Council believes that they need to be given more attention and further analysis with regard to the societal changes we have exemplified here. The deterioration in the security situation and the factors considered in the Government's recently published national security strategy underline the need to regard the nuclear waste project in such a perspective as well. Prime Minister Stefan Löfvén writes in the preface to the *National Security Strategy*:

> The national security strategy covers many different areas of policy, and the actors are in both the public and private sectors. The Government bears overall responsibility, and now that the strategy has been adopted, all ministries have to take it into account as they continue their work with different initiatives. But security is a concern for all of

> society. The active participation of central, regional and local authorities is needed, as well as of private individuals, industry and civil society /translated from the Swedish/.[36]

As an example of a possible measure, the Council finds that it could be reasonable to broaden the remit of the Swedish Civil Contingencies Agency to analyze and continue to follow up future issues in relation to the final repository project. SKB is naturally an important cooperation partner in this work.

In conclusion, it is urgent to view the final repository project in a larger context. The scenarios that have been described in this chapter could also have more or less serious consequences for other large-scale technical systems and infrastructures in society, for example transportation systems, communications, health care and virtual networks. In other words, the final repository project is a gateway to studies of many broadly important future security issues. The goal is to protect the life and health of our citizens and ultimately ensure the survival of society.

[36] *Nationell säkerhetsstrategi.* ("National security strategy"). Swedish Government, Prime Minister's Office 2017. 3.

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4 Future political challenges – financing and retrievability

4.1 Introduction

Final disposal of radioactive waste is a complex issue that involves a number of technical and political challenges. They range from corrosion conditions in hard-to-predict chemical environments over many millennia to the division of risks and responsibilities between present and future generations. While the technical problems can generally be tackled and hopefully solved with the aid of scientific knowledge, the political questions are often the subject of both on-going dialogue and debate and recurrent evaluation and re-evaluation by both political institutions and society at large.

The degree to which a societal issue is politicized – i.e. becomes the subject of public attention and interest, as well as broad social debate – depends to a great degree on its technical complexity and controversial nature. Scientifically and technically complex issues, such as many environmental issues, are often handled by expert organizations, often within more or less clear political frameworks. Highly value-laden issues, such as those involving civil rights and fairness aspects, are frequently and intensively debated in elected assemblies and public media. While politicization can enrich public democratic discourse and result in a comprehensive elucidation of the political alternatives, there are also risks in the form of, for example, difficulties in achieving a consensus and guaranteeing stable principles over time. There are exceptions from these assumptions, and a given issue can be handled in different ways during different periods, depending on how decision-making processes develop and how the public agenda changes. When it comes to nuclear waste, the issue of a final repository for high-level spent nuclear fuel (the final repository) is now, after years of study and research, in a crucial decision-making phase where the Government, supported by the Ministry of Environment and Energy, will soon make a decision. This may lead to further politicization.

Purpose and method

In this chapter we will describe the political debate in the Riksdag (Parliament) over the years regarding two issues that are related to the spent nuclear fuel, namely the financing of a final repository and the possibility of retrieving and using the spent nuclear fuel.

Previous studies concerned with nuclear waste issues in Swedish politics have analyzed party-political dividing lines in the Riksdag.[1] Here we would like to focus on what issues have been raised on the Riksdag's agenda via motions and interpellations. The purpose is to show what types of issues have been debated in the Riksdag over the years, which may indicate what issues will be discussed in the Riksdag in the future in the continued final repository process. This is urgent since the issue of a final repository for spent nuclear fuel will undergo legal review and scrutiny in the coming years. This will in part be done by the Government and will thereby involve political trade-offs within the bounds of the legislation, with consideration given to both financing and the retrievability of the waste. In just such a situation, increased politicization is conceivable, which may be valuable but not unproblematic if it makes it more difficult to achieve a long-term consensus.

In order to get an idea of what issues have been debated in the Riksdag over the years, a search was done in "Documents and Laws" on the Riksdag website.[2] The search term "kärnavfall" ("nuclear waste") returned 1,070 hits. This means that the term "kärnavfall"

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[1] Among others Vedung, E. 1979. *Kärnkraften och regeringen Fälldins fall* ("Nuclear power and the fall of the Fälldin Government," in Swedish); Larsson, S-E. 1986. *Regera i koalition: den borgerliga trepartiregeringen 1976–1978 och kärnkraften* ("Governing in coalition: the non-socialist three-party Government 1976–1978 and nuclear power," in Swedish); Lindquist, P. 1997. *Det klyvbara ämnet: Diskursiva ordningar i svensk kärnkraftspolitik 1972–1980* ("The fissionable material: Discursive orders in Swedish nuclear power policy 1972–1980," in Swedish). *Lund dissertations in sociology*; Vedung, E. och Brandel, M. 2001. *Vattenkraften, staten och de politiska partierna* ("Hydropower, the state and the political parties," in Swedish); Vedung, E. 2005. "Det högaktiva kärnavfallets väg till den rikspolitiska dagordningen" ("The pathway of the high-level nuclear waste to the national political agenda" in Swedish) pp. 33−56.

[2] See the Riksdag's website: https://www.riksdagen.se/sv/dokument-lagar.

is mentioned in 1,070 documents that are archived and searchable on the website, including records of chamber proceedings, committee reports, Government bills, the Swedish Code of Statutes and motions. The first hits are from 1975, after which there are hits from every year. For a year-by-year breakdown, see the table in Appendix 1. There may, however, be duplicates among these hits, i.e. one document may be counted several times. There is also some uncertainty in the search engine, which means that the number of hits can vary slightly between searches. We have not gone through all of these documents, but have limited ourselves to our two issues: *financing* and *retrievability*.

We have been interested in getting an indication of which party-political issues have been on the Riksdag agenda over the years, and more specifically what has been said regarding the two issues of financing and retrievability. We limited ourselves to going through motions, interpellations and replies to specific questions. In all, 145 motions, 4 interpellations and 22 written questions turned up in response to the search term "kärnavfall" ("nuclear waste"). The most active party in writing motions and written questions was Miljöpartiet (MP, the Green Party) with 77, followed by Moderaterna (M, the Moderates) with 25, Folkpartiet (L, the Liberals) with 20, Centerpartiet (C, the Centre Party) with 15, Vänsterpartiet (V, the Left Party) with 15, Kristdemokraterna (KD, the Christian Democrats) with 14, Socialdemokraterna (S, the Social Democrats) with 12, Ny demokrati (NYD, New Democracy) with 1 and Without Party Designation, with 2. Sverigedemokraterna (SD, the Sweden Democrats) have one interpellation.

First we take a closer look at the issues that have been raised in relation to financing of the final repository, which have involved criticism of the cost calculations for decommissioning and disposal, the size of the fee to the Nuclear Waste Fund, and who will get money from the Fund. Then we discuss the issues that have been raised concerning the possibility of retrieval, and more specifically the choice of deep boreholes as an alternative to the KBS-3 method. Each section ends with a brief summary, and the chapter concludes with a broader discussion.

4.2 Financing of the final repository

The cost of decommissioning of reactors, plus management and final disposal of spent nuclear fuel, is estimated today to be over SEK 100 billion. However, in view of the long-time perspective (the nuclear waste needs to be isolated from humans for 100,000 years) and the size and special nature of the project, this estimate is highly uncertain. This is discussed in last year's state-of-the-art report.[3] The Act (1984:3) on Nuclear Activities and the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities regulate the obligations of the reactor owners and how waste management is to be financed[4], but the idea is that these costs should not burden future generations, but rather should be defrayed from the revenues obtained from the sale of nuclear-generated electricity.

Since the early 1980s, all reactor owners are required to pay a fee to cover the future cost of decommissioning, dismantling and final disposal. The amount of the fee is a certain number of öre (1 Swedish krona = 100 öre) per kWh of electricity delivered by the nuclear power plants. Every three years, the Swedish Nuclear Fuel and Waste Management Co (SKB) makes a cost estimate that is checked by the Swedish Radiation Safety Authority (SSM). Based on this estimate, the Government then sets the size of the fee to the Nuclear Waste Fund. The nuclear waste fee for the period 2015–2017 has been set at 4 öre/kWh.[5] Since 2008, a fee can also be set as a flat amount if, for example, a fee-liable licensee no longer delivers nuclear-generated electricity.

For the first 14 years, the money was deposited in interest-bearing accounts at the Riksbank (the Swedish central bank). Since 1996, the fee assets are managed by the Nuclear Waste Fund, which is a government authority. The mission of the Nuclear Waste Fund is to manage the capital and preside over disbursements from the Fund. Another government authority, SSM, decides how the funded assets may be used.

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[3] Swedish National Council for Nuclear Waste. 2016. SOU 2016:16 *Nuclear Waste State-of-the-Art Report 2016. Risks, uncertainties and future challenges*.
[4] See the chapter "How the requirements on a final repository for spent nuclear fuel have evolved in Swedish legislation" in this report.
[5] Swedish National Council for Nuclear Waste. SOU 2016:16.

The financing issue has been debated frequently in the Riksdag. The 1,070 hits obtained in the original search on "kärnavfall" included 41 motions, 5 interpellations and 4 written questions concerning costs and the Nuclear Waste Fund. Below is an account of the themes that have recurred over the years.

4.2.1 Criticism of the cost calculations for decommissioning and disposal

The difficulty of estimating what the actual costs of nuclear waste management will amount to in the end is a recurrent theme in the motions. However, only one motion takes up the difficulty of estimating the costs incurred by decommissioning (including dismantling) of nuclear power plants. It is the Green Party that criticizes the cost calculations for decommissioning of nuclear power plants, claiming that they are highly unreliable. The motion refers to a cost calculation for decommissioning of a reactor in Ringhals of the same type as a reactor that has been decommissioned in the USA. The cost of decommissioning the Ringhals reactor is estimated to be SEK 900 million, while the actual cost in the USA was SEK 2,600 million, three times as much for the same reactor type.[6]

4.2.2 Criticism of the financing model

In a motion from 1995, the Centre Party takes up the Government's proposed financing model, which led to today's Nuclear Waste Fund. In the motion, the Centre Party focuses on how the fee is determined. The Government's proposal is that a basic amount should be paid to the Fund. Previous calculation models are to be used to calculate this amount, but in the new model no contingency allowance is added for improbable events. In order to ensure that adequate funds are available in the event of a premature closure of a reactor, the reactor owner shall instead provide "acceptable guarantees". A basic payment shall be made in accordance with a base

[6] Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).

scenario, and any additional costs that may be incurred above this base scenario shall be covered by these acceptable guarantees. According to the Government proposal, acceptable guarantees may take the form of credit insurance, surety bonds or real estate mortgages, but nuclear power plants may never be pledged as collateral. The Centre Party criticizes the proposed model because it violates the precautionary principle, and the party believes that the calculations should be based on the previous calculation models. The reason they don't want a system with guarantees is that it leads to lower payments to the Fund. The Government's proposal also entails that the power companies tie up their assets in guarantees, and these assets will then not be able to be pledged for other purposes, such as security in renewal of the energy systems. Moreover, the authors of the motion find it inappropriate that hydropower plants are used as security for activities related to nuclear power production. The Centre Party wants the system to be based on adequate Fund payments calculated with a wide margin of safety. Then if there is money left in the Fund, it can be paid back to the reactor owner.[7]

In a motion from 1996 and an almost identical motion from 1997, Roland Larsson (C) also criticizes the new financing system that is discussed above. The new system was introduced in 1996 and led to the establishment of the Nuclear Waste Fund, where a portion of the calculated waste management costs that previously served as a basis for the fees paid by the nuclear power industry to the Fund was replaced with guarantees and security as described above. In his motions, Larsson writes that as a result of the new system, the total fees paid to the Nuclear Waste Fund have decreased by about SEK 1 billion per year. According to Larsson there are two reasons for this decrease. The first is that the Fund's assets have been invested in inflation-indexed securities with the National Debt Office. This means that it will in practice be the taxpayers who bear the financial risk. The second reason is that the portion of the costs for waste management that is difficult to predict will be covered by guarantees. According to Larsson, this means that

[7] Motion to the Riksdag 1995/96:N14 "med anledning av prop. 11/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Lennart Brunander et al. (C).

hydropower plants and other facilities will probably be mortgaged. This in turn means that if the assets in the Nuclear Waste Fund are not sufficient, the costs will have to be borne by hydropower and other electricity production. This violates the principle that nuclear power should bear its own costs, and Larsson therefore wants legislation to be passed stipulating that hydropower and other electricity production may not serve as security for the costs of managing the waste from nuclear power.[8]

In the same year, 1996, the Christian Democrats also discuss the financing proposal that was discussed by the Centre Party above. The Christian Democrats are in principle positive to the financing proposal, but object to the fact that the Nuclear Waste Fund's assets are to be deposited with the National Debt Office. A side effect of this is that the state's borrowing requirement will decrease as deposits with the National Debt Office increase. The Christian Democrats are particularly doubtful regarding a sentence in the Growth Bill (1995/96:25) that states:

> Next year the Nuclear Fuel Fund will be moved from the Riksbank to the National Debt Office, which will reduce the national debt and the state's borrowing requirement by about SEK 18 billion.

The author of the motion interprets this as if the state confiscates the SEK 18 billion paid in by the companies and counting it as a net income for the state. The author of the motion objects to this and thinks it would be better if the Fund's Board of Governors were allowed to determine how the Fund's assets are to be managed.[9]

The Moderates also discuss how the assets of the Nuclear Waste Fund should be invested. They conclude that the security provided by the Nuclear Waste Fund is based on the assumption that the paid-in fees can be invested with a good return and under safe forms. Traditionally the assets have been deposited in an interest-bearing account at the Riksbank. The Government's proposal is to create the Nuclear Waste Fund and deposit the assets with the National Debt Office. The Moderates support the idea of a Nuclear

[8] Motion to the Riksdag 1996/97:Jo784 och 1997/98:N260 "Finansiering av kärnkraftens avvecklingskostnader" ("Financing of the decommissioning costs of nuclear power") by Roland Larsson (C).

[9] Motion to the Riksdag 1995/96:N11 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Dan Ericsson (KDS).

Waste Fund, but are critical to having to deposit the assets with the National Debt Office. The Moderates want it to be possible to invest the assets of the Nuclear Waste Fund in a diversified portfolio that also includes equities.[10]

Commenting on the Government's proposal of a Nuclear Waste Fund, the Green Party, like the Centre Party, notes that there is no guarantee that funds will be available for waste disposal if the Fund's assets are depleted. If a nuclear power company is forced into bankruptcy, the money that is in the Fund today will not suffice to pay for a final repository. The Green Party is also critical to the fact that the calculations of costs that will arise far in the future are based on the assumption of economic growth and a real interest rate 1.5 percent. The Green Party wants the real interest rate to be set at 0 (zero) percent and to have this stipulated in the Financing Act.[11] This is repeated in a motion from 1996.[12] The advantage would be that the generation that uses the nuclear energy will set aside exactly the amount of resources that it is estimated that waste management and disposal would cost if it took place today. According to the authors of the motions, this would be a more morally acceptable principle for the calculation.[13] The authors further note that of the SEK 45 billion that waste management is calculated to cost in total, the Fund contains SEK 16 billion (at that time, 1995). This isn't enough if early decommissioning is required, so the payment to the Fund has to be increased.[14]

The Liberals discuss in 2006 that it may be impractical that the companies are liable for the costs all the way up to sealing of the final repository, since future technological advances may lead to postponement of repository closure. The state cannot be sure that companies that have owned reactors will not go out of business and

[10] Motion to the Riksdag 1995/96/11:N12 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Karin Falkmer et al. (M).

[11] Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).

[12] Motion to the Riksdag 1996/97:Jo768 "Kärnavfall" ("Nuclear waste") by Eva Goës et al. (MP).

[13] Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).

[14] Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).

thereby have difficulty paying for the waste after the reactor has been shut down. Here the authors take up the closure of Barsebäck due to political decisions, where the Liberals say that it is not reasonable that the owners should bear the entire cost of disposal since fees levied on electricity production cannot be used to cover these costs.[15]

The Liberals say that the problem of prolonged liability is greatest for small enterprises with small waste volumes. For this reason the Liberals want the Government to investigate the possibility for small enterprises to transfer their fee liability for the waste to another entity, for example an enterprise that recycles the fuel or an insurance company. In the latter case, an insurance policy could cover the extra cost that may arise later in the waste management process.[16]

In a motion from 2016, the Christian Democrats want to create good business conditions for the nuclear power producers and therefore abolish the nuclear power tax. As a result of the abolished nuclear power tax and the fact that the Nuclear Power Phase-Out Act has been repealed, the authors of the motion want SSM, in consultation with the National Debt Office, to investigate how changes in operating times affect the Nuclear Waste Fund. But the principle should still be that the costs of final disposal of spent nuclear fuel and nuclear waste should be covered by the entity that generated the waste and that the state should not have to pay for decommissioning or disposal.[17]

[15] Motion to the Riksdag 2005/06:MJ26, "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Lennart Fremling et al. (FP).
[16] Motion to the Riksdag 2005/06:MJ26, "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Lennart Fremling et al. (FP).
[17] Motion to the Riksdag 2016/17:3393 "Utgiftsområde energi" ("Spending area energy") by Pernilla Gunther et al. (KD).

4.2.3 The size of the fee to the Nuclear Waste Fund

The size of the fee to the Nuclear Waste Fund was mentioned above and is a recurring issue in motions. In 1992, Annika Åhnberg (no party designation)[18] submits a motion where she says that the paid-in fees for the first plants to be decommissioned will not cover the costs of waste management and dismantling of reactors. She goes on to say that a phase-out of nuclear power may begin earlier than expected and that resources must then be available to cover the decommissioning costs. Åhnberg therefore wants the Government to explain how a nuclear power phase-out will be financed in different alternative situations, in compliance with the principle that the reactor owner pays.[19]

In several motions, the Green Party addresses the need to raise the fee to the Nuclear Waste Fund and end what they say amounts to a subsidy of nuclear-generated electricity.[20] In three motions – one from 1997[21], one from 2000[22] and one from 2001[23] – the focus is on subsidies to nuclear power, and two main types of subsidy are

[18] Åhnberg left VPK (now V) and subsequently joined S; during the intervening period she had no party designation.
[19] Motion to the Riksdag 1992/93:N39 "med anledning av prop. 1992/93:98 Ändring i lagen (1984:3) om kärnteknisk verksamhet, m.m." ("in response to Gov. Bill 1992/93:98 Amendment to the Act (1984:3) on Nuclear Activities etc.") by Annika Åhnberg (-).
[20] Motion to the Riksdag 1994/95:N26 "med anledning av prop. 1994/95:222 Ny ellagstiftning" ("in response to Gov. Bill 1994/95:222 New electricity legislation") by Eva Goës et al. (MP); Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP); Motion to the Riksdag 1996/97:Jo768 "Kärnavfall" ("Nuclear waste") by Eva Goës et al. (MP); Motion to the Riksdag 2004/05:MJ38 "med anledning av prop. 2004/05:150 Svenska miljömål – ett gemensamt uppdrag" ("in response to Gov. Bill 2004/05:150 Swedish environmental objectives – a joint mission") by Åsa Domeij et al. (MP); Motion 2005/06:MJ26 "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste"); Motion to the Riksdag 2011/12:N9 "med anledning av skr. 2011/12:141 Kärnkraft utan statliga subventioner" ("in response to comm. 2011/12:141 Nuclear power without state subsidies") by Lise Nordin et al. (MP); Motion to the Riksdag 2013/14:N334 "Avskaffa Kärnkraftens subventioner" ("Abolish subsidies to nuclear power") by Lise Nordin et al. (MP).
[21] Motion to the Riksdag 1997/98:N6 "med anledning av prop. 1996/97:176 Lag om kärnkraftens avveckling" ("in response to Gov. Bill 1996/97:176 Nuclear Power Phase-Out Act") by Birger Schlaug et al. (MP).
[22] Motion to the Riksdag 1999/2000:N24 "med anledning av prop. 1999/2000:63 Godkännande av avtal om ersättning i samband med stängning av Barsebäcksverket, m.m." ("in response to Gov. Bill 1999/2000:63 Approval of agreement on compensation in conjunction with closure of the Barsebäck plant, etc.") by Birger Schlaug et al. (MP).
[23] Motion to the Riksdag 2001/02:N366 "Energipolitiken" ("Energy policy") by Lotta Nilsson Hedström et al. (MP).

identified. One is that the reactor owners do not pay all their environmental costs, partly because the financing to cover the future costs for managing and disposing of the nuclear waste is not sufficient. The Green Party says that the nuclear power producers should be made to pay their full costs, which, according to the authors means in practice that nuclear power will phase itself out.[24]

In a motion from 2012, the Green Party identifies six subsidies. One of the subsidies is again that the nuclear waste fee is not sufficient but needs to be raised in order for the industry to bear its own costs. The motion criticizes the Government for only having raised the fee to 2.2 öre/kWh, despite the fact that SSM has proposed 3 öre/kWh.[25] A similar motion is presented the following year. In 2013, the authors write that the Nuclear Waste Fund has announced that more than SEK 30 billion is lacking to pay for final disposal of the Swedish nuclear waste. The authors then refer to a calculation done on behalf of Radio Sweden's Science Radio, which showed that the fee should be increased by a factor of five to around 10 öre/kWh in order to cover the deficit in the Nuclear Waste Fund. The Green Party recommends an increase, and reiterates that the failure of nuclear power to pay all the costs for the management of its own waste products clearly amounts to a subsidy.[26]

The Liberal Party presents a motion in 2006 that the fee should be raised. The motion deals with the Government's proposal to raise the fee from 0.15 öre/kWh to 0.2 öre/kWh, which they reject because they say the calculations are based on insufficient data.[27] In a motion regarding the same bill, Åsa Domeij (MP) takes up the need to raise the fee. She says that we cannot know what the costs of safe final disposal will be since we don't know what the final repository will look like. And even the waste is encapsulated in different containers and emplaced in underground rock caverns, it is uncertain how the encapsulated material will react to very long-

[24] Motion to the Riksdag 2001/02:N366 "Energipolitiken" ("Energy policy") by Lotta Nilsson Hedström et al. (MP).
[25] Motion to the Riksdag 2011/12:N9 "med anledning av skr. 2011/12:141 Kärnkraft utan statliga subventioner" ("in response to comm. 2011/12:141 Nuclear power without state subsidies") by Lise Nordin et al. (MP).
[26] Motion to the Riksdag 2013/14:N334 "Avskaffa Kärnkraftens subventioner" ("Abolish subsidies to nuclear power") by Lise Nordin et al. (MP).
[27] Motion to the Riksdag 2005/06:MJ26, "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Lennart Fremling et al. (FP).

lasting radiation. We do, however, know, says Domeij, that all budgets for large infrastructure projects are overrun. It is an open question whether money set aside for nuclear waste disposal will cover all the costs in the end. In view of the fact that all experts say that the electricity price and thereby the margins for nuclear-generated electricity will continue to increase, Domeij says that it is not reasonable for the Nuclear Waste Fund to be underfinanced. The motion therefore propose that the fee for nuclear waste management be raised considerably and that strict payment liability be ensured by making it clear that it is the companies that have to contribute more money if it turns out that the money in the Fund is not enough.[28]

In 2014, the Christian Democrats do not want the fee to be raised. This is in reference to a proposed increase from 2.2 öre/kWh to 4.0 öre/kWh. The reason is that such an increase would entail a higher cost for the reactor owner, but also because it creates uncertainty as to what the fee will be in 2016 and later, since the fee is usually revised every three years, and not as proposed after only one year. Pending a more permanent method for calculating the fee for nuclear waste, the fee should therefore not be increased.[29]

In an interpellation from 2015, Mattias Bäckström Johansson (SD) also questions an increase of the fee to the Nuclear Waste Fund from 2.2 to 4 öre/kWh. It is not the increase as such that Bäckström Johansson criticizes, but the fact that this fee is only levied on nuclear power. Bäckström Johansson says that the same principle should apply on similar grounds "for other production categories and activities".[30]

[28] Motion to the Riksdag 2005/06:MJ24 "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Åsa Domeij (MP).
[29] Motion to the Riksdag 2014/15:1675 "Skatter och avgifter på energiområdet" ("Taxes and charges in the energy sector") by Pernilla Gunther (KD).
[30] Interpellation 2014/15:519 "Kärnkraftens förutsättningar" ("The premises of nuclear power") by Mattias Bäckström Johansson (SD) to Minister Ibrahim Baylan (S).

4.2.4 Disbursements from the Nuclear Waste Fund

A broadening of who can obtain funding from the Nuclear Waste Fund is a recurrent issue in the motions, as well as the interpellations. The Green Party motion from 1995 proposes that municipalities, concerned parties and environmental organizations should get assistance from the Nuclear Waste Fund for competence enhancement.[31]

In a motion from 1999, Saarinen et al. (MP) point out that information on nuclear waste management is furnished by the nuclear power industry itself. In their motion, the authors highlight the imbalance in resources that exists between the nuclear power industry on the one hand and government authorities and environmental organizations on the other. According to the motion, the environmental organizations are supposed to represent the public, and when the environmental organizations cannot do this due to insufficient resources, this is sometimes perceived as obstruction. Giving the municipalities greater resources is discussed as an alternative, but is dismissed because "environmental groups have a wealth of experience of how municipal officials act in these contexts, and the picture is anything but flattering when it comes to allocating resources so that the public has access to both accurate and comprehensive information". Saarinen et al. therefore assert that in order to ensure an EIA process "worth the name," resources must be given to civic groups that are critical of the proffered plans. These civic groups are held up as important bodies possessing vast knowledge that should receive funding from the Nuclear Waste Fund. Local opposition groups should also get support to meet their needs for information and training.[32]

In a motion from 2000, Ingegerd Saarinen (MP) once again points out that the fact that SKB is by far the dominant source of information on the site selection process is a problem. According to Saarinen, SKB has an annual information budget of SEK 20 million. Saarinen says that dissemination of information was not intended

[31] Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).
[32] Motion to the Riksdag 1999/2000:MJ757 "Resurser till alternativgrupper" ("Resources to alternative groups") by Ingegerd Saarinen et al. (MP).

to be a part of SKB's mission from the start, but the Financing Act (1992:1537) was amended to make this possible in 1995. Saarinen questions the propriety of relying on a special-interest company to be the primary source of information in a feasibility study municipality. In its review statement on RD&D 98, the Government demanded that SKB provide comprehensive information, but Saarinen claims that this is not a demand that can be made on a company that represents a special interest. Saarinen says that it should be incumbent on public authorities, municipalities and private organizations to provide information. Other actors than SKB must also be able to contribute to knowledge acquisition and competence enhancement in the nuclear waste issue.[33]

Similar issues are raised in January 2000 in an interpellation by Left Party member Kjell-Erik Karlsson where both the question of Fund disbursements to environmental organizations and the need for comprehensive and objective information are taken up.[34]

In a motion from 2004, the Christian Democrats also take up the need of support to voluntary organizations. The Christian Democrats write that they want to encourage the civic engagement that exists in society and that voluntary organizations are an important part of a democracy. The Christian Democrats are therefore positive to giving financial support to voluntary organizations so that they can participate in the consultation process on nuclear waste. They further assert that it is important that financial support not result in a separate national consultation process parallel to the local one, and that support should therefore be given to local groups and organizations. Local voluntary organizations should be given support by raising the maximum amount that the municipalities can obtain from the Nuclear Waste Fund from SEK 4 to 7 million.[35]

In a motion from 2006, the Liberals are critical to the idea that non-profit organizations should be funded by the fees for final disposal. The Liberals feel that it is important that non-profit orga-

[33] Motion to the Riksdag 2000/01:MJ836 "Kärnavfallspolitik" ("Nuclear waste policy") by Ingegerd Saarinen (MP).
[34] Interpellation 1999/2000:194 by Kjell-Erik Karlsson (V) to Environment Minister Kjell Larsson concerning information and consultation on nuclear waste.
[35] Motion to the Riksdag 2003/04:MJ47 "med anledning av prop. 2003/04:116 Miljöbedömningar av planer och program" ("in response to Gov. Bill 2003/04:116 Environmental assessment of plans and programmes") by Sven Gunnar Persson et al. (KD).

nizations have an opportunity to participate in the review and debate of the design of final disposal, but that these organizations should be supported from public funds.[36]

In a motion from 2004, the Moderates say that non-profit organizations should not be funded via the Nuclear Waste Fund. There are several reasons why non-profit organizations should not receive support from the Nuclear Waste Fund. The authors refer to the fact that a fee is paid into the Fund for the purpose of financing the management and disposal of spent nuclear fuel and certain associated costs. The definition of a fee is that it should be used for a specific purpose, otherwise it is to be regarded as a tax. The Moderates find it doubtful whether information activities on the part of national and municipal authorities regarding final disposal should be financed by the Fund, and believe it should instead be regarded as a public interest that such activities be financed by taxes. Opening up the Fund for other actors and as an indirect organization subsidy would entail that what has previously been a fee is transformed into a tax, according to the motion. The Moderates also say that it is the responsibility of the Swedish Nuclear Power Inspectorate (SKI) to provide correct information, and that it is SKB that should undertake extensive consultation procedures. Allowing non-profit organizations to be a state-subsidized party in the process amounts to a strong dismissal of SKI's and SKB's work. Further, the authors write that if the government authority is dysfunctional, the Government has instruments to correct this.

According to the Moderates' motion, another argument against giving non-profit organizations support from the Fund is that such organizations are entitled under the Environmental Code to appeal decisions on final disposal of spent nuclear fuel. This would mean that one party receives state support to prepare and pursue a court process against the party that pays fees into the Fund. This would not be good, according to the authors, who also say that "state-funded dissemination and acquisition of information should be

[36] Motion to the Riksdag 2005/06:MJ26, "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Lennart Fremling et al. (FP).

neutral". This would not be the case if non-profit organizations were to receive support.[37]

4.2.5 Funding of free research on nuclear waste

In her motion from 2000, Ingegerd Saarinen (MP) says that the Financing Ordinance should be amended so that independent researchers can obtain funding for their research from the Nuclear Waste Fund. The research results would then also be published in scientific articles, whereby the issues would be peer-reviewed by the scientific community, something which she says is lacking in the present-day system.[38] This viewpoint recurs in a motion from 2008 where the Centre Party criticizes the fact that the nuclear power industry has itself had to pay for all research on the final repository and that critical researchers have received few or no research grants. The Centre Party writes that the Government's research minister thinks that research should remain free of political influence, but that nuclear waste research is not free of such influence. Further, the authors write that the industry's nuclear waste research must be supplemented by interdisciplinary research by independent researchers with funding from state research councils. SSM has its own research grant, but it amounts to only SEK 40 million and therefore doesn't cover a fraction of the research that would be needed. The Centre Party therefore wants to establish a new research programme under some national research council and gives Vinnova as an example. The funds should be taken from the Nuclear Waste Fund and the programme should be started as soon as possible.[39]

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[37] Motion to the Riksdag 2003/04:MJ48 "med anledning av prop. 2003/04:116 Miljöbedömningar av planer och program" ("in response to Gov. Bill 2003/04:116 Environmental assessment of plans and programmes") by Catharina Elmsäter-Svärd et al. (M).

[38] Motion to the Riksdag 2000/01:MJ836 "Kärnavfallspolitik" ("Nuclear waste policy") by Ingegerd Saarinen (MP).

[39] Motion to the Riksdag 2008/09:Fö218 "Forskning om svenskt kärnkraftsavfall" ("Research on Swedish nuclear power waste") by Eva Selin Lindgren and Sven Bergström (C).

4.2.6 Summarizing discussion

The high cost of decommissioning and dismantling of reactors, and of management and disposal of the spent nuclear fuel, is a challenge to handle politically. Many issues have been brought up in the motions, but few answers have been given. There are many questions, not least when it comes to how the costs are to be estimated, since we are dealing with a unique project where the time frames are unclear. It is therefore assumed that the questions will remain unanswered for a long time to come.

An issue that has attracted increasing attention has concerned the size of the costs of future decommissioning of the nuclear power reactors. A closely related question concerns how big the fee to the Nuclear Waste Fund should be. If the former question is technical-economic in nature (depending on legal and political decisions regarding the design of the repository), the latter is mainly political, since more factors can be weighed in and since different financing systems can be considered. Those who want to raise the fees focus on the importance of ensuring that enough money will be available when the time comes, even though the costs are difficult to estimate since a decision has not yet been made on the choice of method. Those who want to keep the existing fee and not raise it justify their standpoint by saying that they do not want to burden nuclear-generated electricity with more costs, which would make it less competitive.

On the other hand, no-one has directly questioned the principle that it is the reactor owners who should pay the costs incurred by the waste. The Liberal Party thought it is impractical that the companies are liable for the costs, since the final date when the repository will be sealed is not known, and this is extra problematic for small enterprises.

Who is entitled to apply for funds from the Nuclear Waste Fund, and for what purposes, is also a controversial issue. Some say that non-profit organizations should get funding since they are an important counterforce to both SKB and the site selection municipalities and can provide a more objective perspective. The idea that non-profit organizations are more objective is, however, contradicted by others who see even these organizations as special interests that are expected to appeal the decision on the final repository. Another viewpoint that is offered is that non-profit organizations should not be supported by the Fund, but by taxes. In this question, however, a new financing procedure for NGOs[40] has been established during the years covered by the study, which has dampened the debate on the issue. The Swedish EPA's appropriation direction for 2017 has instructed them to distribute up to SEK 2,500,000 to non-profit environmental organizations to support their activities in connection with issues related to the final disposal of nuclear fuel. It is possible that this will lead to new debates on the matter.

Criticism has been levelled at the fact that money from the Fund is used to provide information to the public, since such activities should be paid for by taxes. One motion has raised the question of whether the Nuclear Waste Fund should be used to fund free research and be distributed via research councils such as Vinnova and Formas.

How the paid-in fees are invested has been a subject of discussion, with some recommend they be deposited with the National Debt Office while others want it to be possible to invest the fees in equities.

The table below shows which issues have been raised by which party and during which parliamentary year.

[40] NGO = Non-governmental organization.

Parliamentary year	Issue	Party
1992/93; 1994/95; 1995/96; 1996/97; 2004/05; 2005/06; 2011/12; 2013/14	The fee to the Fund should increase	without party designation, MP
1995/96	Difficult to estimate costs for decommissioning of nuclear power plants	MP
1995/96	Municipalities, concerned parties and environmental organizations should get funding from the Nuclear Waste Fund	MP
1995/96	The Nuclear Waste Fund's financing model with guarantees instead of payment to the Fund	C, MP
1995/96; 1997/1998	Criticism of Nuclear Waste Fund's financing model, using e.g. hydropower as security	C
1995/96; 1996/97; 1997/1998	Criticism of depositing Nuclear Waste Fund's assets with the National Debt Office	C, KD, M
1995/96; 1996/97	Real interest rate should be set at 0%	MP
1996/97; 1997/1998	Nuclear Waste Fund's financing model leads to reduced payments to the Fund	C
1999/2000; 2000/01, 2003/04	Civic groups, environmental organizations and opposition groups should receive subsidies from the Nuclear Waste Fund for information and training	MP, V, KD
2000/01; 2008/09	Free research should receive funding from the Nuclear Waste Fund	MP, C
2003/04; 2005/06	Non-profit organizations should not get money from the Nuclear Waste Fund	M, FP
2005/06; 2014/15	The fee to the Fund should not increase	FP, KD, SD
2005/06	Possibility to transfer fee liability for the waste to another entity	FP
2016/17	Investigate importance of changed operating times for the Fund	KD

4.3 Retrievability

Retrievability has to do with giving future generations the technical option of retrieving the waste if they decide to do so.[41] The Council's State-of-the-Art Report 2010 deals with retrievability in a separate chapter. There it is observed that the question has been debated back and forth. The climate issue is sometimes used as an argument that nuclear power should continue to play a role in the energy mix, and new reactor technology offers potential for reusing spent nuclear fuel.[42] Public opinion in Sweden has varied over the years, but since 2010 it has become less positive to retrievability.[43]

During the 1990s, interest in retrievability declined due to the fact that the Swedish Nuclear Power Inspectorate increasingly emphasized safety as the most important factor. At that time, SKB switched from using the term "deep repository" to calling it a "final repository". Interest in retrievability revived at the end of the 1990s when the IAEA and the OECD assumed a more positive attitude. However, the Swedish National Council for Nuclear Waste concludes in the 2010 state-of-the-art report that the issue of retrievability has played a marginal role in the final repository project.[44]

In 2013 the Council conducted a structured interview with the members of the Riksdag. One question had to do with how they viewed retrievability of spent nuclear fuel. Slightly more than half of the 200 MPs who responded said that the final repository should be designed to permit the option of retrieval of the nuclear waste.[45] The reasons for their answer are not given in the survey.

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[41] See Söderberg, O. 2002. *På väg mot geologisk slutförvaring av radioaktivt avfall: Omvändbarhet och återtagbarhet.* ("Towards geological disposal of radioactive waste: Reversibility and retrievability," in Swedish). An international discussion of the possibilities of going back one or more steps in the deposition process, for a survey of different perspectives on retrievability and reversibility. The Swedish National Council for Nuclear Waste (formerly called KASAM) concluded in 1998 that a final repository: "should be designed so that it makes controls and corrective measures unnecessary, while at the same time not making controls and corrective measures impossible." KASAM. 1998. SOU 1998:68 *Nuclear Waste State-of-the-Art Report 1998*, p. 13.

[42] See also the chapter "A new generation of nuclear reactors?" in this report.

[43] Swedish National Council for Nuclear Waste. 2010. SOU 2010:6 *Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme*; http://som.gu.se/digitalAssets/1593/1593613_svenska-trender-2015.pdf (downloaded 31 Jan. 2017).

[44] Swedish National Council for Nuclear Waste. SOU 2010:6.

[45] Palm, J. 2014. 2014. *Kunskapsläget hos Sveriges Riksdagsledamöter om kärnavfall och dess slutförvar* ("State of knowledge of Swedish MPs regarding nuclear waste and its final disposal," in Swedish). See under "publikationer" at www.karnavfallsradet.se.

Below we will discuss how retrievability has been debated in the Riksdag based on our search (with interest limited to motions, interpellations and written questions). The search terms "kärnavfall" ("nuclear waste") and "återtagbarhet" ("retrieval") get 17 hits, including 1 committee report and statement, 1 record of chamber proceedings, 3 motions and 12 Swedish Government Official Reports. Since there were so few hits on these search terms, we took a closer look at what arguments were presented in the committee report, the record of chamber proceedings and the motions. In the record of chamber proceedings, only retrievability was mentioned and no arguments were presented. We also tried different combinations of search terms, but few gave hits. An account is given below of the contents of the motions and the committee report.

4.3.1 Conflicting performance requirements and deep boreholes as an alternative

One motion in 2000 by Kjell-Erik Karlsson et al. (V)[46] has to do with several issues in relation to nuclear waste, but only retrievability is dealt with here. Retrievability is linked here to choice of method and performance criteria. The authors say that before a method can be chosen for a final repository for spent nuclear fuel, the performance criteria for the final repository must first be stipulated (by whom is unclear, but presumably by SKB). According to the authors, the trade-offs that must be made between conflicting performance criteria in choosing a method must be discussed openly. The authors mention the three performance criteria that have so far been discussed and defined:

1. No post-closure monitoring: The repository shall not require monitoring or maintenance to function properly, which means that waste must be inaccessible to protect against undesirable and inadvertent intrusion.
2. Retrievability: The repository shall be designed so that the waste can be retrieved if future generations should wish to repair or improve the repository or use the fissionable material.

[46] Motion to the Riksdag 2000/01:MJ787 "Hantering av kärnavfall" ("Management of nuclear waste") by Karlsson, Kjell-Erik (V).

3. Inaccessibility: The repository shall be designed so that retrieval of the waste can be interrupted quickly if future generations find that the risks of retrievability are greater than the benefits.

Karlsson et al. conclude that even a layman can see that there are conflicts between the requirements of inaccessibility and retrievability. They go on to say that the KBS-3 method can only compete with disposal in deep boreholes “if and when retrieval is given priority over performance criteria 1 and 3”. According to the authors, this is because disposal in deep boreholes satisfies the requirements of inaccessibility and no post-closure monitoring, while KBS-3 better satisfies the requirement of retrievability. The choice between deep boreholes and KBS-3 is therefore dependent on which trade-off society wishes to make between different performance criteria. The authors therefore find it difficult to accept that the KBS-3 method is the only method being considered and would like to have a better basis for comparison with other methods.

Another motion from the same year comes from Ingegerd Saarinen (MP)[47] and also concerns several aspects of the nuclear waste issue. The two motions are very similar in their argumentation. In relation to retrievability, this motion also focuses on the conflicting performance requirements. The motion mentions the same three performance requirements: no post-closure monitoring, inaccessibility and retrievability of the waste. Saarinen would like to see an open discussion of the trade-offs that must be made if the performance criteria conflict with each other (by whom is not specified, but presumably by SKB). Saarinen also asserts that there is an obvious conflict between the requirements of inaccessibility and retrievability. She also stresses that society must prioritize, but she says, in contrast with the Left Party’s motion, that the best way to prioritize is by a continuation of the DIALOG project. The DIALOG project was conducted by SKI in the early 1990s and the purpose, according to the motion, was to devise a decision-making process in the nuclear waste issue in which all parties had confidence. Regulatory authorities, environmental organizations and municipal representatives participated in the DIALOG project, but not SKB.

[47] Motion to the Riksdag 2000/01:MJ836 “Kärnavfallspolitik” (“Nuclear waste policy”) by Saarinen, Ingegerd (MP).

The motion also discusses the fact that how well the KBS-3 method stands up in comparison with other methods depends on what trade-offs society makes between different performance criteria. The motion also says that KBS-3 can only match deep boreholes if inaccessibility is given priority over no post-closure monitoring and retrievability. The author also says that on the surface, retrievability can be regarded as a safety valve. At the same time, Saarinen says there it is also a question of personal values, where some people think the most important thing is to protect future generations from the spent nuclear fuel, while others think that freedom of choice is more important and that future generations must be given a chance to use the spent nuclear fuel as a resource. Saarinen also goes on to write that:

> … it is very important that the different performance criteria are ranked in order of priority before beginning the site selection process. The performance criteria will determine the choice of method, and the choice of method will in turn determine such factors as repository depth and choice of host rock.[48]

The author of the motion then stresses again that the conclusions of the DIALOG serve as a basis for the continued process, and that performance criteria similar to the three mentioned above should be formulated for choice of method and site selection.

Both the motions were rejected, and the Environment and Agriculture Committee’s report 2000/01 noted that deep boreholes has been studied by SKB and that the study has been referred for consultation. The Committee recommends that no action be taken on the request in both motions for further clarification of the conflicting performance criteria. The Left Party and the Green Party register a dissenting opinion. In a special statement, Åke Sandström (C) writes that there is no safe method for how and where long-term disposal of the spent nuclear fuel can be achieved. Sandström goes on to say that agreement is lacking as to whether KBS-3 is to be regarded as a final repository or a deep repository with the option of retrieval. However, Sandström’s conclusion does not concern the issue of retrievability, but rather a phase-out of nuclear power.

[48] Motion to the Riksdag 2000/01:MJ836 “Kärnavfallspolitik” (“Nuclear waste policy”) by Saarinen, Ingegerd (MP).

The concluding motion is from 2006 and is written by Per Bolund and Tina Ehn (MP) and is concerned solely with deep boreholes. In this motion, the authors want the Government to commission an investigation of deep boreholes as an alternative disposal method. They recommend that SKI and SSI should themselves investigate alternative methods.[49] One of the arguments for investigating deep boreholes is that deep boreholes would make it more difficult to retrieve the waste, since it would require much more advanced technology than the KBS-3 method. This motion was also rejected. The Defence Committee's report does not take up retrievability; the motion is rejected for the reason that SKB has sole responsibility to investigate this matter.[50]

4.3.2 Summarizing discussion

As we can see above, the principle of retrievability has slightly different dimensions. One dimension is that it should be possible to retrieve the waste in the event future generations want to modify or repair the final repository. Another dimension is that the waste should be retrievable to enable the fissionable material to be used. The criterion of inaccessibility and the criterion of retrievability both entail that the waste should not be permanently disposed of, but should be retrievable. However, the criterion of retrievability entails designing the repository so that the waste can be permanently disposed of if future generations so desire.

Two of the motions discuss these three criteria, but do not express any direct preference as to how the criteria should be ranked. What all motions instead want to demonstrate is that deep boreholes should be further investigated by SKB, since deep boreholes is considered to be a method that makes it more difficult to retrieve the waste (which indicates a preferred ranking of priorities on the part of the authors).

In the Swedish National Council for Nuclear Waste's interview survey in 2013, it was found that approximately half of Sweden's MPs want to have a repository with retrievability. SKB's proposal

[49] Motion to the Riksdag 2006/07:Fö234 "Alternativa metoder för lagring av radioaktivt avfall" ("Alternative methods for storage of radioactive waste") by Per Bolund and Tina Ehn (MP).
[50] Defence committee report 2006/07:FöU5.

to use the KBS-3 method for a final repository is aimed at making retrievability possible. However, half of the MPs do not want the waste to be retrievable, which should occasion a discussion of the question.

The table below shows which issues have been raised by which party and during which parliamentary year.

Parliamentary year	Issue	Party
2000/01	Choice of final disposal method depends on ranking of performance criteria in order of priority	V, MP
2000/01; 2006/07	KBS should be compared with deep boreholes	V, MP
2000/01	Priority ranking of performance criteria should be done via DIALOG project	MP

4.4 Concluding reflections – financing and retrievability

In this chapter we have discussed two issues that can be expected to lead to further debate and politicization, despite their complexity.

A final repository for spent nuclear fuel entails great costs. This poses a great challenge in estimating how much money today's generation should set aside so that future generations will not have to pay for the waste now being generated by nuclear power. The size of the fee to the Nuclear Waste Fund will presumably continue to be a subject of debate, and given the different opinions that have been expressed it is possible that the issue will become even more topical when the final repository is reviewed by the Government in the near future. What the assets in the Nuclear Waste Fund are to be used for is also a political question that requires constant reconsideration. Arguments have been offered both for and against the proposition that the Nuclear Waste Fund should fund information activities and free research. In this respect, the present-day decision-making process is really nothing new.

The question of retrievability has not been on the Riksdag's agenda for the past ten years. Forsling writes that at the time of the national referendum in 1980, the idea that the waste should be reprocessed was abandoned, since a functioning system for partitioning and transmutation (P&T) was far from developed, and even if such a system existed, a final repository would nonetheless be needed for the waste remaining after P&T. Retrieval is not discussed as an alternative in SKB's application to build a final repository. The Swedish National Council for Nuclear Waste commented on this in its consultation response to the Land and Environment Court in 2012.[51] SKB writes in its reply to the consultation response that SKB does not consider it to be economically defensible "or otherwise appropriate" to reprocess nuclear fuel in new plants. At the same time, SKB has concluded that if Sweden wants to invest in advanced nuclear power in the future, there will be a surplus of plutonium in existing spent fuel for starting new reactors. This means that there will be a quantity of spent nuclear fuel that needs to be disposed of. However, we saw in our interview survey with Swedish MPs that half thought that the final repository should be designed so that retrieval of the nuclear waste is possible. This is indicates that the issue will also continue to be of political interest. On the other side of the coin is the principle of inaccessibility, which at least in the motions described above is considered to be incompatible with the retrievability allowed by KBS-3. Neither the MP survey nor the Riksdag material we have presented here shows whether this incompatibility is still considered to exist. It remains to be seen whether this issue will be resurrected during the ongoing decision-making process, and if so whether this will lead to increased politicization.

As we pointed out above, politicization is a natural and important aspect of the democratic debate, but it is also important to achieve consensus in matters of a long-term nature. This can be achieved in different ways, for example via parliamentary committees that agree on largest common denominators, i.e. that manage to find as much common ground as possible. Public authorities can also play a role in identifying solutions that gain broad acceptance, which the Swedish National Council for Nuclear Waste intends to do. At the end of the day, these political challenges will be dealt with in the statutory processes that control decision-making and that rest on a stable democratic foundation.

[51] Swedish National Council for Nuclear Waste. 2012. *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).

Appendix 1. Table showing number of hits and parliamentary year

Parliamentary year	Number of hits	Parliamentary year	Number of hits
2017/18	1	1995/96	23
2016/17	57	1994/95	38
2015/16	21	1993/94	15
2014/15	20	1992/93	17
2013/14	17	1991/92	13
2012/13	13	1990/91	17
2011/12	53	1989/90	21
2010/11	58	1988/89	27
2009/10	37	1987/88	10
2008/09	98	1986/87	18
2007/08	20	1985/86	10
2006/07	12	1984/85	12
2005/06	80	1983/84	10
2004/05	47	1982/83	3
2003/04	26	1981/82	1
2002/03	28	1980/81	1
2001/02	26	1979/80	3
2000/01	35	1978/79	4
1999/2000	51	1977/78	1
1998/99	33	1976/77	1
1997/98	52	1975	2
1996/97	36	1974	1

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Defence committee report 2006/07:FöU5 *Kärnteknisk säkerhet och strålskydd* ("Nuclear safety and radiation protection," in Swedish.

http://som.gu.se/digitalAssets/1593/1593613_svenska-trender-2015.pdf (downloaded 31 Jan. 2017).

Interpellation 2014/15:519 "Kärnkraftens förutsättningar" ("The premises of nuclear power," in Swedish) by Mattias Bäckström Johansson (SD) to Minister Ibrahim Baylan (S).

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Motion to the Riksdag 2014/15:1675 "Skatter och avgifter på energiområdet" ("Taxes and charges in the energy sector") by Pernilla Gunther (KD).

Motion to the Riksdag 2013/14:N334 "Avskaffa Kärnkraftens subventioner" ("Abolish subsidies to nuclear power") by Lise Nordin et al. (MP).

Motion to the Riksdag 2011/12:N9 "med anledning av skr. 2011/12:141 Kärnkraft utan statliga subventioner" ("in response to comm. 2011/12:141 Nuclear power without state subsidies") by Lise Nordin et al. (MP).

Motion to the Riksdag 2008/09:Fö218 "Forskning om svenskt kärnkraftsavfall" ("Research on Swedish nuclear power waste") by Eva Selin Lindgren and Sven Bergström (C).

Motion to the Riksdag 2006/07:Fö234 "Alternativa metoder för lagring av radioaktivt avfall" ("Alternative methods for storage of radioactive waste") by Per Bolund and Tina Ehn (MP).

Motion to the Riksdag 2005/06:MJ24 "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Åsa Domeij (MP).

Motion to the Riksdag 2005/06:MJ26, "med anledning av prop. 2005/06:183 Finansieringen av kärnavfallets slutförvaring" ("in response to Gov. Bill 2005/06:183 Financing of the final disposal of nuclear waste") by Lennart Fremling et al. (FP).

Motion to the Riksdag 2004/05:MJ38 "med anledning av prop. 2004/05:150 Svenska miljömål – ett gemensamt uppdrag" ("in response to Gov. Bill 2004/05:150 Swedish environmental objectives – a joint mission") by Åsa Domeij et al. (MP).

Motion to the Riksdag 2003/04:MJ47 "med anledning av prop. 2003/04:116 Miljöbedömningar av planer och program" ("in response to Gov. Bill 2003/04:116 Environmental assessment of plans and programmes") by Sven Gunnar Persson et al. (KD).

Motion to the Riksdag 2003/04:MJ48 "med anledning av prop. 2003/04:116 Miljöbedömningar av planer och program" ("in response to Gov. Bill 2003/04:116 Environmental assessment of plans and programmes") by Catharina Elmsäter-Svärd et al. (M).

Motion to the Riksdag 2001/02:N366 "Energipolitiken" ("Energy policy") by Lotta Nilsson Hedström et al. (MP).

Motion to the Riksdag 2000/01:MJ787 "Hantering av kärnavfall" ("Management of nuclear waste") by Karlsson, Kjell-Erik (V).

Motion to the Riksdag 2000/01:MJ836 "Kärnavfallspolitik" ("Nuclear waste policy") by Ingegerd Saarinen (MP).

Motion to the Riksdag 1999/2000:MJ757 "Resurser till alternativgrupper" ("Resources to alternative groups") by Ingegerd Saarinen et al. (MP).

Motion to the Riksdag 1999/2000:N24 "med anledning av prop. 1999/2000:63 Godkännande av avtal om ersättning i samband med stängning av Barsebäcksverket, m.m." ("in response to Gov. Bill 1999/2000:63 Approval of agreement on compensation in conjunction with closure of the Barsebäck plant, etc.") by Birger Schlaug et al. (MP).

Motion to the Riksdag 1997/98:N6 "med anledning av prop. 1996/97:176 Lag om kärnkraftens avveckling" ("in response to Gov. Bill 1996/97:176 Nuclear Power Phase-Out Act") by Birger Schlaug et al. (MP).

Motion to the Riksdag 1996/97:Jo768 "Kärnavfall" ("Nuclear waste") by Eva Goës et al. (MP).

Motion to the Riksdag 1996/97:Jo784 och 1997/98:N260 "Finansiering av kärnkraftens avvecklingskostnader" ("Financing of the decommissioning costs of nuclear power") by Roland Larsson (C).

Motion to the Riksdag 1995/96:N11 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Dan Ericsson (KDS).

Motion to the Riksdag 1995/96/11:N12 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Karin Falkmer et al. (M).

Motion to the Riksdag 1995/96/11:N13 "med anledning av prop. 1995/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Birger Schlaug et al. (MP).

Motion to the Riksdag 1995/96:N14 "med anledning av prop. 11/96:83 Säkrare finansiering av framtida kärnavfallskostnader m.m." ("in response to Gov. Bill 1995/96:83 More reliable financing of future nuclear waste costs etc.") by Lennart Brunander et al. (C).

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SKB. 2015. Supplement III – March 2015. "Appendix K:2 Ämnesvisa svar på kompletteringsönskemålen" ("Discipline-specific responses to requests for supplementary information ") in *Ansökan om tillstånd enligt miljöbalken (1998:808) till anläggningar i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavfall* ("Application for a permit under the Environmental Code (1998:808) for facilities in an integral system for final disposal of spent nuclear fuel and nuclear waste". Stockholm: Svensk Kärnbränslehantering AB.

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5 A new generation of nuclear reactors?

5.1 Introduction

Swedish nuclear power plants, which are all light water reactors, use only uranium as nuclear fuel. Uranium consists of two isotope, uranium-235 and uranium-238, of which only uranium-235 is fissile and can thereby be used for energy production in light water reactors. In order for uranium to be used as nuclear fuel in light water reactors, the concentration of the uranium-235 isotope must be enriched from 0.7 to 2–4 percent. The uranium-238 in nuclear fuel can also capture neutrons and form uranium-239, which is transformed relatively quickly by two beta decays to the fissile isotope plutonium-239. About 30 percent of the total energy produced in the Swedish light water reactors comes from fission of other nuclei than uranium-235 that are formed in the reactors during operation, mainly plutonium-239. Nevertheless, only a very small fraction of the theoretical energy content of the nuclear fuel is utilized for energy production before the fuel either has to be reprocessed or, as in Sweden, kept isolated from the biosphere for a very long time, at least 100,000 years. It has therefore long been a long-term goal of the nuclear power industry to develop technology where new fissile nuclear fuel is generated during energy production (Gen IV systems). The following text describes the state-of-the-art in the field, with a focus on technical challenges. Issues related to risks and safety are for the most part left out of the discussion, but may of course pose significant challenges and problems.

5.2 International trends

The world market price of uranium has varied widely during the past 10 years, with a clearly discernible falling trend. Ten years ago the price was USD 1.25/kg of U_3O_8, but fell to USD 0.40/kg U_3O_8 two years later. Since then the commodity price of uranium has been more stable, but has nevertheless declined gradually to about USD 0.20/kg U_3O_8 in December 2016. This indicates that the supply of uranium is plentiful at present. The countries that produce the most uranium are Kazakhstan (39.3 percent of world production), Canada (22.0 percent), Australia (9.4 percent), Niger (6.8 percent), Russia (5.0 percent) and Namibia (4.9 percent) (2015 production figures).[1]

When it comes to the use of nuclear power technology today and projected future use, the picture is very different in different parts of the world. There is a clear trend in Western Europe, with the exception of France, towards phasing out or reducing nuclear power production, while new nuclear power plants are under construction in Asia (particularly China and India), Russia, several former Soviet republics and the USA and more are in the planning stage.[2] All reactors currently being built are of conventional design, and most are pressurized water reactors.[3]

5.3 Transmutation

Transmutation is the transformation of one element or isotope into another element or isotope. This is brought about either by nuclear reactions when the element is irradiated with high-energy particles that react with its atomic nucleus, for example in a nuclear power plant, or by spontaneous radioactive decay. Nowadays transmutation can be achieved by the use of particle accelerators, but this produces extremely minute quantities of the desired element. Transmutations also occur in nuclear power plants, such as those in Sweden, for example when uranium is split (undergoes fission) and

[1] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx (downloaded 15 Dec. 2016).
[2] IAEA. 2015. Nuclear Power Reactors in the World.
[3] http://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-archive/reactor-archive-june-2016.aspx (downloaded 15 Dec. 2016).

the elements barium and krypton are formed, or when uranium-238 is transformed into plutonium-239. Small nuclear reactors can be used to produce neutrons for transmutation purposes, such as for the production of radioactive isotopes for research and clinical diagnostics. Transmutation has been dealt with in previous state-of-the-art reports as regards the fundamental principles,[4] a research update,[5] recycling of nuclear fuel[6] and future Generation IV systems.[7] Transmutation of by-products that are formed in e.g. water-cooled nuclear power plants and that decay very slowly (long-lived isotopes) – such as plutonium, neptunium, americium and curium – could shorten the length of time the spent nuclear fuel needs to be safely isolated. Besides having high radioactivity, these elements are extremely toxic and must for this reason be handled with extreme caution. Spent nuclear fuel from a light water reactor contains about 1 weight percent plutonium, and about 0.1 weight percent each of neptunium, americium and curium.[8] When such elements are irradiated with fast neutrons in a nuclear reactor, they can undergo fission so that the original element is split into lighter elements that are either stable or have a shorter half-life than the original radioactive elements. This could therefore be a way to reduce the waste volume that needs to be kept in a geological repository and the length of time the waste needs to be safety isolated from the biosphere.

5.4 Generation IV systems

In order to better utilize the energy content of uranium and reduce the length of time until the waste can be considered harmless, i.e. when the radiation emitted by the waste is of the same order of

[4] KASAM (Swedish National Council for Nuclear Waste). 2004. SOU 2004:67 *Nuclear Waste State-of-the-Art Report 2004 – Section III The Nuclear Waste Issue and the Future.*
[5] Swedish National Council for Nuclear Waste. SOU 2011:14 *Nuclear Waste State-of-the-Art Report 2011 – geology, barriers, alternatives*, Chap. 4.2.2.
[6] Swedish National Council for Nuclear Waste. SOU 2013:11 *Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures*, Chap. 4.
[7] Swedish National Council for Nuclear Waste. SOU 2014:11 *Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making*, Chap. 4.
[8] Westlén, D. 2016. "Fjärde generationens kärnkraft – Teknik, möjligheter och förutsättningar." ("Fourth generation of nuclear power – Technology, potential and premises," in Swedish). Energiforsk AB. See: https://energiforskmedia.blob.core.windows.net/media/21817/fjarde-generationens-karnkraft-energiforskrapport-2016-317.pdf (downloaded 15 Dec. 2016).

magnitude as the natural radiation level, a concept for nuclear power production known as Generation IV systems (Gen IV systems) has been developed. This system includes:

- a reactor where fission occurs with fast neutrons, so-called breeder reactors, even though other concepts with thermal or epithermal neutrons exist,
- a plant that separates (partitions) the useful isotopes in the spent fuel from the remaining waste, and
- a plant that fabricates new fuel from the recovered elements.

With a breeder reactor, it is theoretically possible to extract many times more energy from natural uranium than with today's water-cooled nuclear reactors. However, a breeder reactor requires that the fuel to be used has first been reprocessed and contains some plutonium. Furthermore, the spent fuel from a breeder reactor must be reprocessed before it can be reused. The three parts of the Gen IV system are often developed independently of each other, but all are necessary parts for a Gen IV system to work as a whole.

A breeder reactor generates new fuel and is called fast because the neutrons that split the atomic nuclei have a higher energy than in water-cooled nuclear power reactors. This means that water cannot be used as a coolant, so liquid sodium or lead are used instead. The reason is that water slows down the neutrons too much, so other liquid coolants that do not slow down the fast neutrons as much must be used. These coolants are much more chemically reactive than water and can cause great damage in the event of a leak. It is estimated that uranium yields 70 times more energy in a breeder reactor than in a conventional nuclear reactor if the fuel rods in the breeder reactor consist of a mixture plutonium and uranium, e.g. 15 percent plutonium and 85 percent uranium, in oxide form. The idea is that plutonium, which does not exist in nature but is created in a nuclear reactor, is recovered from the spent fuel from these reactors by reprocessing. It is also possible in breeder reactors to transform thorium – which only has one natural isotope, thorium-232 – to uranium-233, which has a fissile nucleus.

Nuclear reactors that use fast neutrons were developed more than 60 years ago, and the first reactor that delivered electricity to the grid was EBR-I (Experimental Breeder Reactor I) in the USA, which started in in 1951.[9] The probability of fission, known as the capture cross section, is greater with slow neutrons than with fast neutrons, but only a few isotopes can undergo fission, such as uranium-235, uranium-233 and plutonium-239. With fast neutrons, many more elements can undergo fission, which means that the heavy elements that are built up in an ordinary nuclear reactor, and which are the reason such a long storage time is required for the spent fuel to decay to harmless levels, can also be split. This permits both better utilization of the energy content in the nuclear fuel and a shorter isolation time for the waste. However, this cannot be accomplished in a single step; the fuel must be removed from the reactor and the useful fractions used to make new fuel.[10] [11]

The knowledge of how to separate uranium and plutonium from each other on an industrial scale (partitioning) has existed for 70 years. In order for a Gen IV system to work, neptunium, americium and curium must also be separated from each other to be used in new fuel. Furthermore, in view of the Non-Proliferation Treaty, it is widely considered unacceptable to have a separate plutonium stream. For this reason, the research on partitioning in Europe today is focused on GANEX (Grouped Actinide EXtraction) processes where uranium, plutonium, neptunium, americium and curium are separated together. This must be done in a safe manner with chemical systems that do not leave any significant quantities of secondary waste.

The nuclear fuel used to date has mainly been MOX (Mixed OXides) fuel, which consists of uranium and plutonium oxides. For the new Gen IV system that is under development, completely new fuel types are being investigated such as nitrides, carbides and inert matrix fuels. These fuels are much more efficient than MOX but are not being fabricated industrially today.

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[9] American Nuclear Society Nuclear news. November 2001. See: http://www2.ans.org/pubs/magazines/nn/docs/2001-11-2.pdf (downloaded 15 Dec. 2016).
[10] Swedish National Council for Nuclear Waste. SOU 2013:11e, Chap. 4.
[11] Westlén, D. 2016. "Fjärde generationens kärnkraft – Teknik, möjligheter och förutsättningar." ("Fourth generation of nuclear power – Technology, potential and premises," in Swedish". Energiforsk AB. See: https://energiforskmedia.blob.core.windows.net/media/21817/fjarde-generationens-karnkraft-energiforskrapport-2016-317.pdf (downloaded 15 Dec. 2016).

5.5 International research on partitioning and transmutation and fast reactors

Research on fast nuclear reactors is being conducted in a number of places in the world, such as Russia, France, China and India. It is technically much more advanced to operate fast reactors than the water-cooled thermal reactors that are in use today. Research and development on fast nuclear reactors is extremely expensive, and only big countries or groups of countries have the means to conduct this type of research. At the same time, research must also be conducted on reprocessing of nuclear waste from both conventional and fast reactors in order to obtain suitable nuclear fuel for the fast reactors. The fact that the projects are conducted at all is due to the huge gains in the form of much better utilization of the energy content of the uranium, and possibly also to be able to use thorium as nuclear fuel, plus the fact that fast reactors are expected to generate smaller volumes of nuclear waste requiring safe isolation for shorter times than today's nuclear waste. Virtually all projects have been plagued by serious technical and safety-related problems.[12] Some projects have been put on ice, for example in Japan, or undergone great changes, such as in France.

France has a long-range plan to continue the research and development work on fast nuclear reactors and Gen IV systems. At present they are pursuing the ASTRID project, an experimental reactor that will be built at Marcoule in southern France.[13] ASTRID will be a successor to the Phénix and Superphénix experimental reactors that were both taken out of service in the late 1990s after more than 10 years of operation. The Swedish Research Council has a bilateral agreement with France to enable Swedish-French research projects to be conducted where Swedish researchers will have access to the French research infrastructure in e.g. nuclear technology. Japan plans to collaborate with France in the ASTRID project instead of pursuing its own project. The goal is that the ASTRID reactor should be in commercial operation in around 2040.

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[12] Green, J. *Nuclear Monitor* 831, 2016, pp. 1–5.

[13] CEA. 2012. *Report on Sustainable Radioactive Waste Management*. See: http://www.cea.fr/english/Documents/corporate-publications/report-sustainable-radioactive-waste-management.pdf (downloaded 15 Dec. 2016).

The most successful demonstration plants have been or are in the Soviet Union/Russia, which built its first fast nuclear reactor in 1955, followed by the BN-350 reactor in 1973 in present-day Kazakhstan. The BN-600 reactor has been in operation since 1986, but it uses only highly enriched uranium as nuclear fuel, and since it does not produce more fissionable material than it uses it cannot be regarded as a Gen IV nuclear reactor. The latest reactor, BN-800, began to be planned in 1983, reached criticality in 2014 and was connected to the electricity grid at the end of 2015. The Russian demonstration plants have experienced a number of incidents that have disrupted operation for shorter or longer periods.

5.6 Research activities in Sweden

Sweden has good expertise in the different parts of the Gen IV system, with research programmes at Chalmers, KTH and Uppsala University that provide a good basis for Swedish participation in Gen IV projects. Complementary research is being conducted at the three higher education institutions with only small overlaps and with high quality by international standards. Chalmers is conducting chemical research on partitioning processes and fabrication of new types of nuclear fuel. KTH is working actively on reactor design and conducting research on uranium-based fuels, although mainly for thermal reactors. The research in Uppsala is focused mainly on safeguards, involving development of methods for detecting radioactive material and methods for checking how radionuclides are distributed in a process so that proliferation of nuclear materials can be prevented.

5.7 Conclusions

The development of fast nuclear reactors, permitting transmutation of spent nuclear fuel on a large scale in a Gen IV system, is proceeding very slowly. The technical difficulties appear daunting and the development costs huge. It is uncertain whether the Gen IV system will become a reality in the present century. The countries that are particularly active in this area today are Russia, France, India and China. The thermal reactors in use today, which are moderated with ordinary or heavy water, will continue to dominate for the next 50 years.[14] This means that transmutation will not be a general method for reducing the volume of nuclear waste or reducing the time the waste has to be kept isolated from the biosphere in the foreseeable future.

[14] MIT. 2011. *The Future of the Nuclear Fuel Cycle.* Se: https://energy.mit.edu/wp-content/uploads/2011/04/MITEI-The-Future-of-the-Nuclear-Fuel-Cycle.pdf (downloaded 15 Dec. 2016).

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Green, J. 2016. "The slow death of fast reactors". *Nuclear Monitor* 831, pp. 1–5.

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Swedish National Council for Nuclear Waste. 2014. 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.

Swedish National Council for Nuclear Waste. 2013. 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.

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See: https://energiforskmedia.blob.core.windows.net/media/ 21817/ fjarde-generationens-karnkraft-energiforskrapport-2016-317.pdf (downloaded 15 Dec. 2016).

6 Organization for a century of challenges

6.1 Introduction

The industrial organization for the final repository for spent nuclear fuel (the final repository) has to work with extreme time perspectives. The organization has to build and operate a final repository in the space of *a century*, which means that the end result of the project – a closed repository – will be the fruit of the efforts of 3–4 generations. The end product has to function for at least *100,000 years*, i.e. the repository has to protect the surrounding environment from the radioactive fuel for as long as the fuel remains a threat to man and the environment. Naturally, it is impossible to physically inspect the repository during the post-closure period. Instead, passive safety is required, which means it must be guaranteed that the final repository remains safe without post-closure monitoring. Passive safety is guaranteed by means of a safety assessment, which involves complex calculations and evaluation of the repository's ability to keep the radioactive fuel isolated for at least 100,000 years after closure.

These extreme time perspectives, especially for passive safety, make unique demands on the industrial organization. The two widely differing time perspectives can also lead to conflicts, for example regarding resource allocation. The challenges faced by the organization differ from the challenges faced by an industrial organization that delivers to an existing market with customers that use and judge the product in the present. For example, the long construction and operating time makes high demands on continuity and transparency in the processes that together must guarantee long-term passive safety. The demands on continuity and transparency, with the ultimate goal of delivering long-term safety, give the final repository's industrial organization a unique identity and necessitate a safety culture that includes not only the core of the project organization, but also every contractor and consultant. These demands must be met at the same time as changes in the external environment can impose new challenges.

The Act (1984:3) on Nuclear Activities (the Nuclear Activities Act) contains rules governing the organization of the holder of a licence for nuclear activities. As regards the final repository's industrial organization, this means that financial, administrative and human resources must be available as required by Sec. 13 of the Nuclear Activities Act to achieve organization's the ultimate goal: a final repository with long-term passive safety. Due to the unique demands and challenges, the design of the organization is a matter of public interest, and it is vital that open and transparent studies be made of the final repository's industrial organization in order to verify that sufficient resources are available to achieve the ultimate goal. The Swedish National Council for Nuclear Waste has previously pointed out the need for research on the industrial organization for the final repository.[1]

The purpose of this chapter is to highlight a number of questions that need to be answered to demonstrate that a proposed industrial organization has the capability to put in place a final repository with long-term passive safety. The questions are posed to the material on safety assessment and organization included in the Swedish Nuclear Fuel and Waste Management Co's (SKB's) 2011 application for a licence to build a final repository for spent nuclear fuel. The material provides a good point of departure for studies, but ignores central issues regarding the balance between the two time perspectives, the risks of conflicts and collaboration to deal with internal surprises and global changes, and the concrete role of the safety assessment in the industrial organization.

During the work with this chapter, the Swedish Radiation Safety Authority (SSM) published a supervision report on activity oversight of SKB's safety leadership.[2] The report highlights the difficulties

[1] Swedish National Council for Nuclear Waste. 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*.
[2] SSM. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* ("Activity oversight safety leadership SKB," in Swedish).

of maintaining the highest priority for radiation safety issues in an organization in the throes of change and with an increasing focus on cost-cutting and operation of existing facilities, such as Clab and SFR. The report further underscores the importance of open organizational studies that provide an opportunity to “stop and think” before launching an industrial organization to build and operate the final repository. Observations from the activity oversight are presented in the following text.

The following section takes a closer look at the two time perspectives and examines the basic issues of the role of the safety assessment and the need to understand the organization’s identity, which is responsible for continuity in the activities by coordinating activities in space and time into a functioning whole, independent of the individual.

6.2 The two time perspectives

Figure 6.1 illustrates the two widely differing time perspectives which the organization has to balance at all levels, from general strategy development to practical day-to-day work. The two time perspectives will hopefully permeate all aspects of the project: resource allocation, procurement, competence assurance, quality assurance, knowledge acquisition, technology development, safety and Human–Technology–Organization. In all areas, the immediate demands from the work of construction and operation must be weighed against the general demand of achieving passive safety.[3]

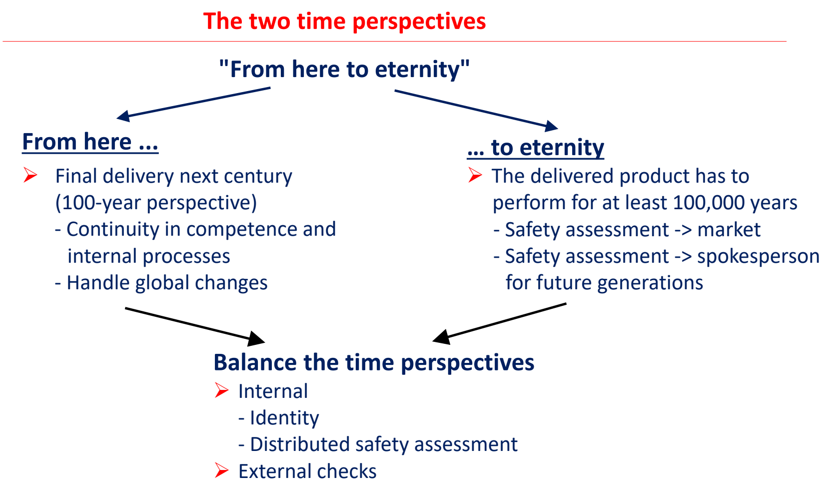
The expression “From here to eternity” was used in State-of-the-Art Report 2012[4] to illustrate the tensions between the two time perspectives. There are many examples of companies that have survived for 100 years, but a project with final delivery in a century is unique. This puts the focus on continuity in competence and processes in the face of a century of external changes. In comparison with 100,000 years, the “From here” period of a mere cen-

[3] The expression “balance the two time perspectives” has been chosen to emphasize that the trade-off between the requirements will be an ongoing process during construction and operation.

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

tury is a brief instant, but this is the time available to the industrial organization to guarantee the function of the end product up to, during and beyond a future ice age.

Figure 6.1 The organization has to balance the two time perspectives



The basic premise for the following presentation is that the perspectives will be represented by different parts of the organization with different competencies and duties.

The short-term perspective is represented by units with responsibility for encapsulation, transportation, construction and operation of the final repository. Decisions and actions have great, usually immediate financial consequences and require continuous follow-up by the company and project management.[5] *The long-term perspective* is represented by units with responsibility for development and execution of the safety assessment. In connection with the

[5] In SKB. 2011. Appendix VU "Verksamhet, ledning och styrning – Uppförande" ("Activity, management and control – Construction"), pp. 7–10, SKB defines three different decision levels: President with staff, the Nuclear Fuel Programme and the Spent Fuel Repository Project. The expression "company and project management" encompasses all three levels. The nature of the matter determines at which level decisions must be made. SKB's President bears ultimate responsibility for nuclear safety, including both pre-closure (operational) and post-closure (long-term) safety. The Nuclear Fuel Programme is responsible for preparing and administering safety analysis reports and for technology development and research, while the function Safety in the Project (SIP) is within the Spent Fuel Repository Project. SIP shall prepare safety issues and present recommendations to the project manager for decisions.

safety analysis reports to SSM[6], the safety assessment work is undoubtedly in focus for the company and project management, but the question is what the follow-up looks like between these occasions.

There is good reason to pause and consider the design and role of the safety assessment from a company perspective.

The safety assessment process is the result of more than thirty years of development work both in Sweden and internationally. An important resource for the process is the calculation apparatus. This consists of large databases and a numerous mathematical models that make it possible to study possible transport pathways for radionuclides to pass through engineered barriers and rock and emerge in the surrounding biosphere. The process is controlled by a systematic and carefully documented methodology. The methodology determines the design of scenarios, which may for example indicate the risk of canister failure, and the calculation apparatus is used to calculate the risks to man and the environment. The result is a number of safety cases that determine what requirements (design premises) the rock and the engineered barriers must fulfil.

The safety assessment is a complex process for which specialized competence exists at SKB and SSM. This competence includes not just methodology and calculations but also the means to communicate the process and results. A crucial challenge in the 100-year perspective is retaining and developing this safety assessment competence.

The role of the safety assessment during the development of the final repository concept and for the execution of final disposal can be described by means of *two idealized images*. During the development process up until a permissibility decision, the *societal perspective* dominates. The safety assessment can be compared to a spokesperson for the future generations which the final repository is supposed to protect from the radioactivity in the spent nuclear fuel. After a licence has been granted the construct a final repository, the company perspective will begin to compete with the societal perspective. We have previously observed that the "Spent Fuel Repository" company does not, like other companies, sell its

[6] For example, a preliminary safety analysis report (PSAR) is required to start construction of the repository, and will be expanded to a safety analysis report (SAR) prior to application for a licence for trial operation. The construction process lies between these two occasions.

products on market in the present. In the *company perspective* the safety assessment can serve the function of a market analysis, and safety cases can serve as a (virtual) market.

The safety cases in a market role would strengthen the safety culture in the Spent Fuel Repository project. But the market metaphor can engender conflicts. SKB's senior management and board of directors is also supposed to safeguard the financial interests of the owners in a project where the assets in the Nuclear Waste Fund may prove to be insufficient. The board of directors can rely on control via the design premises and considers it more efficient to concentrate the safety assessment to the programme level with verification and updates of design premises and safety reporting to SSM.

Observations in SSM's supervision report indicate that SKB is currently moving towards a hierarchical safety culture. For the final repository, such a culture entails that the balance between the two time perspectives is determined at a high level in the organization. The report states:

> SSM draws the conclusion that the commitment to safety issues that exists at the employee level is not always regarded by managers as an asset for the organization.

In the background, the owners, the nuclear power companies, tend to exert stricter control, which can, according to SSM, lead the project away from SKB's main task:

> SKB needs to evaluate whether Vattenfall's influence may induce SKB to act more in line with the wishes of the owners than with the needs of the core activity and the obligations and responsibilities that accompany the role of licensee.

In a strictly hierarchical safety culture, there is a risk that the goal of "pre- and post-closure radiation safety" will be replaced by the goal of "acceptance by the regulatory authority".

> SSM concludes that SKB has a tendency to adopt SSM's view instead of having its own clear standpoint on crucial issues.[7]

[7] SSM. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* ("Activity oversight safety leadership SKB," in Swedish), pp. 2, 19.

In the long run, this attitude leads to an instrumental interpretation of the concept of "safety" with SSM in the role of SKB's market.

However, this instrumental interpretation violates SKB's own core values, which specify "Safety" as the first of three guiding lights in its code of conduct. In order to preserve credibility and authenticity, SKB must practicing what its core values preach. But SSM's observations underscore the need for an open research project to critically follow SKB's development and study the industrial organization for the final repository. In the following presentation, we assume that SKB will live up to its core values and continue its ambitious safety assessment work in order to arrive at a "clear standpoint of our own in crucial issues".

A functioning project organization must balance the two different time perspectives. External checks of the balance may utilize already existing processes, such as SSM's reviews, international panels of experts, consultation with stakeholders, transparency forums, etc. Achieving and maintaining this balance within the organization requires internal structures and processes based on operations over which the organization has full control. Figure 6.1 proposes studies two mechanism to handle the two perspectives: creation of an identity and development of a distributed safety assessment.

- *Identity.* The company's identity represents its self-image[8] and is created by the mutual interaction between company employees when they act in their respective roles.[9] An important observation is that this identity is independent of the individuals that work in the company; People can leave the company and new ones can join it, but this doesn't change the company's identity. On the other hand, the company and project management may change roles and relationships and thereby change the organization's identity with unchanged personnel. However, the manage-

[8] Albert and Whetten. 1985. "Organizational identity." This classic work posed the question: "How do we see ourselves?" An organization's identity is determined by what employees perceive to be the central attributes of the organization, what distinguishes it from other organizations and what creates continuity in the organization's work.

[9] Espejo et al. 1996. *Organisational Transformation and Learning – A Cybernetic Approach to Management,* pp. 74–76. The authors view an organization as a closed network of interacting individuals. Relationships develop within the network, imparting meaning to the symbols that are used, creating norms for interaction and gaining acceptance for the division of decision-making power in the network. Through these relationships, the organization creates its own identity.

ment literature shows that for a well-established company with a well-developed identity, such an identity change takes a great deal of time and resources. Of interest for our discussion of the Spent Fuel Repository project is the fact that a clear identity promotes continuity and can bridge over generation changes. But it is vital that the company and project management get it right from the start. Our earlier discussion about control via the safety cases as a market or remote control via design premises hits at the trade-offs that must be made early in the project. The trade-offs reflect the desired balance between the two time perspectives. This balance becomes a very important part of the project's identity.

– *Distributed safety assessment.* Striking this balance requires that the organization maintain a continuous dialogue between units that work with construction and operation and units that work with safety assessment. But the discussion of the market metaphor raises the question of whether dialogue at the project level alone is enough and what SKB's intentions are in this case. Studies are needed of how a more distributed safety assessment can develop and deepen the safety culture. A distributed safety assessment entails that the dialogue concerning long-term (post-closure) safety and the challenges during construction and operation be expanded to all levels in the organization, from the strategic level to the levels with individual contractors during the construction phase and to teams for deposition of individual canisters during the operating phase. This is a challenge for the safety assessment, which must adapt its message to all underlying levels. But a research project about distributed safety assessment includes more than the dialogues. Studies must be made of accompanying procedures, protocols and checks to verify that the safety work guarantees passive long-term safety in the closed and abandoned repository. Distributed safety assessment entails that construction, operation and safety assessment meet at all levels of the organization.

Based on documents from SKB, the two mechanisms are discussed in the following two sections. The goal is to identify a number of research topics that should be included in research projects concerning the industrial organization for a final repository for spent nuclear fuel.

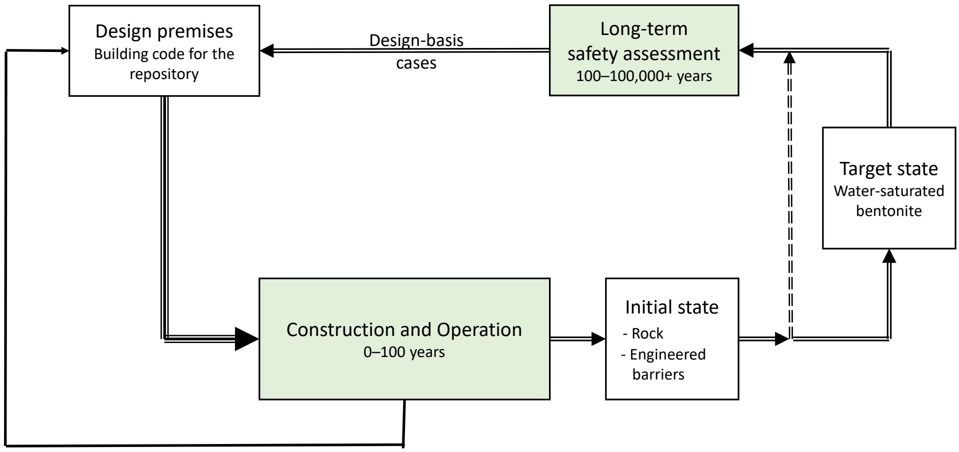
6.3 Construction-operation and safety assessment: a common identity?

How can a common identity be created for a project that encompasses such widely differing activities as extensive rock excavation works spanning over a century and an abstract and complex safety assessment with a time perspective of at least 100,000 years?

SKB has indirectly illustrated the problem in a figure in the application to the Land and Environment Court.[10] SKB's figure is entitled "The safety assessment's impact on design". The expression "The safety assessments" refers to both the assessment of long-term (post-closure) safety and the assessment of safety during repository operation (pre-closure safety). Figure 6.2 is a simplified version of SKB's figure where the two time perspectives are more clearly illustrated.

[10] The figure that is referred to is Figure 3-1 in: SKB. 2010. "Säkerhetsredovisning för drift av slutförvarsanläggning för använt kärnbränsle (SR-Drift) kapitel 3 – Krav och konstruktionsförutsättningar" ("Safety analysis report for operation of final repository for spent nuclear fuel (SR-Operation) Chapter 3 – Requirements and design premises," in Swedish) p. 6.

Figure 6.2 The link between the two time perspectives based on SKB's illustration of how the safety assessments influence the design



The figure has been simplified by combining all activities related to design, construction and operation, including work on the reference design, under the heading "Construction and operation". SKB's figure contained three feedback loops from these activities to "Design premises". These have been combined into one feedback in Figure 6.2, indicated by a single solid line. Figure 6.2 also takes into account the Swedish National Council for Nuclear Waste's statements of opinion on SKB's RD&D programmes and consultation responses regarding SKB's application and state-of-the-art reports[11] and indicates a "Target state" between "Initial state" and "Long-term safety assessment".

The double-line arrows show the links between the two time perspectives. The dialogue between the representatives of the two time perspectives, construction-operation and safety assessment, is conveyed by "Design-basis cases," "Design premises," "Initial state" and "Target state". "Design-basis cases" point to critical criteria which the rock and the engineered barriers must fulfil in order to guarantee passive long-term safety. These criteria must be reflected

[11] Swedish National Council for Nuclear Waste. SOU 2012:7, Chap. 3; SOU 2015:11 *Nuclear Waste State-of-the-Art Report 2015. Safeguards, record-keeping and financing for increased safety*, Chap. 6; SOU 2016:16 *Nuclear Waste State-of-the-Art Report 2016. Risks, uncertainties and future challenges*, Chap. 7.

in the design premises, which stipulate detailed and verifiable requirements which the rock and engineered barriers must fulfil.[12] According to SKB, the initial state is the point of departure for the long-term safety assessment and describes the state of engineered barriers and underground openings immediately after deposition.[13] "Target state" refers to the state when all barriers have achieved the barrier function that is assumed in the safety assessment's main scenario. This primarily entails that the bentonite in buffer and backfill has been water-saturated, which can take up to several hundred years.

Development and verification of design premises plays a vital role in the dialogue between construction-operation and long-term safety assessment. But Figure 6.2 shows that there is a competing feedback from construction-operation directly to design premises (single solid line). The question is how the design premises are to be realized in construction-operation. Here as well there is a latent competition between the two time perspectives, indicated by a single solid line in the double solid line. The industrial organization must clearly divide the responsibility between the two main processes *safety assessment* and *construction-operation*. We will return to this issue in the next section.

The feedback from construction-operation lies entirely within the framework of the short-term perspective. If we go back to SKB's original figure, we find three important activities in construction-operation that can feed back to the design premises, namely production and construction, handling of engineered barriers and operational safety. The design premises must be possible to check and verify during construction and operation; they must not impose requirements on the engineered barriers which they cannot fulfil, and they must not risk operational safety. The requirements on changes in the design premises from construction-operation

[12] The design premises may for example pertain to water flow rate and fracturing around a deposition hole, or the density of the buffer.
[13] SKB. 2011. The "top document" in the application for a licence for construction, ownership and operation of a nuclear facility for the final disposal of spent nuclear fuel and nuclear waste. The top document defines the initial state as: "Properties of the spent nuclear fuel and the engineered barriers when they are finally put in place in the final repository and are not handled further in the final repository". In the case of the geosphere and the biosphere, SKB 2011 Appendix SR in "Safety analysis report for final disposal of spent nuclear fuel" states that the initial state "refers to the natural conditions before the rock excavation work begins," p. 12.

may conflict with the requirements from the long-term safety assessment.

Figure 6.2 illustrates the fundamental relationships that create the identity of the Spent Fuel Repository project. How the company and project management choose to configure these relationships via the organizational structure and job descriptions determines the balance between the two time perspectives. This balance should handle conflicts within the project. The relationships in Figure 6.2 indicate an important such conflict area, namely formulation of design premises and realization of these premises in construction-operation. In the final analysis, both desired balance and conflict handling are a question of priorities in the allocation of available resources.

Two stylized identities can be used to illustrate the interaction between identity, internal relationships and priorities. The units that work with *construction and operation* may have an entirely different view of the project's identity than the units that work with *safety assessment*. "The project builds rock caverns for final disposal of spent nuclear fuel" indicates an identity anchored in the century perspective, while there is a risk that "The project provides protection from spent nuclear fuel for humans and the ecosphere for at least 100,000 years" ignores the difficulties of actually realizing a final repository. The question is what priorities the identities lead to, for example when formulating and realizing design premises or when distributing resources to assure competence (i.e. recruit qualified personnel). SSM's supervision report mentions that already today, cost-saving demands may lead to delays in replacement recruitments.[14]

We have considered the risk of conflicts between the main processes safety assessment and construction-operation. Let us change our point of view and ask about the interactions and dynamics in the system. How can the system be changed to adapt to changes in the surrounding environment? We can note that the activities form a part of two feedback loops or cycles of operations. The long loop through long-term safety assessment and construction-operation (double-line arrows) ties together the two time perspectives, while

[14] SKB. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* ("Activity oversight safety leadership SKB," in Swedish), p. 14.

the short loop between construction-operation and design premises lies entirely within the short-term century perspective).

The system with two loops in Figure 6.2 is organizationally and operationally closed. The effect of all operations is handled within the system. The result of an operation is processed by the following operations in the cycle and returns in modified form as a new input value to the original operation. In the system literature, such systems are characterized as organizationally or operationally closed, which signals a very stable situation.[15]

The importance of the two overlapping loops or cycles is evident in a comparison with the situation in an ordinary producing company. Here as well there are two loops with some overlap: one loop that is closed over the market and characterizes sales of the product, and one loop that is closed over the production process itself. The production process corresponds to construction-operation in Figure 6.2, which, along with an interpretation of the safety assessment as a market analysis, reveals the similarities between the system for construction and operation of a final repository and a company that produces for a real market. The interesting observation here is that the market-oriented company has turned out to be well-equipped for adapting to changes both in the surrounding world and internally in the production process. The two loops permit effect communication, so that prices, volumes and product quality can be adapted to changes in the market or the production process. There are no direct equivalents to this situation in the final disposal process. For an organizational study, however, a relevant research question as to what extent the two loops contribute to the system's ability to deal with both internal surprises and global changes, which can come for example in the form of new knowledge about the barriers and via technology development.

[15] The term "organizational closure", "operational closure" is used in the English-language literature (Maturana, H.R. and Varela, F. 1980. *Autopoiesis and Cognition: the Realization of the Living;* Varela, F. 1979. *Principles of Biological;* Luhmann, N. 2002. *Theories of Distinction*.). The systems develop a very strong identity, which, using a term borrowed from mathematics and physics, is characterized as "eigenbehaviour", "eigenstate" (von Förster, H. 1984. "Principles of self-organization: in a social-managerial context"). Such a state can guarantee continuity in structure and processes, but can also result in a system that is inflexible and unable to deal with big changes in the surrounding world, for example new knowledge or new processes. The conflict between continuity and flexibility touches on a classic problem in organization theory.

The two loops have further consequences. The loops lead to a double-closed system with the capacity for change without giving up its closure, i.e. without at any stage giving up control over any part of its own operation.[16] The system avoids changes in its internal structure, instead handling changes within the framework of existing operations.[17] Structural changes can threaten the system's identity, and the double closure thus provides protection for this identity. This has considerable consequences for external actors, such as SSM, which may decide that a challenge must be met by structural changes, for example new types of operations. This aspect of the double-closed system in Figure 6.2 can be illustrated by the discussions the Council has held regarding the necessity of measurements (monitoring) in sealed areas to verify that the bentonite is water-saturated in the way that is assumed in the safety assessment.

SKB's application to the Land and Environment Court does not mention the target state. In SKB's version of Figure 6.2, the big loop goes directly from the initial state to the long-term safety assessment (indicated by the double-dashed arrow). In its statements of opinion to the Land and Environment Court, the Council has criticized the difficulty of verifying design premises with regard to the water saturation of the buffer solely by means of measurements of the initial state, i.e. just before closure of a deposition tunnel. In the Council's state-of-the-art reports from 2015 and 2016, the Council has therefore referred to international efforts to monitor the evolution in sealed areas.[18] By introducing a new operation involving post-closure measurements, it is possible to monitor the processes in a deposition tunnel after closure and check that the buffer is water-saturated as assumed in the safety assessment, i.e. that the final repository can achieve the target state.

The long-standing discussion of monitoring programmes, design premises and initial state/target state shows that opposition to

[16] Double-closed systems are discussed in detail by von Förster, H. 2003. *Understanding Understanding*.

[17] Beer, S. 1975. *Platform for change* has compared the ability of organizations to deal with challenges from the external environment not by means of structural changes but by shifting the balance between its operations in accordance with Le Chatelier's Principle in chemistry. A chemical reaction in equilibrium responds to a change in e.g. pressure or temperature by shifting the point of equilibrium.

[18] Swedish National Council for Nuclear Waste. SOU 2015:11, Chap. 6; Swedish National Council for Nuclear Waste. SOU 2016:16, Chap. 7.

structural changes is great already in the planning stage. The need for monitoring in sealed areas can be perceived as a threat to the project's identity. The project's capability to deliver a repository with passive long-term safety is an essential part of the organization's identity, and the need for post-closure monitoring can be perceived as a questioning of this capability.

Together with sister organizations in the EU, SKB is currently participating in a project dealing with monitoring in sealed areas.[19] The fact that such monitoring is thereby gaining broad acceptance can be taken as evidence that the measurements instead increase confidence in the repository's passive safety. At the same time, the measurement results may lead to internal surprises. Monitoring may reveal an evolution that lies beyond the safety assessment's tolerance limits. The organization must be able to deal with such eventualities.[20]

In this section we have discussed the identity of the Spent Fuel Repository project, the balance between the two time perspectives, continuity in the activities, the capacity to deal with surprises and external changes, and opposition to structural changes. This is an example where the design of the industrial organization has consequences for society and therefore needs to be thoroughly examined. Due to the extreme time perspectives this is unfamiliar territory, but society has a need to oversee and check the activities and make sure that the organization in charge of these activities remains efficient and legitimate. If society wants to influence the design of the organization, now is the time, since the planning is already under way.

6.4 Remote control or distributed safety assessment?

In this section we discuss how the double-closed system in Figure 6.2 is configured in the industrial organization. By "configured" we mean how the relationships between different units and functions in the

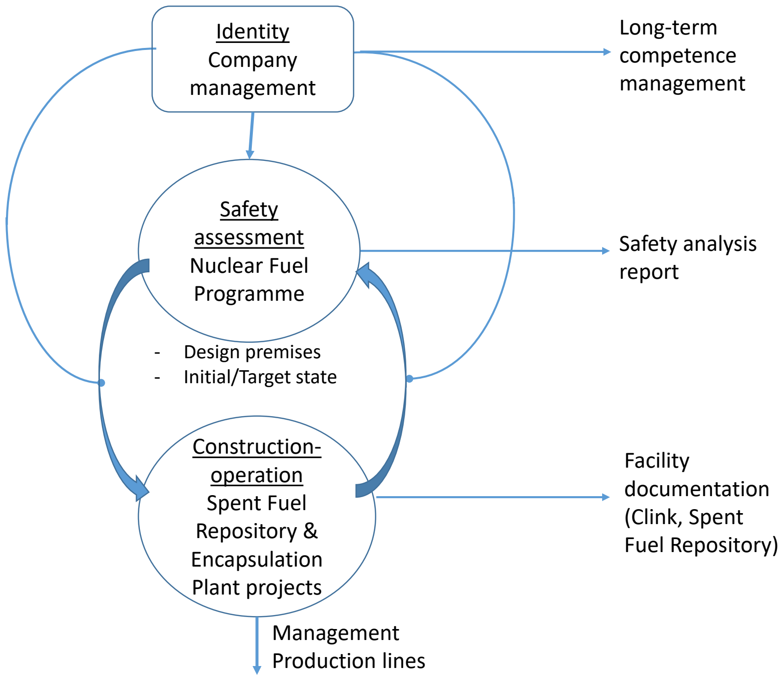
[19] SKB. 2016. *RD&D Programme 2016. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste*, p. 84.
[20] Possible results of the measurements and how the industrial organization deals with these outcomes were discussed in the Swedish National Council for Nuclear Waste's report SOU 2016:16, Chap. 7.

organization are designed. The intention is not to judge organization charts or job descriptions, but to single out areas that require organizational studies. The focus is on the relationships between the main processes construction-operation and safety assessment.

SKB examined the relationships between the two main processes in its report on the 2010 research and development programme (RD&D 2010)[21] and in its 2011 application for a licence to build the final repository.[22] The Council said in its review statement on RD&D 2010 "that SKB should, as soon as possible, initiate systematic studies of what the organization should look like," but SKB did not return to this subject in RD&D 2013. One interpretation of the absence of a follow-up of issues SKB itself had brought up is that SKB does not think that open research projects about the industrial organization are needed.

[21] SKB. 2010. *RD&D Programme 2010. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste,* Chap. 8, pp. 113–114.
[22] SKB. 2011. Appendix VU. "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"), sections 5.4 och 5.5, pp. 20–23.

Figure 6.3 Relationships at the project level between construction-operation, safety assessment and identity with regard to passive long-term safety



The figure is a schematic illustration of how the relationships between the main processes are configured for the execution phase in the industrial organization, which is described in SKB's application.[23] The figure shows units responsible for the main processes during the construction phase.

The figure interprets at the project level the discussions in the preceding section about the time perspectives and the double-closed system in Figure 6.2. The point of departure is SKB's illustration of the relationships in RD&D 2010 and the application[24], but has been

[23] SKB. Appendix VU. "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"), pp. 7–13.
[24] SKB. 2010. *RD&D programme 2010.* Figure 8–9, p. 114 and Figure 5–3, p. 20 in Appendix VU "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"). The figure also had an important role in SKB's contribution to the seminar on organization issues surrounding construction and operation of a final repository for spent nuclear fuel that was arranged by the Council in November 2014.

modified here to illustrate the involvement of all three decision levels in SKB: President with staff, the Nuclear Fuel Programme and the Spent Fuel Repository Project (see footnote 5).

During the construction phase, the Spent Fuel Repository Project is responsible for construction of the repository in Forsmark and the Encapsulation Plant Project is responsible for construction of the plant in Oskarshamn. SKB is the client organization in the projects. The first project is presided over by the Nuclear Fuel Programme Department and the second by the Department of Operations, both of which report directly to the President. The construction phase ends and the operating phase begins when SKB obtains a licence for trial operation after approval of the safety analysis report. Responsibility for the final repository will then be transferred from the Spent Fuel Repository Project in the Nuclear Fuel Programme Department to the Department of Operations.

Responsibility for the long-term safety assessment rests with the Nuclear Fuel Programme, i.e. the second decision level directly below the President. This programme will also plan for operational safety. According to the management planning, the Nuclear Fuel Programme is responsible for: "preparation and administration of the final repository's safety analysis report for pre- and post-closure safety."[25]

According to our analysis is the preceding section, continuous interaction is required between safety assessment and construction-operation during the entire construction period to guarantee passive long-term safety for the repository after closure. This interaction is described in Figure 6.3 as an ongoing dialogue between the two main processes concerning design premises and initial/target state. The parties in this dialogue are, on the one hand, the Nuclear Fuel Programme and, on the other hand, the Spent Fuel Repository Project during the construction phase and the Department of Operations during the operating phase. The company management follows the discussions and can control the balance between the two time perspectives via directives and resource allocation.

We can note that the parties to the dialogue are at two different decision levels in the organization during the construction phase

[25] SKB. 2011. Appendix VU. "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"), p. 8.

and in two different departments during the operating phase. We also find that the Nuclear Fuel Programme has overall responsibility for both safety during operation (pre-closure safety) and long-term safety (post-closure safety), which are combined in the management document under the heading “safety work” or “safety issues”. This terminology is used in the following description of the management plan. Pre-closure (operational) safety and post-closure (long-term) safety relate to two different time perspectives. The methods for handling them are different and the analysis in the following section points to possible conflicts between them.

The management plan gives an account of safety work at all levels. At the president level there is a safety committee for dealing with “general, strategic and fundamental safety issues”.

Department S, Nuclear Safety, has a staff function. It comprises SKB’s audit function and can carry out independent safety review. The real authority of Department S in today’s organization hints at future conflict interfaces between safety officers and individuals in the line management or in the final repository project with responsibility for advancing the activity. SSM’s observations in the supervision report show that this should be an important aspect of a research project on the final repository’s industrial organization:

> SSM notes that the safety department at SKB does not appear to have the necessary weight and status. It is not natural that it is to the safety department that an employee can turn if he cannot get the attention of his immediate superior. There is an attitude toward the safety department’s task and role in the organization that is manifest in the fact that the safety department is sometimes pushed aside by the line organization. SSM believes it is important that a safety department can stand strong, competent and independent to defend its own standpoints in matters of importance and to take action to remedy any deficiencies and needs found in the operation.[26]

The group Safety in the Project (SIP) is an interesting function within the Spent Fuel Repository Project.[27] The group is supposed to work with safety issues and present its recommendations to the project manager for decision. The management plan assumes that

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[26] SSM. 2016. Supervision report *Verksamhetsbevakning säkerhetsledarskap SKB* (“Activity oversight safety leadership SKB,” in Swedish), p. 2.

[27] SKB. 2011. Appendix VU. “Verksamhet, ledning och styrning – Uppförande” (“Activity, leadership and management – Construction”), p. 10.

most of the SIP group's members are involved in the project's regular operation and that the members together possess: "competence in nuclear safety, analysis and modelling, design, production and environment". The purpose is to continuously monitor "geoscientific conditions with a bearing on site adaptation" and "unforeseen events that could affect quality-critical work operations". The group's work area includes both pre-closure (operational) safety and post-closure safety. We noted in the preceding section that these areas have an important influence on the balance between the two time perspectives and can give rise to conflicts. The SIP function is a possible organizational tool for solving such conflicts, for example with regard to updating of the design premises. The management plan defines as one of the main tasks for the SIP group:

> Judge how the operation's activities affect the range of options that is available with respect to long-term safety.[28]

An alternative formulation of this main task would be:

> Judge how the requirement on passive long-term safety affects the range of options that is available with respect to the operation's activities.

The two formulations illustrate how the double-closed system with the requirement of balancing the two time perspectives cuts through all levels of the industrial organization. A central question for a research project is how this balance can be maintained at all levels during the entire construction period, i.e. permeate all parts of the organization for a century. Our reasoning around the project organization in Figure 6.3 and the management planning suggests two interesting questions for a research project. *The first question* concerns how the dialogue between the experts at the decision-making levels in Figure 6.3 should be configured, i.e. what the relationships between SKB's experts in long-term safety assessment and in management of a highly complex project should look like. *The second question* concerns how personnel in production and technology development should be involved in the work of guaranteeing passive post-closure safety, and the answer concerns e.g. the role of the SIP group.

[28] SKB. 2011. Appendix VU. "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"), p. 10.

Reflection on two stylized organization models offers some insight into the significance of the two questions. We call the models the hierarchical model and the recursive model. Both models are based on the double-closed system with design premises and initial/target state as mediators between the two time perspectives. But the two models differ in terms of the role which these mediators and the safety assessment play in communication within the project.

In the *hierarchical model*, the safety assessment process stays at the departmental level within the Nuclear Fuel Programme. The design-basis cases are discussed at the project level with the person in charge of construction-operation, which leads to (possibly updated) design premises, which are communicated down through the organization by well-documented procedures. Responsibility for interpreting and realizing the design premises rests entirely with the unit in charge of construction-operation. Information on measurements and initial state is communicated upward in the organization by similarly well-documented procedures. It can be said that in the hierarchical model, the system is remote-controlled towards long-term safety via the design premises.

In the *recursive model*, the complex calculations and analyses are done in the Nuclear Fuel Programme, but methods and results, for example in the form of design-basis cases, are distributed to other levels in the project. Responsibility for interpretation and realization of the design premises is divided between the two main processes, but this division of responsibility must be clearly regulated. A dialogue equivalent to that at the project level is held at all self-governing levels. The term "recursive" means that the same dialogue structure is found at all levels of the project.[29] The demands on well-documented procedures are the same as in the hierarchical model. In this model as well, the design premises are determined at the project level, but the dialogues at underlying levels can result in suggestions for modifications. The recursive model requires more resources than the hierarchical model and requires greater efforts from the team around the safety assessment process in order to communicate methods and results within the project. You might

[29] See for example Beer, S. 1979. *Heart of enterprise*, pp. 308–324.

say that in the recursive model, the system is guided towards long-term safety via distributed safety assessment.

SKB's application emphasizes design premises and controls, which indicates that SKB's organizational model is closer to the hierarchical than the recursive type. A test of SKB's direction following a positive outcome of the application is the mandates and resources that are allocated to the SIP group.

A reasonable hypothesis is that the hierarchical model is cost-effective in a surprise-free world. The recursive model increases the costs in the organization, but is presumably much better at handling surprises and changes in the surrounding world. A question is which model can better handle big internal surprises in the final disposal process. For example, a demonstration facility may deliver data indicating that it is necessary to go in and repair barriers in closed deposition tunnels. Such a surprise may have a traumatic impact in an unprepared organization.

6.5 Challenges from the external environment

The industrial organization has to execute its main task of building a final repository with passive long-term safety at the same time as it has to deal with challenges from the external environment during the construction period. The challenges may come in three different guises: (1) *global factors* which can pose threats or help the organization achieve its main task, (2) *dialogues with regulatory authorities* concerning the main task, but also operational safety and environmental impact, (3) *dialogues with other stakeholders*, for example municipalities, environmental groups and private individuals, to gain acceptance for the activity.

6.5.1 Global factors

Preparedness for and handling of global factors (i.e. factors in the external environment) and changes in these factors are classic themes in organization theory. The discussion of the double-closed system in section 6.3 in this chapter points out that such a system has good adaptability to global changes – within certain limits. The system is highly resistant to outside attempts to make changes in the chains of established operations.

Appendix VU in the application for a licence for a final repository shows that SKB has designed the organization to handle three important global factors: competence assurance, technology development and knowledge development.[30] The section on competence management is very concise, while technology development and knowledge development are broadly established in SKB and each has its own chapter in the management document.

Systematic studies of global factors and how they are dealt with in an industrial organization to deliver a long-term safe final repository are an important part of organizational studies in future RD&D programmes.

6.5.2 Dialogues

From the viewpoint of society there is a clear difference between the goals of the two types of dialogues (see above) between the industrial organization for final disposal and the actors in the surrounding environment. The goal of the expert dialogues with licensing and supervisory authorities is verification and inspection, while the goal of the dialogues with other stakeholders is transparency. Dialogues of the first type are regulated by legislation, while dialogues of the second type may have some support in legislation (e.g. consultations), but may also be carried out at the initiative of external actors or the organization itself.

Sweden has long experience of both types of dialogues. Methods, protocols and procedures exist. The question is how existing forms for such dialogues need to be developed and what resources are available, particularly for dialogues aimed at transparency.

[30] SKB. Appendix VU. "Verksamhet, ledning och styrning – Uppförande" ("Activity, leadership and management – Construction"), p. 11 and Chaps. 6 and 7. See also Swedish National Council for Nuclear Waste. SOU 2016:16, Chap. 2.

6.6 Conclusion

Open and transparent studies are needed of the industrial organization that will put in place a final repository for spent nuclear fuel with passive long-term safety. The need for such studies follows from the two extreme time perspectives under which the final repository will be produced and the integrity of the repository will be guaranteed: a century perspective and a 100,000-year perspective.

The purpose of the chapter is to highlight and clarify several questions which should be addressed by organizational studies. The focus is on conflict risks and interaction between activities representing the two time perspectives. The point of departure has been SKB's own presentation in the 2011 application for a licence for a final repository, summarized in two figures taken from the appendix on safety assessment and the appendix on management organization. The analysis has been augmented with results from SSM's recently published supervision report on SKB's safety leadership. The questions relate to continuity, identity, adaptation to global changes, resistance to structural changes and the place of the safety assessment in the organization chart.

The analysis in this chapter confirms the need for organizational studies. It is urgent to get such studies under way, since the build-up of the industrial organization will begin immediately after a positive decision on SKB's application. Special interest should be devoted to the following areas:

- Competence assurance. Building a final repository with passive long-term safety requires competence in a very wide spectrum of areas. Continuity of competence and competence development comprise one of the most important factors for achieving the goals of the activity. SKB plans to have its own programme for competence assurance. In this case, SKB and society share a common interest.
- Conflict risks and adaptability. Society has a direct interest in ensuring that the final repository project can deal with internal conflicts and adapt to unexpected events in the project and changes in the surrounding world without compromising its goals. Studies of this capacity touch upon several of the themes dealt with in this chapter: identity, the balance between the two time perspec-

tives, the final repository project as a double-closed system, and remote control via design premises or distributed safety assessment.

– The role of the safety assessment in the organization. The assessment of long-term safety constitutes a highly specialized process which has developed over a period of 30 years. Its results can be found in every little operation in the final repository project, but its place and resources in the concrete industrial organization are as yet unclear.
– External environmental analysis. Considerable changes will occur in the external environment during the time period covered by construction and operation of the final repository. Not even the most systematic external environmental analysis can foresee the future, but it can prepare the industrial organization for the unexpected.

Previous organizational studies

Frostenson (2010) studied the important interplay between SKB and external actors such as the municipalities, Oskarshamn and Östhammar, that are highly dependent on the nuclear waste chain. Besides Frostenson's study, a number of organizational studies have been done under the aegis of different projects. Within the framework of the SKI/SSI project RISCOM Pilot (Andersson et al. 1998), Espejo and Gill (1998) carried out an analysis of the Swedish national nuclear waste management system. Espejo (2003) conducted similar analyses of the British and French systems within the framework of the EU project RISCOM II. Espejo (2007) summarizes the results based on the RISCOM model (Wene and Espejo, 1999; Andersson et al. 2006). In all of these previous organizational studies, the focus was on the relationships between different actors in the nuclear waste system. Studies of the internal organization that will build and operate a final repository for spent nuclear fuel were not of interest.

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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 a 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. This year's report, SOU 2017:8, is entitled *Nuclear Waste State-of-the-Art Report 2017. Nuclear waste – an ever-changing issue.* The report examines various issues which the Council considers important in the final repository programme. The report contains the following chapters:

- How the requirements on a final repository for spent nuclear fuel have evolved in Swedish legislation
- Future scenarios for the final repository project
- Future political challenges – financing and retrievability
- A new generation of nuclear reactors?
- Organization for a century of challenges

The report can be downloaded at www.karnavfallsradet.se

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